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Knowledge Platform for Resistance Spot Welding

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Abstract

Virtual weldability testing and prototyping significantly reduces the time and cost needed in product and process development. However, implementation is often inhibited due to lack of accurate information, support tools and methods to capture all knowledge elements from across the development process. Furthermore, results from previously conducted tests are often unavailable due to absence of knowledge reusability schemes and enabling tools. In this paper, a knowledge platform development is presented which has been implemented in industrial cases from Swedish automotive industries. The platform is demonstrated to be a key element in enabling effective virtual testing and prototyping.

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Keywords: *Knowledge modeling, knowledge reusability, knowledge platform, Simulation, Virtual testing, Resistance spot welding*

1. Introduction

With advances being made in virtual tools and methods for process design and analysis, new opportunities are opened to transform the current industry into one of fully digitalized supported by tools and platforms for knowledge reusability. This is part of the global effort to embrace the smart factory or the industry 4.0 paradigm. The drivers for implementing these virtual tools and methods is to expedite the product, process and manufacturing development process and reduce the cost incurred thereof while delivering better quality products and services.

Resistance Spot Welding (RSW) is a joining process with significant value adding contributions in many industrial sectors including the auto industry. The cost and time spend to develop the process significantly affects the total product and process development.

RSW process development can be benefitted from digitalized approaches to significantly improve the efficiency and effectiveness of the product and process development. The implementation of digitalized solutions is nevertheless inhibited due to lack of accurate or structured information, support tools and methods to capture and make available relevant knowledge elements from across the development process.

Process planning of RSW is critical to the overall development due to the determination of the critical process parameters set and its interaction with product and manufacturing designs. Hence, digitalization process planning to overcome the above mentioned challenges would result in improved overall process.

In this paper, a conceptual platform that provides the information and knowledge for a virtual weldability testing and prototyping is proposed and its implementation is presented.

The remainder of the paper is organized as follows. Section 2 discusses RSW process planning and the challenges therein is presented. Following this in Section 3, a knowledge platform, as the main goal of this study is described with the proposed architecture which is later illustrated in Section 4. Finally concluding remarks are given in Section 5.

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2. Resistance spot welding process planning

RSW process planning comprises setting several design and process parameters which demand the use of virtual tools. These parameters are then subjected to tests, often several times in iterative manner for validation. Since these tests are made on physical prototypes, it is evident how much resources this requires in terms of time and cost.

In addition to the 'conventional' parameter to be set for RSW process planning, new sets of requirements driven by reduction in weight requirement and new material combinations, the need for intensive welding tests and prototyping have become all the more critical.

For instance in an auto body case, reduction of weight demands considerations to the number of welded sheets, sequence of layers of material in case of multi-sheet stack-ups, and use of emerging new materials. In the studied welding process, a number of sheet metals are welded together and forms a stack-up. Generally here, "Stack-up" is the first and low level hierarchy for the product concept that is mostly made of welding one, two, three or even four layers of sheet metals. Properties such as sheet metals' various thickness, their sequence inside the stack-up and kinds of implemented base and coat materials in each sheet can generate a large variety for the produced stack-ups. The composition of utilized "base and coat materials" plays critical role in the weld results [1]. "Part" as a given name for the third level of product hierarchy is made from numbers of welded stack-ups while "Final structure" of car body refers to the highest hierarchy that is achieved from welding the numbers of parts together.

Above brief description about the numbers of welded sheets and hierarchy levels in car bodies demonstrate the importance of weigh in the automotive industry. Selecting low weight materials in the best combinations and sequence can create competitive advantage for the companies. High weight products affect negatively cars environmental impact and performance while low weigh products are desirable and can be compatible with future generation of cars.

New materials and compositions with various attributes in strength, hardness, formability, electrical and thermal properties are steadily developed and introduced to the market by material suppliers. The new materials, some of them with rather extreme strength properties, are often more difficult to weld than old material variants. Thus, the car manufacturers should always investigate utilization of these new materials, setting their weld parameters and the manner of their combinations and sequence inside the car bodies. The ones with sufficiently good welding results should be preserved for more analysis to add in the product and process development plans.

The critical challenges in RSW process planning could be addressed by knowledge reusability and implementing digitalized approaches in replacement of the physical tests with the virtual ones. These topics are briefly described in the following.

2.1. Replacing time-consuming physical *tests and prototyping*

RSW parameters are mostly set by time-consuming weld trials and prototyping that is defined as a main obstacle for time responsiveness in this area. In face with various unknown material combinations, short response time is required to set the welding parameters and reporting the weld results. Responsiveness can be increased by the following solutions:

- Taking advantage of already done experiences, available knowledge in RSW process and historical test results
- Implementing virtual tests instead of physical ones

Virtual testing can significantly increase responsiveness of RSW process while it saves material and energy consumptions simultaneously. By saving material, energy and time, total cost is decreased and more margin of profit will be generated by the companies. Outcomes simply satisfy sustainability concept and bring competitive advantage and brand promotion for the frontiers in this area. Using already done test results refers to knowledge reusability. Based on one of the industrial case studies in the BiW pillar structure, after applying virtual tool and reusing the knowledge, lead-time reduction was around 50% [2]. Fig 1 represents digital enablers and details of the developed process flow there. The studies showed that by replacing physical tests with virtual ones, reduction in lead-time can be achieved.

2.2. Lack of tool to reuse knowledge and support decision-making process

Lack of any tools to collect all historical data and absence of formal databases within the studied companies is a main barrier for knowledge reusability. Documentation of all welding tests and organizing data is the first step to develop the knowledge platform. Creating a knowledge based-database is required to take advantage of already done test results with various material combinations, process parameters, nominal real and virtual sizes of spots and nuggets, spatter conditions, etc.

In addition, welding designers and process planner need a tool to help them to select the materials and process parameters and choose the best combination of them from the beginning and first stages of the product developments. Simultaneously after-sale services also need such a tool to facilitate repairing parts by re-welding and fixing damaged sections. A digital tool or knowledge-based database with fast, easy and convenient search and data retrieving capability is the best solution for all weld experts all along the chain. Transferring RSW knowledge inside the tool creates a smart digital tool that decreases human errors in decision processes and results in fast and right decisions even if in face with complicated situations.

Making decision about weldability of material combinations and accepting or rejecting weld results in this study is done by developing a number of modules within the knowledge platform such as: product combination and hierarchy recognition module, nominal measures module, process modules, test module, real and virtual measures module, weld window module and weld status generator module.

Digital documentation of stack-up properties, implemented material combinations, manufacturing conditions, spot and nugget details, weld status and keep tracking of their test results improve pattern recognitions for the weld experts and increase predictability of test results in face with similar cases.

Simultaneously, it saves time and money in setting of weld

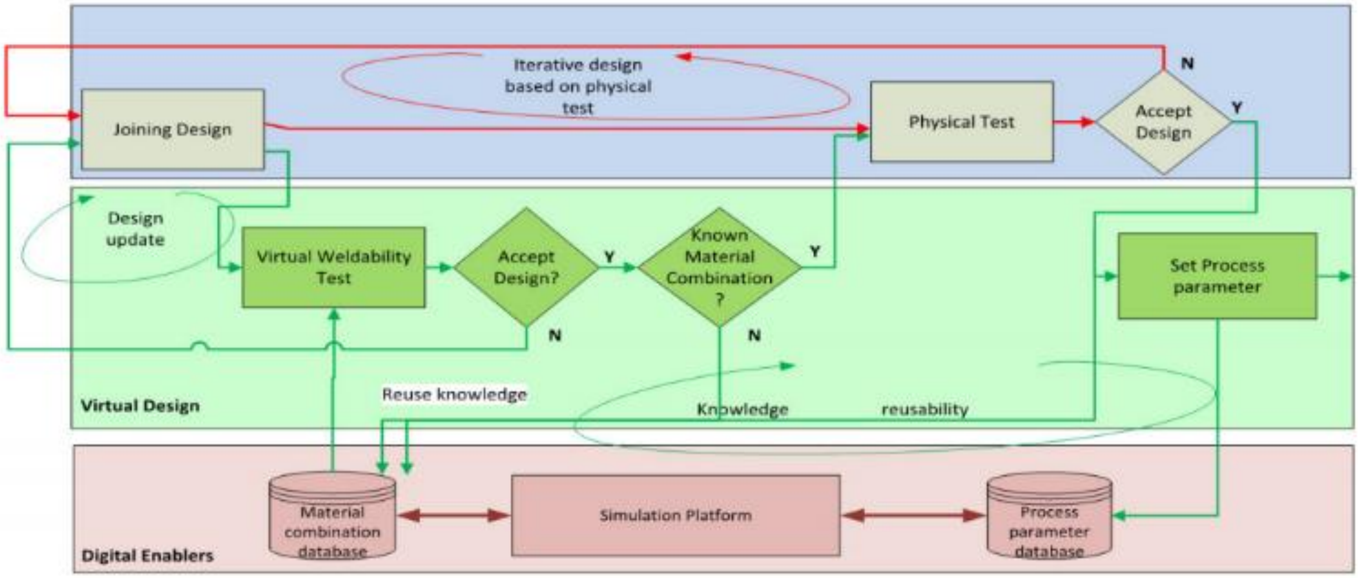

Fig.1. Process flow and digital enablers to implement virtual testing in RSW process [2]

parameters by avoiding repetition of already done successful or unsuccessful weld trials. By the help of this tool, products are developed, manufactured and repaired in a cost effective manner.

3. Knowledge reusability as a main goal

Knowledge is consider as a vital source for creating competitive advantage [3]. According to the survey of Technology Services Industry Association in 2016, there is a growing interest in knowledge management investments [4]. Knowledge is achieved through a process of data analysis, communication and information generation, which finally form the knowledge [5]. Knowledge concept is categorized to tacit and explicit groups. “Tacit knowledge” is defined as a personal experience and exists in informal rules and procedures on the experts’ mind or in their personal documents. That is why it is difficult for extraction and evaluation [6]. Capturing this knowledge will be happened by just face-to-face interaction or observation. On the other hand, “Explicit knowledge” is available in the formal documents inside the companies and it is easy to achieve.

Recent advances in information technology provide an appropriate environment for systematic knowledge management and data extractions. Creating knowledge-based systems enhance knowledge accessibility, learning, sharing and reusing [7]. Artificial intelligence techniques help experts in modeling of knowledge and reusability of that [8]. All forms of knowledge can be embedded inside “corporate memory” and are useful for decision-making actions [9]. To build a knowledge-based system, activities such as knowledge capturing, discovery, formalizing, evaluating and integrating are required [10]. Electronic knowledge repositories for storing knowledge enhance its usage in the required time [11]. Effective usage of already done experiences and learned lessons make competitive advantage in various areas including design, engineering, maintenance, planning and quality management [8].

Based on above description, the primary goal of this study is reusing knowledge, which is achievable by creating a knowledge schema within a platform. Acquisition of tacit and explicit knowledge within the studied companies are done in this path. The proposed knowledge platform in this work is generated based on studies on auto industries and repair services having similar requirements in RSW process.

The platform is generated through the following methodology. First, the data and knowledge base schema are developed based on the requirements of virtual and physical RSW process. The schema is then populated with data, information and knowledge elements through information gathering and knowledge elicitation methods with the process planners, simulation analysts, manufacturing process developers and equipment developers. The platform is then tested for specific cases and validated.

4. Platform architecture

The proposed architecture of knowledge platform is composed of three elements namely:

1. Knowledge elicitation tools
2. Virtual modeling and simulation tools
3. Knowledge-based databases and data analytics

Fig2 shows these elements and their relationships.

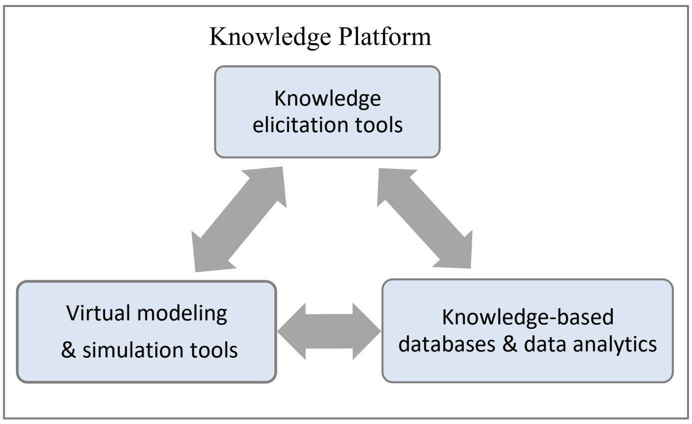

Fig.2. Knowledge platform architecture

Knowledge elicitation tools refers to the tools used to extract and formalize knowledge. Knowledge elements are captured with the combinations of concept mapping, entity-relationship modeling, data flow modeling, document analysis, group discussions and also interviews with experts and practitioners. The knowledge and information gathered in such a way are then structured and formalized using elicitation, i.e., rules and algorithms embedded.

Virtual modeling and simulation tools refer to welding simulation tools where the virtual tests are conducted. These tools need to be integrated with the knowledge-based databases and data analytics module in order to reuse, add or modify existing knowledge elements. The virtual test results such as simulated nugget sizes, welding process parameters, valid and invalid material combinations, etc., are stored for future references.

Knowledge-based databases are developed based on identified weld entities and types of their relationships plus data modeling of all extracted parameters in RSW context. Weld quality parameters and parameters of physical and virtual tests are included in the developed databases. Modularizing and encapsulating various entities with their relevant parameters in separate modules are done in the path of data modeling.

Regarding the illustrated relationships between platform elements in Fig 2, it is obvious that knowledge elicitation tool as a first step, generates data for both simulation tools and developed databases. Simulation tool requirements lead to defining some parameters inside the databases while some other parameters, nominal measures and material combination attributes inside the database provide data for the simulation tools. That is why simulation tools and knowledge-based databases have bi-directional relationship and data transactions within the developed platform. On the other hand, the outputs of the developed knowledge-based databases provide data for knowledge elicitation tools. Therefore, knowledge cycle can be completed, and taking advantage of knowledge reusability can be continuously achieved with the help of the developed platform.

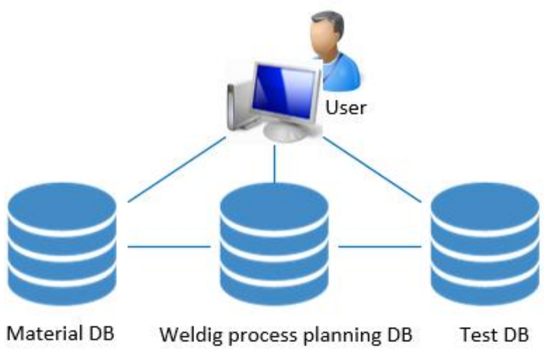

Fig.3. Developed knowledge-based databases

Abstraction of the knowledge schema and developed databases (DB) are shown in Fig 3. Such developed databases are able to keep track of all material combinations, process parameters, virtual and physical measures of welded spots and nuggets while extract the final test results and automatically interpret weld conditions based on the embedded knowledge inside them. The knowledge-based database has three different components namely:

1. Material DB
2. Welding Process Planning DB
3. Test DB

Moreover, a user-friendly interface was created to connect the users to databases and make it possible for them to retrieve data simply and rapidly. For data modeling inside the databases and increasing repeatability and future scalability of the developed data model, identified entities and their relevant attributes have been encapsulated in some separate tables in order to create a modular scalable architecture of welding data in RSW process. Detailed descriptions of the databases are given in Fig 4.

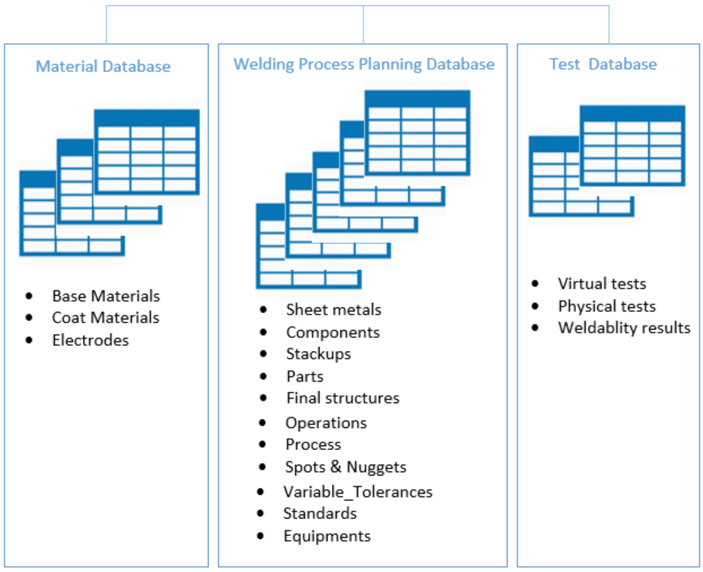

Fig.4. Details of developed knowledge-based databases

- *Material database:* It comprises all required raw materials for RSW process. It represents all extracted entities, parameters and attributes that properly describe materials. For example, "Base and Coat" materials are two main material entities that describe properly by parameters such as: composition, thickness, thermal conductivity, thermal expansion, electrical conductivity, resistivity, strength and so on. Other materials such as "Electrode" and their respective attributes are documented in the material database as well.

- *Welding process planning database:* It comprises attributes of various entities such as: sheet metal, component, stack-up, part and their welding sequences to make the final structure of the car body. This database contains operations data, their sequences and welding process parameters such as pulse, cycle number, current, force, welding time, geometries of upper and lower electrodes plus nominal measures of spots and nuggets and entities of equipment, standards, variable & tolerances and their attributes.

- *Test database*: It comprises test preparations and all required data to make a valid model. It also make documentation of the required data and models to run the simulations and keeps track of implemented testing methods and all virtual and real measures of spots, nuggets and test parameters (such as tensile and yield strengths, expulsion limit, indentation depth, hardness, failure modes and spatters). This database makes a basis for comparing physical tests with the virtual ones for specific stack-up and helps the simulation tool users to recognize and eliminate problems arising from simulated environment and welding modeling.

Regarding weld status, final test results are automatically represented in a smart manner by the created knowledge platform in this study. As user usually enter just raw data, the need for expert users can be eliminated by the proposed solution. Interpretation of the input data, weld window calculation and decision making about accepting or rejecting the weld results are done automatically by the system and is reported in the developed "Weldability results" interface. This attribute of the developed platform supports experts for making decision about weldable combinations while it eliminates subjective data analysis and human errors in data interpretations.

Minimum Successful Weld Current = 8.5 which belongs to 59/G2
Maximum Successful Weld Current = 10 which belongs to 59/G7

Weld Window = 1.5

Entered minimum allowed current	Weld Window	Weld Status	EpoxyCondition
0.9	1.5	OK	Not OK

Information of all spots relevant to the entered Stackup ID:

Stackup_ID	Spot_ID	Test Date	Process_ID/Pulse Group no.	Minimum Nugget Size	Real Nugget Size	Failure Mode	Spatter
5	46	2017-09-01	59/G1	6	[7.7,6.1]	NULL	NO
5	47	2017-09-01	59/G1	6	[7.7,5.8]	NULL	NO
5	48	2017-09-01	59/G1	6	[7.5,5.7]	NULL	NO
5	49	2017-09-01	59/G2	6	[8,6.8]	NULL	NO
5	50	2017-09-01	59/G2	6	[7.8,6.4]	NULL	NO
5	51	2017-09-01	59/G2	6	[8.1,6.3]	NULL	NO
5	52	2017-09-01	59/G3	6	[8.5,6.9]	NULL	NO
5	53	2017-09-01	59/G3	6	[8.6,6.8]	NULL	NO
5	54	2017-09-01	59/G3	6	[8.4,6.8]	NULL	NO
5	55	2017-09-01	59/G4	6	[9.1,7.3]	NULL	NO
5	56	2017-09-01	59/G4	6	[9.2,7.1]	NULL	NO
5	57	2017-09-01	59/G4	6	[9.2,7.2]	NULL	NO

Fig.5. A sample of automatic reported weldability results

Fig 5 shows a sample of automatic weld window calculation and the reported weld status. To build such a knowledge platform, all relevant algorithms, rules and calculations are extracted by knowledge extraction methods and transferred inside the developed databases. Moreover, the ability of comparing parameters, intermediate results and the way for interpreting them was built inside the developed knowledge platform.

Fig 6 shows short abstraction of the developed interface for industry application. By clicking on each item, another page with relevant attributes appears and make it possible for the user to enter, delete, search or retrieve the data (one sample is shown in the appendix A). Entered data is automatically pulled based on their defined relationships in the model to generate various reports for the users. Minimum data entry for search and submission was the main concern during creating the user-friendly interface in this study.

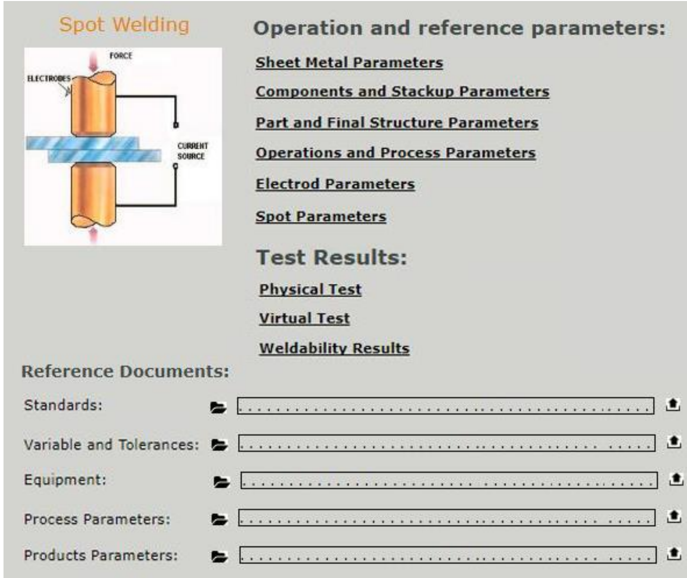

Fig.6. Developed user-friendly interface for RSW

Conclusions

The present work developed a knowledge platform for RSW process based on the requirements obtained from industrial cases. This platform architecture comprise elements of knowledge elicitation tools, virtual simulation tools and knowledge-based databases. Elicitation tools collect knowledge of RSW process while simulation tools make it possible to replace physical tests with the virtual ones and eliminate time-consuming physical weld trials and prototyping in many cases. Virtual testing enhances the feasibility of the weld plan and helps to make a robust welding.

This study addresses "knowledge reusability" that can be achieved through capturing knowledge and transferring it inside the created knowledge-based databases. By reusing past experiences and reviewing historical welding test results with accompanying virtual tests, it would be possible to save time, material and energy consumptions simultaneously. In this way, unnecessary efforts to set welding parameters can be eliminated while total cost and material and energy wastes are decreased too. Short time to weldability assessments and setting successful process parameters increase responsiveness of RSW process.

The created knowledge platform is supportive for decision-making conditions and helps designers and process planners to select best weldable material combinations from the first stage of the product development phase. It also supports after market and repair experts in fixing damaged car bodies.

Making decision about accepting or rejecting the welding results are automatically done by the created knowledge platform in a smart manner. For this reason, human errors in data interpretation are minimized, therefore there would be no need for professional users in extracting welding test results. User-friendly interfaces are developed to facilitate platform implementation within the industry, and finally the created knowledge platform is tested and verified by utilizing inside the studied industrial companies that can be called as a consortium.

Separation of knowledge schemas and data customizations are done during the development path because the member companies in consortium had some sensitive data that do not want to share with the other members.

Acknowledgements

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Appendix A.

A sample of the developed interface for entering RSW process parameters is depicted at the bottom of this page.

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A.1. Example of the developed interface for RSW process parameters