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Development of Knowledge-Based Systems for Aluminum Welding

Computer programs offer the extensive knowledge of experienced engineers

BY R. J. NAPOLITANO, H. KULLUK, M. L. NAGURKA, R. P. MARTUKANITZ AND P. B. DICKERSON

Welding engineers experienced with aluminum possess knowledge generally unavailable to others, including those in need of such information such as designers and manufacturers of welded aluminum structures. The experienced engineers are often asked to: 1) recommend appropriate filler metals, 2) recommend starting welding parameters; and 3) diagnose difficulties encountered during aluminum welding. Developing computer-based expert systems in these areas can reduce the time required for others to access the desired information, overcome the limitations associated with the present methods of obtaining this information and provide knowledge transfer by exposing users to the thought processes of experienced welding engineers. Examples of two computer-aided welding systems are described in Refs. 1 and 2.

The present method of determining appropriate filler metals and welding parameters in industry is through the use of selection charts and tables. Although these have served their purpose well, there are advantages to computer methods. With appropriate design, knowledge-based systems can be extended rather easily to contain more information deemed useful to the user. The computer software can provide more complete information that would require literally hundreds of footnotes and additional charts and tables in the present method. For example, the appropriate setting for arc voltage, and consequently amperage, depends on the particular type of filler metal employed in the gas metal arc welding (GMAW) process. The 5XXX series filler metals, with magnesium as the primary alloying element, require higher current and lower arc voltage to ensure proper metal deposition compared to 4XXX filler metals and maintain total heat input, respectively. Another example is the fact that shielding gas composition as well as flow rate influence weld penetration and cross-sectional area (Refs. 3, 4). The addition of a certain percentage of helium to the argon shielding gas can be advantageous in particular situations. This type of knowledge can readily be incorporated into a knowledge-based system. Another advantage is that it can provide explanations for its conclusions. This exposes users to the thought processes of experienced welding engineers and streamlines knowledge transfer.

Toward this goal, in cooperation with the Aluminum Co. of America (Alcoa), two user-friendly software packages were developed and a third module is in the final prototype stage. One package, the Filler Metal Selector, is a knowledge-based system that recommends optimal filler metals for gas metal arc (GMA) and gas tungsten arc (GTA) welding of aluminum. The second package, the Process Parameter Selector, provides typical starting welding parameters and joint preparations for a variety of base metal thicknesses. Currently under development is a third package, the Weld Defect and Diagnostic System, which is a knowledge-based program to assist in determining causes of weld discontinuities during aluminum welding and to recommend corrective procedures. These three systems constitute the Aluminum Welding Engineer series and represent an integral part of the proposed interactive welding engineering workstation. The software systems were created with the help of several welding engineers, and the systems incorporate their knowledge representing over one hundred years of experience with Alcoa in aluminum welding.

Software Design

After reviewing several expert system shells, it was decided to use Personal Consultant Plus (PC+) marketed by

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ALUMINUM WELDING ENGINEER - Filler Metal Selector
Current objective:
                    ALCOA
             Filler Metal Selector
This Expert System recommends optimal
filler metals for GMA and GTA welding of
Aluminum.
It will recommend fillers for any combination
of alloys being welded, including castings, as
well as when Postweld Thermal processing is being
used.
Information regarding the application, joint
design and particular alloys being welded is
asked, and type of Postweld thermal processing
where appropriate.
** End - RETURN/ENTER to continue
```

Fig. 1 — Filler metal selector introductory screen.

```
ALUMINUM WELDING ENGINEER - Filler Metal Selector
Select the most appropriate application >
  AEROSPACE
  ARCHITECTURAL
  ARMOR-BALLISTIC
  AUTOMOTIVE
  CRYOGENIC
  ELECTRICAL-CONDUCTOR
  FURNITURE
  HOME-APPLIANCE
  NAVAL-MARINE
  PIPING
  PRESSURE-VESSEL
  RAILROAD CAR
  STORAGE-TANK
  STRUCTURAL
  Other
1. Use the arrow keys or first letter of item to position cursor.
2. Press RETURN/ENTER to continue.
```

Fig. 2 — List of typical applications in aluminum welding showing the selection of a piping application.

Texas Instruments. The software is inexpensive, can be run on any IBM or fully compatible computer, is well supported and maintained and is easy to learn and use. It provides the ability to access externally written routines and external databases, can be integrated with graphics, and can explain in text why the system reaches a certain conclusion. Additional access to PC Scheme, a dialect of Lisp capable of running on personal computers, is provided, and it was used extensively in the development of these systems.

Personal Consultant Plus is a rule-based expert system shell. The rules themselves are entered into the knowledge base using the Abbreviated Rule Language (ARL). The knowledge-based designer provides translations for each parameter used in the system. PC+ uses these translations and the format of ARL to generate plain-English translations of the rules, useful for development purposes, and for the conclusions that the end user sees. This is an important aspect of the software that allows the users of the system to follow and understand the experts' thought processes represented by the knowledge base. The software has a data type called a frame which allows the knowledge base to be divided into logical segments. This is extremely useful in the development of large and complex knowledge bases. It also speeds execution times for the end user by loading in only those frames that affect the course of the consultation, *i.e.*, the thought processes represented by the rules. The software is user-friendly, which is exemplified by the presentation of inquiries and conclusions, both graphic and literal, to the end user. This software development tool was used to create the expert systems from the knowledge domains described previously.

Filler Metal Selector

The selection of appropriate filler metals essentially involves optimizing desired weld characteristics under metallurgical and mechanical constraints determined by the materials' chemical and physical properties. The system asks a series of questions related to the above, determines which filler metals are most appropriate for the alloys being welded, evaluates each of these separately and then recommends one or possibly several filler metals. When postweld thermal processing is employed or when welding certain castings and wrought products, there are few filler metals deemed appropriate, and the system simply recom-

```
ALUMINUM WELDING ENGINEER - Filler Metal Selector
PIPING
        The following weld property requirements
        for this application have been assumed:
        WELDABILITY   : VERY IMPORTANT
        STRENGTH      : IMPORTANT
        DUCTILITY     : IMPORTANT
        CORROSION     : VERY IMPORTANT
        HIGH TEMP     : NOT IMPORTANT
        COLOR MATCH   : NOT IMPORTANT
        Do you agree with these values?
YES
NO
1. Use the arrow keys or first letter of item to position cursor.
2. Press RETURN/ENTER to continue.
```

Fig. 3 — Screen showing default weightings of weld properties for a piping application.

```
ALUMINUM WELDING ENGINEER - Filler Metal Selector
Select the particular type of butt joint >
    SQUARE-BUTT-NO-GAP
    SQUARE-BUTT-WITH-GAP
    SINGLE-V
    DOUBLE-V
    SINGLE-U
    DOUBLE-U
1. Use the arrow keys or first letter of item to position cursor.
2. Press RETURN/ENTER to continue.
```

Fig. 4 — Screen for specific type of butt joint with single-V-groove joint design selected.

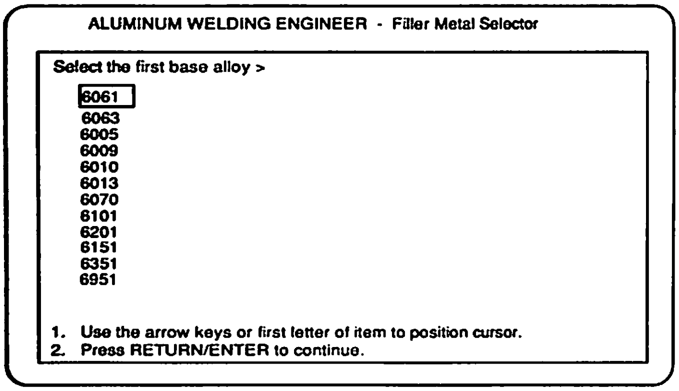

Fig. 5 — Screen for 6XXX series wrought alloys showing 6061 selected.

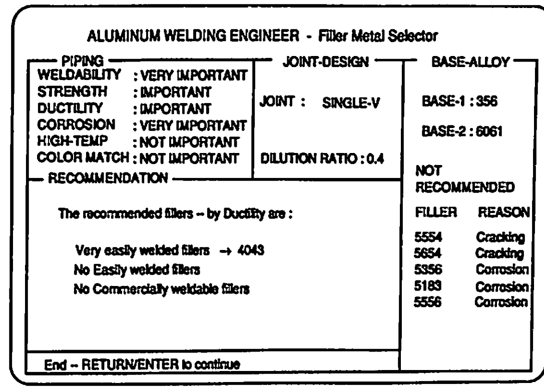

Fig. 6 — Recommendation screen of the filler metal selector for pipe welding 6061 wrought alloy to 356 casting alloy utilizing a single-V-groove joint design.

mends their use.

In general, the following information is required: 1) The application, which dictates desired weld characteristics; 2) the particular joint design; and 3) the base metals being welded.Currently, there is information available for over 60 base metals, including both wrought products and castings.

The system first displays an introductory screen describing the program and its function — Fig. 1. It begins by determining the desired weld characteristics dictated by design requirements and/or service conditions, and then presents the user with a list of possible applications for aluminum welding, such as automotive or aerospace uses, pressure vessels, or home appliances to name a few. This screen is shown in Fig. 2. Once the user selects a particular application, the system retrieves from an external file the default values of the relative importance of six weld properties. The user is shown the default values and may change any or all of the relative weightings. Figure 3 depicts the screen showing relative weightings for a piping application. There are three possible relative weightings that can be assigned to each weld attribute. The weightings (very important, important and not important) determine the order and importance placed on the various weld attributes or characteristics.

The system next asks the user to provide the type of joint that will be welded. For a butt joint, a specific joint design is requested through a screen query, as shown in Fig. 4. A base metal/filler metal dilution ratio is calculated based on the particular joint design and is displayed for confirmation. The default ratio may easily be changed if the user is more confident of a more appropriate dilution ratio.

Information is available for over 60 base metals

The system next asks the user to identify the base materials being welded. The alloy systems that are normally used for the specified application are presented and the system can easily account for welding of dissimilar alloys. Figure 5 shows the screen used for selecting 6XXX series wrought alloys for a piping application.

Once the alloys to be welded are obtained, the system utilizes the dilution ratio to determine applicable filler metals based on the desired joint characteristics. Information pertaining to the applicability of the filler metals is shown by the system, and a final recommendation is made based

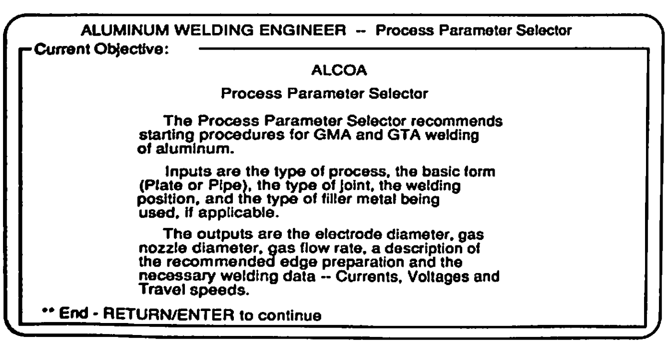

Fig. 7 — Process parameter selector introductory screen.

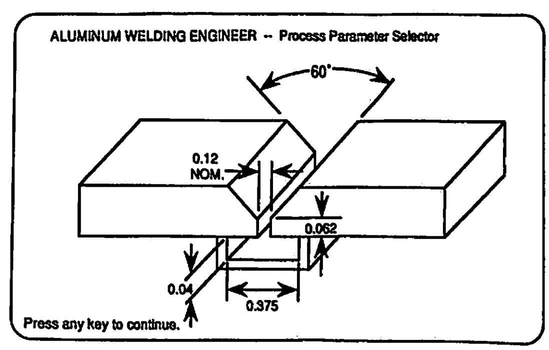

Fig. 8 — Screen output showing recommended single-V-groove joint design for GMA welding a 0.375-in.-thick plate.

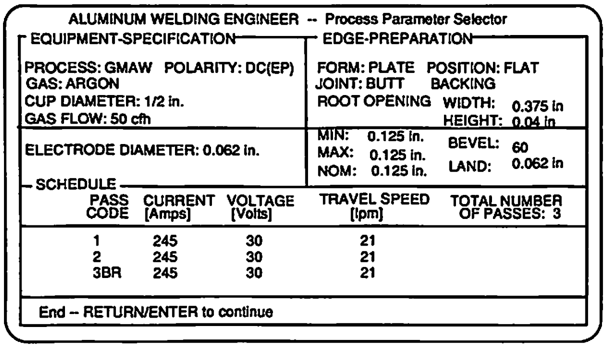

Fig. 9 — Recommendation screen of the process parameter selector detailing suggested gas metal arc welding parameters for 0.375-in.-thick plate welded in the flat position.

on optimizing the desired attributes. Shown in Fig. 6 is the recommendation screen for pipe welding 6061 base metal to a 356 casting alloy utilizing a single-V-groove joint design. The system may also be used to improve the utility of a filler metal by suggesting other joint designs.

Process Parameter Selector

The Process Parameter Selector recommends optimal starting welding parameters for gas metal arc (GMA) and gas tungsten arc (GTA) welding of aluminum. It has over 50 separate databases which contain information about welding parameters, as well as joint designs. It covers both plate and pipe welding and allows for different positions, joint designs and base metal thicknesses.

Over 50 databases contain parameter information

Parameter selection involves collecting information about the particular welding process, the basic form of the base metals, the joint design, the welding position, the base metal thickness and, in certain cases, the type of filler metal employed. The conclusions consist both of the required essential parameters such as current, voltage and travel speed, as well as desired edge preparations.

The general approach the software takes is similar to that of an experienced welding engineer. The program first displays an introductory screen describing the inputs and outputs of the system — Fig. 7. The system first asks which particular process is being used, GMA or GTA welding. It then asks which basic form, plate or pipe, is being used. If pipe is chosen and the process is GMA, the system contains one database that is in the horizontal-rolled position. If pipe is chosen and the process is GTA, the three positions, horizontal-rolled, horizontal-fixed and vertical-fixed may be chosen. If plate is selected, then the system requests what general joint design is of interest. The available joint types are butt, T, lap, corner or edge. The system then asks which welding position is being used, flat, horizontal, overhead or vertical. Also, if GMA welding is chosen, the system needs to know which series filler metal is being used since it affects the choice of welding parameters. The system then retrieves from an appropriate database the available thicknesses for this particular situation and presents these to the user for selection.

The initial screen output shows the recommended joint design, as shown in Fig. 8, for GMA welding of 0.375-in. (9.5-mm) thick plate. This includes root face thickness, groove angle, root opening width and backing dimensions when necessary. The information provided at this screen is also in literal form on the final screen. The final screen, shown in Fig. 9, summarizes the inputs and provides recommendations.

The approach is similar to that of an experienced welding engineer

The Equipment Specification window and the Edge Preparation window are self-explanatory. The Schedule window provides the actual number of passes and the parameters for each pass. The pass coding utilizes BR to specify backgouging on the root side.

System Verification

Extensive on-site testing has been performed for both the Filler Metal Selector and the Process Parameter Selector. Two issues were of primary concern during this process. The first was reevaluating the experts' conclusions and ensuring the accuracy of their results, while the second issue in verification was to ensure that the system reported these same results to the user along with clear explanations as to how certain conclusions were reached. For the Filler Metal Selector, this involved having the experts recommend filler metals when utilizing less common combinations of aluminum base metals. Their results and reasoning were compared to the system's recommendations. When appropriate, modifications to the system were made to further improve its accuracy. In several cases reassessment of the experts' recommendations were made. Hundreds of test cases have been performed for this system with excellent corroboration of the experts' recommendations. For the Process Parameter Selector, information was taken from handbooks that are well maintained and represent values considered optimal by welders with many years of experience in aluminum welding. In this case, several conditions were tested at random by producing weldments using the system's recommendations for welding parameters and joint design. With minor modifications to the parameters, the system functioned as expected and provided excellent starting conditions.

Hundreds of test cases have been performed

Conclusions

The development of the Filler Metal Selector and the Process Parameter Selector as well as initial work in constructing the Weld Defect and Diagnostic System have led to the following conclusions:

1) The application of knowledge-based systems for welding is an effective vehicle for capturing experts' knowledge and transferring it to others. With proper design, such systems allow easy access to the knowledge and thought processes of experienced aluminum welding engineers.

2) The systems significantly reduce the time required to obtain the desired information.

3) Knowledge-based systems can outperform current methods for obtaining desired information.

4) Knowledge-based systems can be used successfully by a wide variety of end users in terms of their degree of experience in aluminum welding.

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