Prototype of an Expert System for Aluminum Welding

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Abstract: - Increasing demand for high quality aluminum welding and the international competition has been leading the ship industry to adopt new advanced IT tools. Prototype knowledge based expert system named *WELDES* (*WELD*ing *E*xpert *S*ystem) has been developed under the frame of the Archimedes project 259(03). The system is able to identify the aluminum welding defects, to correlate them with the welding parameters, which cause them, and to offer advice regarding the necessary corrective actions. The first step in the construction of this program was the systematic classification of the aluminum welding defects and the analysis of the reasons, which cause them. The *WELDES* system is aiming to be used as an industrial tool for the identification, assessment, and correction of aluminum welding defects. The system consists of two modules: the Diagnostic Module, and the Adviser Module. The structure of the program is ideally suited to the knowledge domain of the welding and the ship industry as it makes productive the previous knowledge and uses the acquiring experience of many years in the research and production of high quality welding. The next step is the expert system to be tested in real industrial environment.

Key-Words: - Artificial Intelligence, Knowledge Engineering, Expert Systems, Welding Process, Aluminium

1 Introduction

The increased requirements for high quality aluminum welding in combination with method complexity as well as the conditions of international competition have been leading the manufacturing industry towards the adoption of promoted calculating tools [1-4]. Thus, even if the world of industry is conservative and circumspect towards new technologies, the application of Artificial Intelligence (AI) in the field of manufacturing and naval industry and its important role to the quality improvement of produced products, contributed to its widest and most rapid spreading [4-7]. As a result, a great number of research institutions, universities, and industrial units started an important research effort that aimed towards the growth and application of AI in various applications. The reasons that led to the adoption of AI in the scientific field of mechanical manufactures are mainly the following [2]:

- The lack of a complete descriptive, qualitative mathematic model of many mechanical

processes,
- Sufficient empirical knowledge of operators - technicians - engineers upon the nature of process and the need to be developed and,
- The ability of AI systems to manage vague and inaccurate data that are met in modern productive units

In manufacturing industry, expert systems have been developed in a wide field of applications having as main objectives the most optimal planning of processes and the quality guarantee of produced products. There has also been an increase in the hybrid approach, whereby expert systems are combined with other methods, e.g. CAD systems [8]. A limited number of expert systems have been used for defect identification, analysis, and therapy in the manufacturing industry [9-12].
Besides, an important research effort has been developed in the field of aluminum welding in the last decade. Aluminum welding because of its complexity and the difficulties inherent has not been as fully considered until now as an applicable domain for expert systems. However, systems have been developed for certain aspects of the process and within the industry there is considerable expert knowledge for this process regarding defect identification and prevention, available both from the literature and through systematic investigation and analysis in various institutes and laboratories [3,5,13-17].
Common defects in aluminum welding include cracks, inadequate penetration, incomplete fusion, excessive porosity, undercutting, incorrect weld size, and shape. These defects can result from a variety of possible causes such as incorrect preparation, welding procedures or techniques.
The aim of this project is the development of an expert system for the identification, assessment, and correction of aluminum welding defects through their correlation with welding parameters.
The system consists of two main modules: the Diagnostic Module and the Adviser Module. The structure of the program is ideally suited to the knowledge domain of the welding and the ship industry as it makes productive the previous knowledge and uses the acquiring experience of many years in the research and production of high quality welding.

2 Domain Knowledge Description

The starting point in this work was the analysis of the available standards, to get an overall, well structure view of the problem. This attitude reflected the information data type that welders and process engineers use.
Defective welds are those containing discontinuities (defects) serious enough to affect weld strength or corrosion resistance. Common defects include cracks, inadequate penetration, incomplete fusion, excessive porosity etc. There are also many possible criteria for classifying defects, depending on the task in hand. Several possible groupings were examined, such as, by detection method, by fundamental cause, by product characteristic and so on.
With these in mind it was decided as most convenient, the defects to be arranged according to the classification of weld defect system established by Commission V of the International Institute of Welding. Their document IIS/11W-340-69 and Commission V Document classify the defects into six groups [18]:

- *Series 100, Cracks*: Including Cold cracks, Hot cracks, Crater cracks
- *Series 200, Cavities*: Including Gas pore, Surface pore, Linear porosity, Uniformly distributed porosity, Localized porosity, Elongated cavity and Worm holes
- *Series 300, Inclusions*: Including Solid inclusions
- *Series 400, Incomplete fusion and penetration*: Including Lack of fusion and Lack of penetration
- *Series 500, Imperfect shape or unacceptable contour*: Including Undercut, Excess weld metal, Excessive penetration, Local protrusion, Overlap, Linear misalignment, Sagging, Incompletely filled groove, Root concavity
- *Series 600, Miscellaneous defects not included above*: Including Spatter

Defects in aluminum welding can result from a variety of possible causes, welding procedures or techniques. The causal parameters for the above defects have been classified in the following categories as it is shown in the diagram of Fig. 1:

- *Preparation parameters*: Including Root opening, Root face, Surface condition, Temperature preheat and Temperature interheat
- *Heat input parameters*: Including Voltage, Current and Travel speed
- *Execution parameters*: Including Electrode angle and Welding direction, Arc height and Feed rate

- *Gas parameters*: Including Gas flow rate, and Gas type and Gas quality and
- *Other parameters:* Giving other technical details

An Iskikawa diagram (cause and effect diagram, Fig. 1) was constructed to identify the aluminum welding process parameters that may affect welding defects.

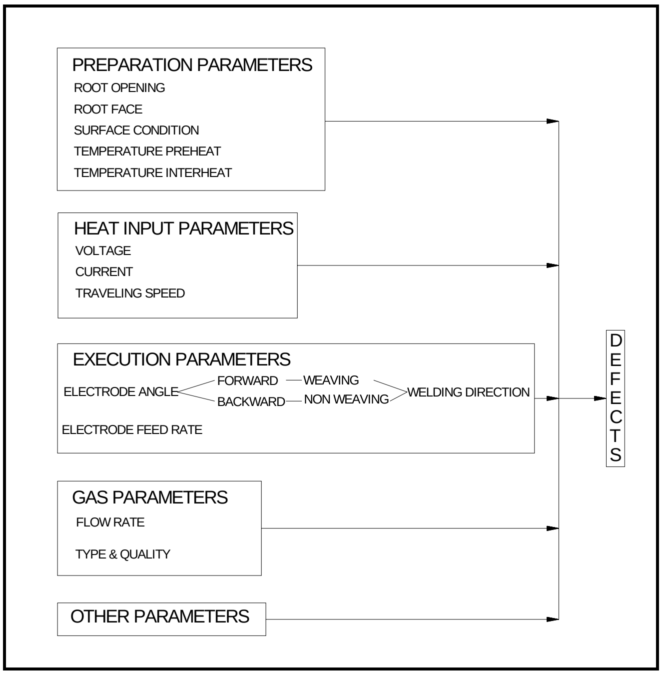

Fig. 1 Cause and effect diagram

Then, a set of dependencies was necessary showing the aluminum welding defects through their correlation with welding process parameters. This knowledge was acquired from the following sources:

- Requirements and recommendations from codes and standards on welding process
- Textbooks, reports and handbooks
- Heuristic inference judgments and experience of welding experts and engineers

Experience and professional judgments play a fundamental role. The knowledge engineering task is performed, through a number of interviews, by collecting and articulating related knowledge. During the knowledge engineering task, the system developer extracts from the production experts their reasoning procedures, strategies and rules for problem solving, and then builds this knowledge into the expert system shell. Following are the example of the questions that are addressed to the specialist:

"On what basis did you think of this cause?"
"How critical is this value?"
"Are you satisfied with this result?"
"What would your decision be if you did not have this information?"
"Are there other factors to consider?"

The solutions were also ranked according to a recommendation ratio. This was determined by obtaining a causal strength value from the expert for each Defect – Parameter pairing. This ranged from 1 (little connection) to 10 (very strong causal influence). Additionally for each parameter, an "adjustability" factor was obtained which reflected the amount of time, effort, and expenditure involved in altering the parameter. The recommendation ratio was then determined by dividing the causal strength by the adjustability factor.

3 Structure of the *WELDES* System

For the correct Expert System construction, it was important to identify sub-tasks within the whole process to allow for the compartmentalization of knowledge. It was deemed necessary to do so for several reasons. Firstly, it suggests a means by which a potentially large knowledge base can be structured. This is necessary as it facilitates several of the knowledge engineer's tasks such as providing causal justifications for solutions, identifying gaps in the knowledge base and updating the system over time. Secondly, with a process such as aluminum welding, which involves different people over the entire process it helps identify the various sources of expertise that it may be necessary to represent. Thirdly, by performing this broad task analysis, the potential users of the system are also identified and this aids decisions regarding the user interface. After consideration of the knowledge sources, the main tasks were identified as follows:

- Diagnosis of defects
- Corrective procedure via welding parameters

Therefore, the system was designed in a modular fashion according to these tasks. The different modules realize the different functions, and a relevant file is established for each module. Overall, the system was divided into two modules: The Diagnostic Module and the Adviser or Welding Parameters Module.
The problem structure in *WELDES* system is illustrated in the diagram of Fig. 2.

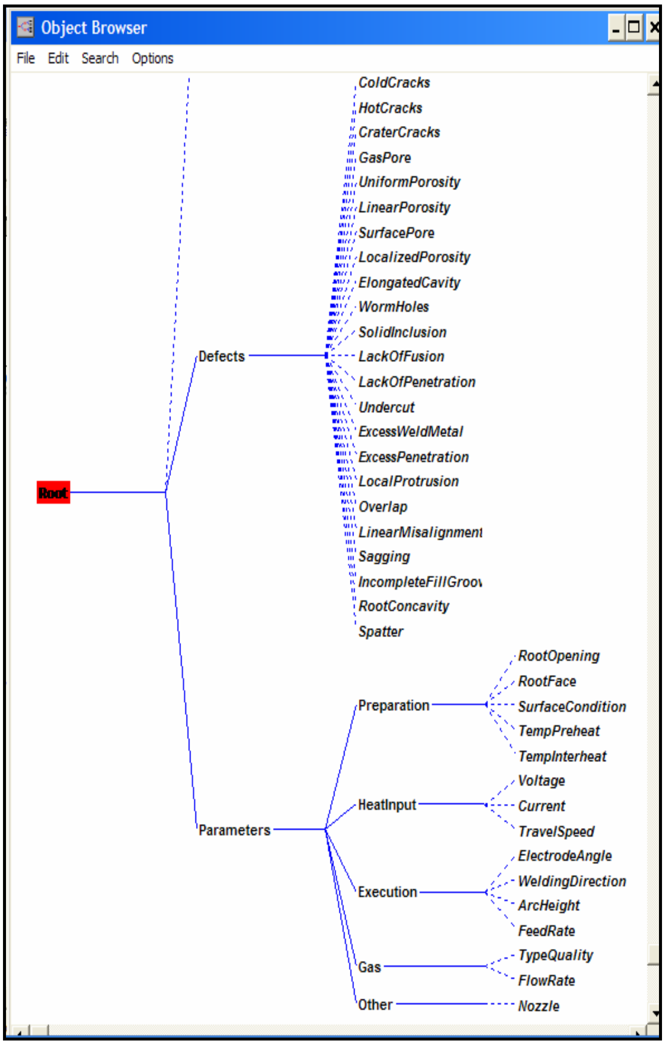

Fig. 2 Graphical view of the problem hierarchy in WELDES system

3.1 Diagnostic Module

The correct diagnosis of defects is essential for the efficient execution of aluminum welds. A large number of possible defects exist and each of these has a number of possible causes. Therefore, in order to reduce the search space it is worthwhile expending some effort on the initial diagnosis. An attempt at diagnosing defects by a series of questions was made, such as;

"Is it surface or internal?"

"Is it a hole or a crack?"

"Is it spherical or elongated?"

This can be somewhat tiresome for the user, and more importantly, the reliability of such a mode of diagnosis is questionable. There are only subtle differences between defects, and it was decided that a description of defect in conjunction with a graphical or pictorial representation would be far more satisfactory in guiding the user through the range of defects.

For this reason a symbolic system for welding defects has been developed, which in conjunction with a graphical image or a picture for each defect will help in defect correct diagnosis and identification. Defects symbols and graphics (or pictures) have been form an essential and integrated part of both static and dynamic user interfaces developed for the project.

The symbol developed for a common defect - Overlap - and the graphical representation of this defect together with an analytical description of the weld appearance can be seen in Fig. 3.

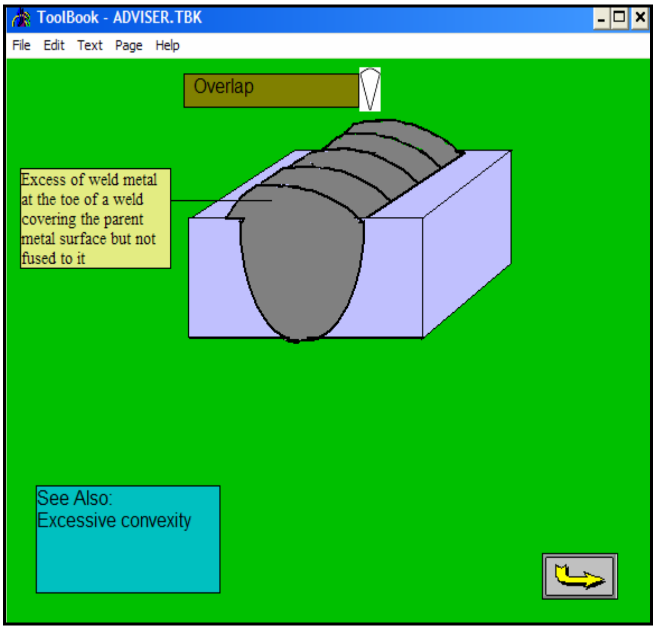

Fig. 3 Graphical representation of a common aluminum-welding defect

3.2 Adviser module

The structure of the Adviser Module is ideally suited to the knowledge domain of aluminum welding process as it makes productive this knowledge and uses the acquiring experience to give advice on how the defects might be avoided.

In attempting to alleviate the defects the solutions fall into five main categories as was suggested by the breakdown of the knowledge domain mentioned above. The first comprises Preparation parameters such as root opening, root face, surface condition, and temperature preheat, and temperature interheat. The second comprises Heat Input parameters such as voltage, current and travel speed. The third comprises Execution parameters such as electrode angle and welding direction, arc height and feed rate. The fourth comprises Gas parameters such as gas flow rate, type and quality of gas and the last comprises Other Various parameters such as nozzle size, gas cover, and crater fill etc.

After the initial diagnosis, the system offers advice regarding the necessary corrective actions. The advice and the relevant corrective actions for Overlap, the characteristic defect mentioned above, is illustrated in Fig. 4.

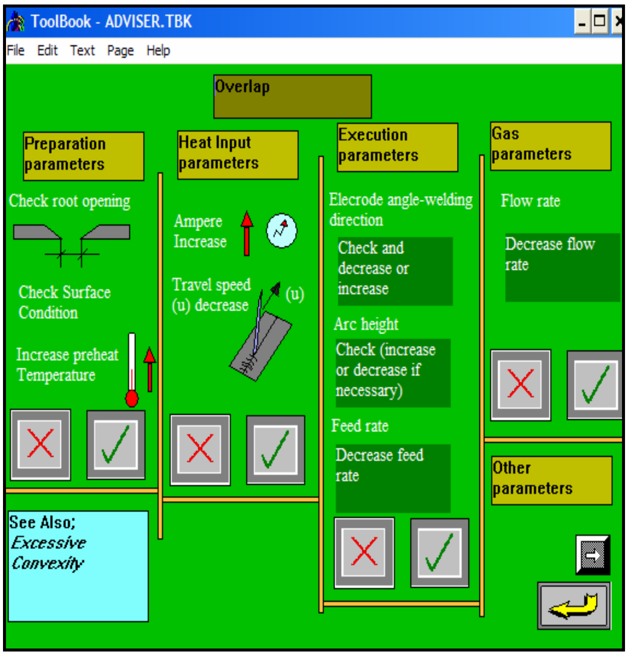

Fig. 4 Corrective actions for avoiding Overlap

3.3 Rules construction

In AI systems a one-track and typical symbolism must be used, which apart from offering the opportunity for a precise representation of knowledge, it should be properly combined with inference mechanisms, which are materialized from strategies of knowledge search of a problem as well as of reasoning.

In the particular application, the searching strategy is materialized through a data driven reasoning. The data are the arithmetic and qualitative values given through our empirical research, since there are no international standardized values of welding parameters. Correspondingly, the method of knowledge representation, which was selected in the particular problem, is the *if-then rules*. These rules were chosen because,

- Knowledge is represented in a way it reaches human knowledge
- Conclusion extraction is accomplished in an easy way
- It is the most practical way of representation for conclusion extraction

The necessary knowledge has been converted into rule format and has been incorporated into the expert system. Rules of the following types were formulated in the knowledge base, mimicking the ways human experts solves similar problems, using the relationships discussed previously. The form of rules used in this problem is showed in Table 1,

Form	***It expresses***	***Explanation <>***
IF agreement, **THEN** action (increase/decrease)	Procedural Knowledge	**If** the agreement is true, **then** execute actions

Table 1 Form of rules

Frames were created as ASCII text files in the form of table shown in Fig. 5. In this case, defect Overlap has been detected in Diagnostic Module after selecting the appropriate graphical image. The user then quits back to the Adviser system. *WELDES* then reasons through the rule base to find all possible related parameters and ranking them as mentioned previously. The user now selects the correction icon and chooses the parameter – Travel speed - he wishes to be given a solution for. The means of altering this parameter and thereby alleviating the defect are then inferred, the user being prompted for information when necessary.

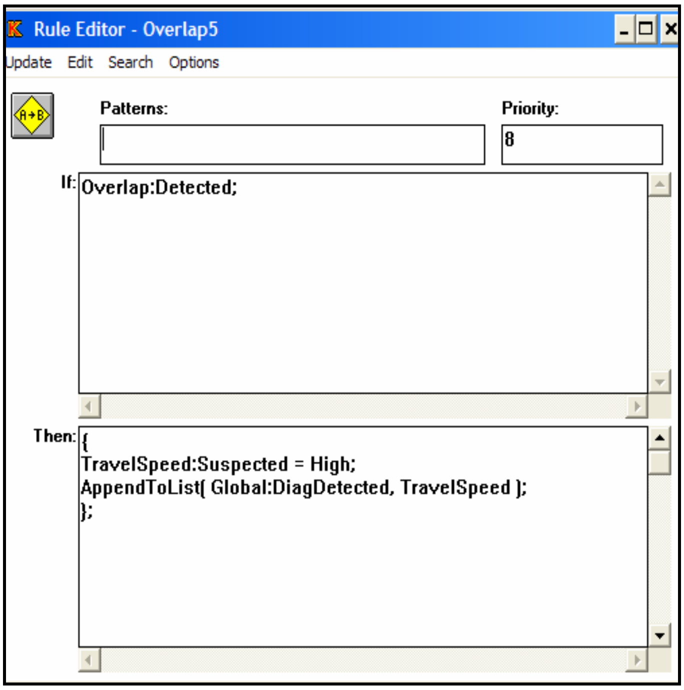

Fig. 5 Rules construction in WELDES System

More than 150 rules are stored, and the system picks up the rules and gives advice based on the preliminary knowledge that has been stored.

4 Conclusion

A prototype expert system for the diagnosis,

assessment, and alleviation of aluminum welding defects, named *WELDES* has been developed. The system is able to identify the welding defects, correlate them to the causal welding process parameters and to offer advice regarding the necessary corrective actions.
Using information gathered during the validation of the system at shipyards and industries new considerations regarding the user interface are being investigated. These include a log of user satisfaction ratings for solutions that will aid the updating of the knowledge base.

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