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INTELLIGENT WELDING IN CONTEXT OF INDUSTRY 4.0

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Abstract: *Welding is analyzed here as an intelligent process in the context of Industry 4.0, with a focus on two aspects: automatization and machine learning. In the case of automatization, starting from the first industrial robots as applied in spot welding in car industry 50 years ago, advances in other welding processes like Gas Shielded Arc Welding (GSAW) and Laser Beam Welding (LBW) are presented. As for the machine learning, starting from the early efforts to use neural networks to correlate input welding parameters with a shape of a welded joint in early nineties, advances in modern machine learning technologies to predict mechanical properties and microstructure are presented.*

Keywords: *welding; industry 4.0, machine learning, neural network, automatization*

1. INTRODUCTION

Modern technological advancement leads to a need to develop more accurate and efficient means of achieving optimal welding parameters, for the purpose of monitoring and improving welded joint quality, without any welding defects [1-4]. The very concept of Industry 4.0 enables this approach to the welding process, through the automation of the process itself and the introduction of the concept of machine learning. Today people are in the latest age the fourth industrial revolution that is, in age Industries 4.0. Industry 4.0 based on the interrelationship of people and the latest technology. In the last few years, the world has been developing and implementing advanced technologies, especially digital technologies in the production processes of industry, and companies that want to stay in the market must monitor the development and modernize and automate their production processes to compete in the global market. Fundamental changes are brought about by digital technologies such as: introduction of the Internet, including open software platforms, open communications, open databases with powerful built-in processors, so that networked production in the industry becomes more flexible and efficient. Digital transformation represents the foundation of Industry 4.0 that characterizes transition to production-driven digital computers. Without digital transformation it would not have come to automated processes that are the foundation of Industry 4.0 thus gaining new insights and ways of managing production. The fourth industrial revolution is based on innovative technological solutions whose implementation in the field of development of production processes contributes to the evolution of technology. Continuous digitalization of production functions and processes in the field of welding influences decision makers to proactively and strategically consider the possibilities of innovative solutions and guided by cost-benefit analysis to make timely and correct decisions that affect the efficiency of the process.

This idea will present the application of neural networks as one of the most popular techniques of artificial intelligence to semi-automatic welding of structural steels. Based on a neural network, developed the Neural Network Soft Sensor (in future text NNSS) application will define the expected mechanical properties of a welded joint, based on the input process parameters, this methodology was successfully applied to melting production and casting progresses [5, 6]. Constant improvement of this concept, based on neural networks, resulted in the possibility of implementation, i.e., this software based on neural network can independently provide optimal parameters for a given welded joint, based on previous input data. The input data for the software will be based on the welding parameters (such as current, voltage, weld speed, etc.), and the output will be the desired mechanical properties of the welded joint (Figure 1).

The goal of this study is to initially provide a technological solution, wherein Neural Network Soft Sensor (NNSS) would enable a quicker and easier way of adopting the adequate welding technologies for structural steels. By using the application which would utilize Neural network soft sensor software for the purpose of establishing the relation between mechanical properties of used materials (in this specific case structural steels) and

welding parameters, along with providing maintenance and update services, which will allow companies from this part of Europe to be competitive both in the regional and the global market.

In this way, the welding process itself would be significantly quicker, and the need for test welding, which represents the standard way of validating the parameters, would decrease due to the fact that neural networks would enable the software to obtain optimal parameters in a more effective and efficient manner, thus saving material costs and time.

This will also decrease the workload of the welders, who are currently in high demand, but low on numbers on our market. While similar technologies exist in the global market, there are no such solutions in the regional market.

2. TECHNOLOGY

Realization of this project idea will consist of five stages, which will improve the quality and efficiency of welded joints, with special focus on saving time, money, energy and materials [7-10].

Implementation of the first stage will result in the development of numerical models of test specimens, which will be performed with varied input parameters (mechanical properties of materials in the welded joints), followed by welding of plates made of structural steel S355J2 [11] (due to the wide application of such structural steels in mechanical and civil engineering industry, and the fact the welding is one of the best and most efficient ways of joining such materials), which will then be tested in order to verify the numerical results and define the input parameters for the Neural network soft sensor (NNSS). These numerical analyses will involve simulating heat input (which is directly influenced by other welding parameters) to a welded joint, and creating a database of results for various parameter combinations) Input for the numerical simulations will be obtained from gathered pWPSs (preliminary welding procedure specifications – documents which define all of the necessary parameters for welding a specific work piece under specific conditions, using a specific combination of base and filler material and a specific procedure). A total of 108 pWPSs will be used for this purpose which will define the combination of relevant parameters: Current ((100-140A; 120-160A; 160-200A), voltage (18-22V;20-22V;22-26V) and weld speed (40-180 mm/min; 60-200 mm/min; 150-350 mm/min).

Following to the previously defined first stage, the second stage will include welding of plates, using Metal Active Gas welding procedure (denoted as 135) [12]. Electrode of commercial name VAC 60 [13] will be used as filler material, and the diameter of the electrode made of this material will be 1.2 mm. Parameter ranges (current, voltage and weld speed) were adopted in a way that ensures that heat input (which depends on all three) is always between 0.5 and 2.0 kJ/mm, a standard range of values for structural steels. Welding will be performed for on a total of 30 plates (24 of which will be used in the experiment, whereas the remaining 6 will be used as a reserve, in the case something is wrong with the first group) which will provide 12 welded joints (along with 3 spare ones), for the purpose of experimental testing which will verify the numerical simulations, since this number of plates will provide sufficiently accurate results.

The third stage would include the cutting of a total of 84 specimens from the 12 welded plates, for testing purposes – 7 specimens will be obtained from a single plate, 3 of which will be used for tensile tests, 2 for hardness and 2 for bending tests, in order to verify the numerical results, and thus obtain the input parameters for the software.

The fourth stage will include testing of these specimens, using both destructive (tensile, hardness bending) and non-destructive methods (radiography). Non-destructive testing will determine if there are any defects in the welded joint which may not be allowed in accordance with the standards, whereas destructive tests will provide the results for mechanical properties of the welded joint, which will be compared with the numerically obtained ones. If the comparison is favourable, i.e. the difference between the experiment and the simulation is sufficiently accurate (within 15% of each other) the corresponding combination of welding parameters will be used as input data for the NNSS application.

The fifth stage will involve the development of the software platform NNSS (intelligent soft sensor), whose core is a neural network. A neural network tasks consists of using the input values of welding process parameters to predict the expected mechanical properties, such as tensile strength, toughness and hardness. The developed NNSS will enable the user to input various combination of input parameters (welding parameters) and use them to determine the optimal mechanical properties for the welded joint in question (depending on its material, exploitation condition, etc.) shown on figure 1.

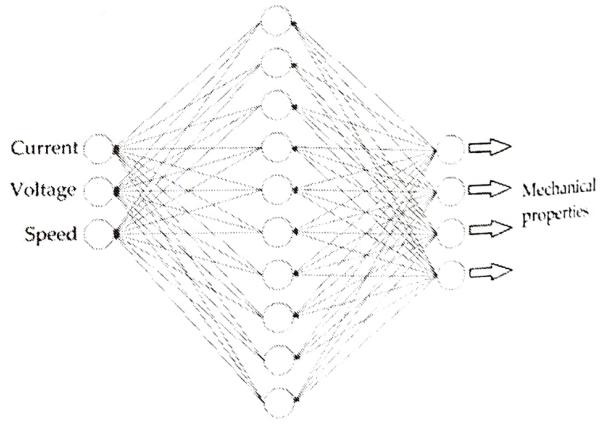

Figure 1: The input and output data for NNSS

Also, fifth stage will involve testing of NNSS using sets of experimental data which were not used in its development. Results obtained by NNSS prediction will be compared to the results which were obtained by experimental tests within the previously defined stages. This testing will be expanded by comparing the results obtained by NNSS software and finite elements method, which will be performed in ABAQUS software, using the finite element method, which have wide usage in modelling and calculating welded joints [14].

An additional benefit resulting from this project idea is reflected in its contribution to the relevant scientific fields – results obtained during its realization will be published

in scientific papers. What makes this contribution particularly important is the fact that this specific application of neural networks in welding is a very new field which is still largely unexplored. In addition, this type of solution is a new concept in the region and is likely to inspire other local companies and teams to get involved in application of neural networks in welding industries.

3. MARKET ASSESSMENT

Solutions based on neural networks are being developed and used in certain parts of the world, e.g. Sweden, India and Japan, however this concept is still rather new and unknown in Serbia and the region. In that sense, Neural Network Soft Sensor (NNSS) has the potential to establish itself as a groundbreaking technology in the regional market. It should be taken into account that foreign companies are also present in the aforementioned market, thus there is a strong possibility of expanding our business on the global market, which is our intention in the later projects which could result from this initial project idea. This project idea will provide customers with a very simple and user-friendly way of searching and selecting of adequate parameters, while saving considerable amounts of time and materials for the company which is using our software.

Welding is widely used in various industrial fields, particularly in mechanical and civil engineering. The most important aspects of these industries in the regional market include energy production, thus our focus will be on storage tanks, pipelines, hydropower and thermal plant equipment and various structural elements related to them.

Ideal customers for this innovative method include small, medium and large entrepreneurships which are involved in various fields of work and provide the basis for constant improvement of welding technologies.

An important part of project idea is implementation of its ability to generate profit in the future. The authors of this project idea thoroughly reassessed the possibilities of profit generation and concluded that the implementation of a breakthrough technology gives strong possibilities to improve market position and revenue potential. New technology puts the company in a favorable position compared to its competitors. Use of intelligent software eliminates the necessity for the following activities:

- Welding engineer analysis required a preliminary welding procedure specification (pWPS), which usually takes 40 work hours (the average cost being 20 euros per work hour);
- Base material, 3 sets of 2 plates (material cost for this steel and dimensions is 20 euros);
- Welding time, including the filler material, shielding gas and electric energy (around 5 work hours, with the rate of 10 euros/ hour);
- Welder's time (around 5 work hours, with the rate of 10 euros/hour);
- Non-destructive tests BW (VT, PT/MT, RT/UT - 42.55 euros)
- Destructive tests BW (Tensile and bending tests – at least one specimen per test, total of 51.91 euros).

Given that there are operating welding machines in any givenr company in Serbia, this software saves approximately about 50 hours of working time for the development of one pWPS.

In Serbia, a typical welding project last 3-6 months, wherein each new project requires defining and qualifying of new procedures, and one company has an average of four procedures per year. Taking into account that during these procedures, a typical amount of costs resulting from presence of defects is around 8000 EUR. This technology will significantly decrease these costs, while also saving the time of everyone involved, thus improving the efficiency.

4. CHALLENGE AND THE INNOVATIVE SOLUTION ADDRESSING IT

Problems which occur during welding of new materials require a lot of time and material in order to determine the optimal welding parameters, taking into account that every parameter combination requires the manufacturing and welding of its own test specimens. In addition, welders are subjected to excessive radiation, there is unnecessarily high power consumption, and significant amounts of waste materials are produced. This is a commonly encountered problem in the industry, which we determined from personal experience.

In addition, the processes described above are time-consuming and costly, which is another factor which can be significantly improved by this solution.

Another advantage of this solution is that it can use predefined welding parameters to determine if their combination will provide satisfying results, in other words it could prevent the applications of welding technologies which could require additional repairs (resources, time and effort). In the figure 2 below is given a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis, done as part of identifying strengths, weaknesses, opportunities, and threats related to development this project idea. Strengths and weaknesses are usually considered internal, while opportunities and threats are usually considered external factor.

Another challenge is to protect all intellectual property resulting from this study, mainly the software which will rely on neural networks, via patent, in accordance with the intellectual property protection laws and regulations. According to these regulations, it is possible to patent software in the case it is a part of an innovative solution which has industrial application, and NNSS falls into this category. All IP resulting from this project belongs to the project team, NNSS weld, and the project does not require the use of third-party intellectual property. The initial plan for this project idea is to submit an application for a national patent, which should be a simple procedure, due to lack of competition in the local market. As for the International patent, additional state-of-the-art analysis will be required, since some slightly similar solutions already exist in other regions, such as North Europe and Asia.

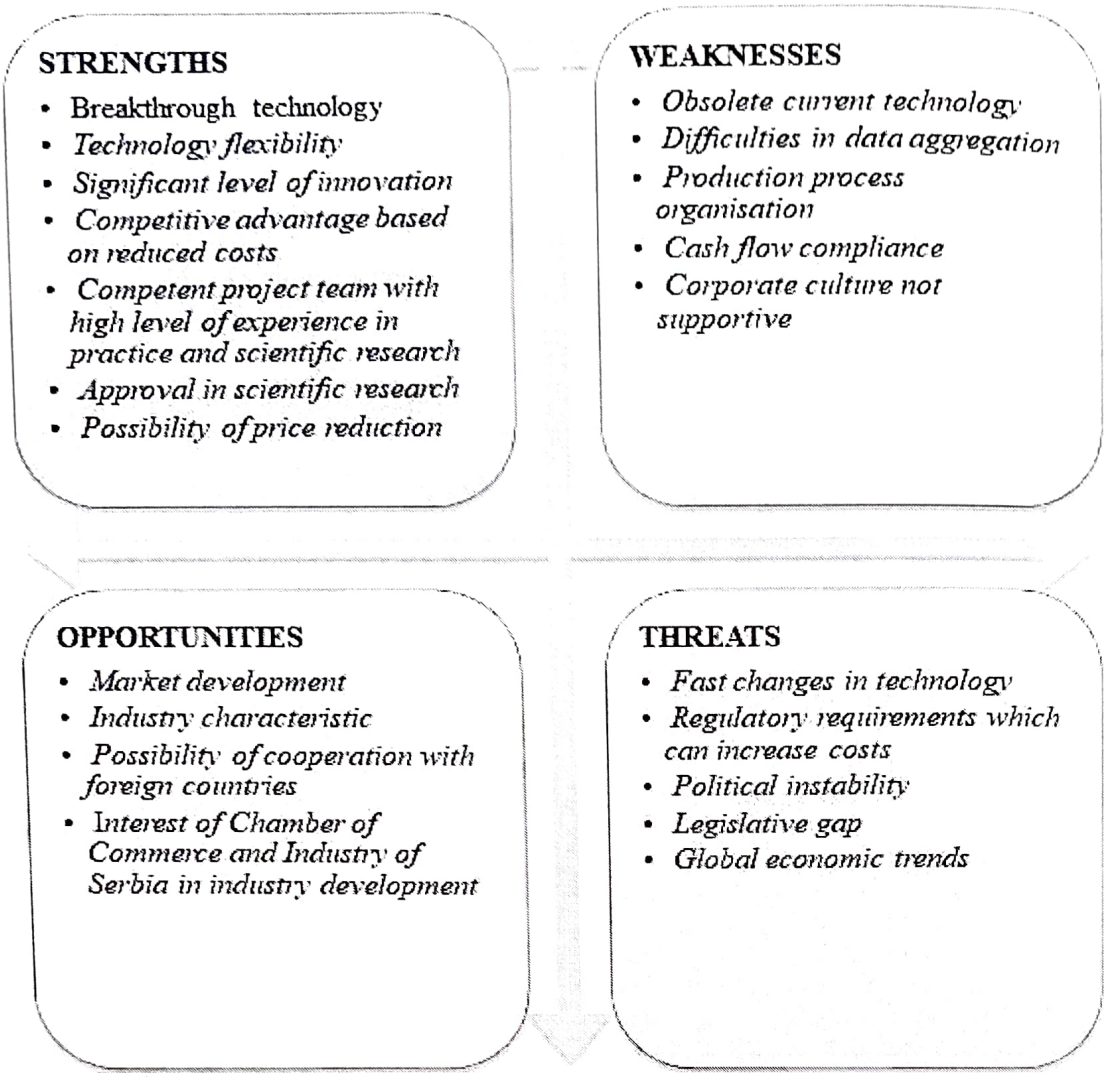

Fig. 2. SWOT analysis

5. DISCUSION AND CONCLUSION

Development of the Neural Network Soft Sensor for the purpose of automatic selection of optimal process parameters, this solution will provide increased welded joint quality, and welding processes optimized in this way would lead to lower electricity consumption and better protection of the environment and welders alike. All of this will result in buyers achieving significant savings in terms of materials, energy and time consumed during the new welding technology adoption process, thus providing financial, practical and health benefits to all parties involved.

Advantage in the regional market is the fact that there are no existing solutions related to the same problem as the one this study imply for solving, since no companies in the region are involved in using Neural Networks as a means of improving of welding procedures.

Estimate is that it will take about a year to properly develop this study develop in project, wherein the first stages will be focused on the development of the prototype, which should provide the initial, basic version of the software. The next stages will focus on improvements in order to obtain the final, working version. The refunding should start from the moment it enters the market, since there is no competition in the region. In order to break even, it will be necessary to get around fifty companies in the region and abroad as customers. It is expected to find between ten and fifteen companies every year.

The initial version resulting from the project will represent a working prototype which will be additionally improved, hence it is expected that our product will start generating profit after 5 years.

An important part of this project's idea is development the possibility to achieve profit in the future. After a detailed analysis of the current state of the regional market, it was concluded that the application of the innovative technology like this would provide competitive advantage over other companies, since none of them offer this kind of service. This results in increased stocks values, increased income and the possibility of further development within the welding industry. The use of Neural network soft sensor Weld application will achieve considerable savings, i.e. it reduces the need for adopting new technologies by using the trial and error method, since optimal welding parameters can be determined with a single test. The traditional system can be time-consuming (over 50 working hours), and with the material used, can exceed 1025 euros in costs. Each time another error is made, the next attempt will cost an additional 1025 euros.

In conclusion, this solution will save at least 1025 euros and 50 work hours whenever a new technology is being adopted. Additionally, welding technologies are widely used in various industries, but there is a shortage of available welders. This solution will allow them to work more efficiently and productively, due to time saved by eliminating the need to test every welding parameter combination.

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REFERENCES

[1] Aranđelović M., Sedmak.S., Jovičić R., Perković S., Burzić Z., Đorđević B., Radaković Z., Numerical simulation of welded joint with multiple various defects. Structural integrity and life, 2021. 21(1): p. 103-107.

[2] Aranđelović M., Sedmak.S., Jovičić R., Perković S., Burzić Z, Radu D., Radaković Z., Numerical and Experimental Investigations of Fracture Behaviour of Welded Joints with Multiple Defects. Materials, 2021. 14(17): p. 4832.

[3] Aranđelović M., Sedmak.S., Jovičić R, Sedmak A., Radaković Z., Finite element analysis of efects of multiple defects on welded joint integrity, in 8th International congress of Serbian society of Mechanics. 2021: Kragujevac, Serbia. p. 172 - 173

[4] Aranđelović M., Sedmak.S., Jovičić R, Kozak D., Đorđević B.. Numerical simulation of crack growth in a welded joint with defects, Procedia Structural Integrity. in Procedia Structural Integrity. 2021.

[5] Dučić, N., et al., Application of Machine Learning in the Control of Metal Melting Production Process. Applied Sciences, 2020. 10(17): p. 6048.

[6] Dučić, N., et al., Casting Process Improvement by the Application of Artificial Intelligence. Applied Sciences, 2022. 12(7): p. 3264.

[7] Tanasković D., Đorđević B., Aranđelović M., Sedmak S., Sedmak A., Đukić M., Tatić U., Repair Welding of Crane Wheels in Steelworks Smederevo, in 8th International Conference on Innovative Technologies for Joining Advanced Materials (TIMA 16). 2016: Timisoara, Romania. p. 180-185.

[8] Tanasković D., Đorđević B., Gajin M., Aranđelović M., Gostović N., Damages of burner pipes due to the working conditions and its repair welding, in ECF22 - Loading and Environmental effects on Structural Integrity. 2018: Belgrade, Serbia. p. 404-409.

[9] Tanasković D., Đorđević B.., Sedmak S., Aranđelović M., He effect of exploitation conditions on the damage of a roller reducer toothed shaft and its repair Machine Design, 2018. 10(4): p. 147 - 162.

[10] Aranđelović M., Milovanović N., Đorđević B., Sedmak S., Martić I., Reparation, inspection and damage analysis of steam boiler. Welding & Material Testing, 2020. 3: p. 9-12.

[11] SRPS EN 10025 Hot rolled products of structural steels. 2020.

[12] SRPS EN ISO 4063:2013 Welding and allied processes - Nomenclature of processes and reference numbers.

[13] Elektrode-Jasenice, Dodatni materijal za zavarivanje. 2010.

[14] Sedmak S., Jovičić R., Sedmak A., Đorđević B., Čamagić I., Numerical analysis of different weld geometries of lap welded joint in ammonia transport tanks. Structural integrity and life, 2017, 3(17) , p. 217 -220

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