

IT SYSTEMS IN AID OF WELDING PROCESSES QUALITY MANAGEMENT IN THE AUTOMOTIVE INDUSTRY

The most important issue for the producers nowadays is to meet the requirements of customers, satisfying their perceived but also the unperceived needs. In order to control the quality of welding processes correctly one must have knowledge of welding drawings, symbols, designs of welded joints, welding procedures, requirements set in codes and standards, also have knowledge of the techniques of inspection and testing connected with the automotive industry. The article shows ways to increase quality in the industry through the use of robotization and computerization. Presented examples and application of IT systems in aid of welding processes quality management in the automotive industry.

Keywords: robotics, computer-aiding, CAE, welding, quality

1. Introduction

The most important issue for the producers nowadays is to meet the requirements of customers, satisfying their perceived but also the unperceived needs. It is important to act in accordance with the safety requirements, standards adopted in the enterprise and also having regard to use value. In the automotive industry, where competition is huge, systematic improvement of the quality of welding processes and minimizing the cost are conditions for remaining on the market. Repair processes and the loss of customer confidence mobilize carmakers to intensify quality control. This is closely connected with the costs. The following table shows the costs of removing defects, depending on the stage of production [15].

TABLE 1
The ratio of cost to remove defects, depending on the stage of production [15]

During designing	1
After approval of the project	10
During technological project	100
During production	1000
After release product on the market	10000

According to Table 1, the sooner poor quality is identified, the costs incurred for its elimination will be smaller. In order to control the quality of welding processes correctly one must have knowledge of welding drawings, symbols, designs of welded joints, welding procedures, requirements set in codes and standards, also have knowledge of the techniques of inspection and testing connected with the automotive industry. Ensuring the good quality of welding involves the identifying, implementation and supervision of a good control

program. To create such a program it is necessary to establish the quality evaluation criteria and their appropriate monitoring. Managing and monitoring the quality of welding is supported by computer software programs [15].

2. The quality management system and qualifications of welding personnel in the industry

Final product safety depends on correctly made joints, and therefore in the automotive industry big emphasis is put on maintaining the high quality standards of welding processes. In order to guarantee that, welding processes ensure high quality and reliability of the manufactured structure it is necessary to meet the specific requirements for the organization of production and qualification of welding personnel. According to ISO 9000 welding is a special process and has a significant impact on the final quality of the product. Therefore, many of specialized standards, quality management systems and allowances are dedicated precisely for welding processes. Instytut Spawalnictwa conducted an analysis of enterprises in terms of implementing quality systems. Nearly 95% of tested companies have implemented at least one allowance system or quality system. ISO 9000 is implemented in 82% of companies, while the PN-EN ISO 3834 in 67% of large and 50% of small and medium-sized concerns. The standard for industrial factories using a welding process or PN-M-69009 were implemented in 30% of large and 20% of small and medium-sized enterprises. Other quality systems and systems of allowances are shown in Fig. 1. Number of implemented welding standards and integrated quality systems beyond confirmation of the high quality production using welding techniques in the automotive industry, also shows a desire to implement innovations in the organization of production [12].

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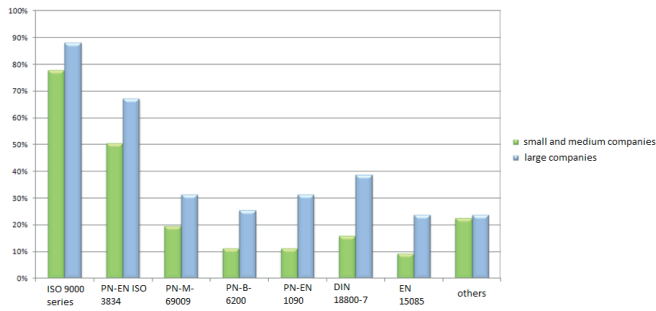


Fig. 1. Quality systems and systems of allowances implemented in audited companies (%) (source: Instytut Spawalnictwa)

Companies that have implemented one of the quality management systems according to the international standards or companies are authorized in accordance with national standards are obliged to employ suitably qualified welding personnel. Such personnel consist of employees who have qualifications confirmed by diplomas: international welding engineer (IWE), technologist (IWT), specialist (IWS), etc., and NDT personnel. Nearly 80% of companies, irrespective of the number of employees, have in their resources personnel who have completed an IWE course. Many companies employ also non-destructive testing personnel (70%). Fig. 2 shows a comparison of the welding coordination personnel employed in small and medium-sized and large enterprises [12].

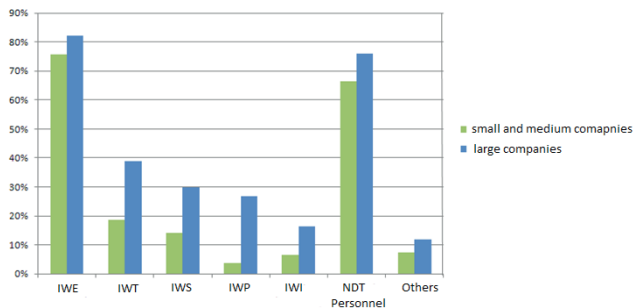


Fig. 2. The welding coordination personnel (%) (source: Instytut Spawalnictwa)

Ways to increase quality in the industry through the use of robotization and computerization

Observance of certain procedures which facilitate quality assurance is extremely important for the welding process because defects of the welded product manifest themselves most often during operation of the structure. Modern quality management in welding is geared to optimize the design, prevent incompatibilities and inspect the quality of the welding process. Obtaining quality requested by the customer and determined by the standard, is closely associated with the possibility of the measurement, control, monitor and optimize the welding parameters. Robotics and computer-aided welding give that capabilities [9, 10].

One way to increase quality and reduce production costs is a robotics and automation of production processes. That is

a reason why for many years the automotive industry is one of the most robotized sectors in the world (Fig. 3). The global investments in industrial robots in automotive industry have been growing significantly since 2010. In recent years, sales of robots in this sector has increased by 27% per year, while 2014 saw a record number of sold robots - 100 000 pcs., which gives a 43% increase comparing to the previous year [9.16].

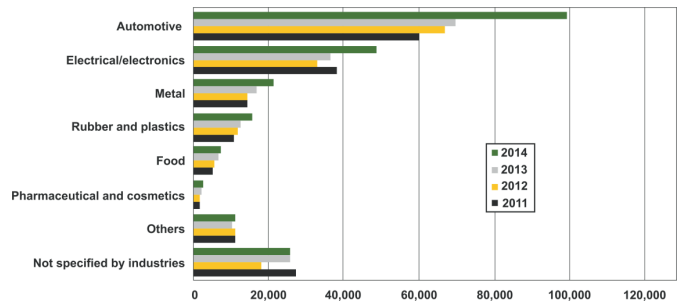


Fig. 3 Sales of robots in the relevant sectors of industry (source: www.ifr.org)

Robotic production means the efficiency and the stability of the process. Industrial robot makes a predetermined number of operation, each time translating them into the same accurate results. Increasing efficiency of the process, quality and increasing security depend not only on the technical aspects. The requirements that are imposed on car manufacturers, apart from repeatable production, are forcing the need for appropriate process design, taking into account factors such as work organization and monitoring of the technical and economic parameters. In addition, in automotive industry, we have to deal with the cyclical implementation of new car models. In the case of such production prerequisite for success is the ability to quickly adapt any processes to the constantly changing situation on the production hall. More often producers seek for methods for optimal management of production processes in order to achieve the best production flexibility at every stage of manufacture while maintaining the existing company quality systems. Speed of information transmission and its topicality are important aspects of a good management. This applies to all departments in the company, starting from the level of planning, the designing, technological process, quality control, reporting and ending with data analysis. Computer aiding gives the possibility of reducing circulation of information. Combined with automation and robotized production it affects the faster completing of orders while maintaining quality and safety. Select of software depends on the company's strategy, its financial capacity and type of production. Providers of information systems offer a wide range of software solutions, which are designed directly for quality management and software that support eg. welding personnel management according to the standard [9, 11, 16].

3. Selecting a proper system to support welding processes

According to research conducted at the Instytut Spawalnictwa (Fig. 4), the most important selection criterion

of the software is saving time (33%). In second place is the ability to integrate devices and functionality of software (17%). 13% of users recognize that on-line access is very important, while for 12% of users the low cost of investment is important.

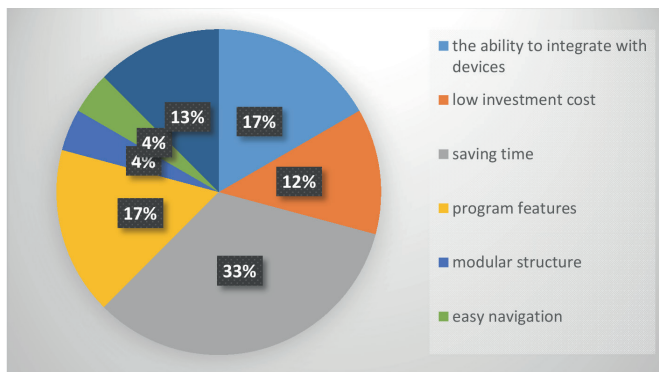


Fig. 4. Main criteria taken into consideration when selecting software (%) (source: Instytut Spawalnictwa)

User needs related to the computerization of welding processes are associated with each stage of production. Starting from design through monitoring process, to the results in terms of technical, economic or social analysis etc. The main tasks of software designed for production management identified for automotive industry are the following:

- management of welding personnel qualification 23%
- development of documentation and calculation of the cost 19%
- simulating processes using finite element method (FEM) 17%
- monitoring and saving parameters 12%
- design and manufacture 10%

Another advantage is the ability to archive data downloaded from the process, in a user-friendly way. Depending on the size and strategy of the company, features that allow performing an analysis of stored data other than in a mentioned above are also important.

Maintaining high-quality welding processes while increasing productivity is the reason why the most sought are complex solution in terms of the welding application. The modular structure allows the combination of multiple functions of the software in one large, integrated system. Thanks to appropriate adjusting the information circulation is quick both when the whole system is working and during operation of the individual modules. Flexible use of all or part of the program is an added benefit. Skilful software selection allows the expanding of its functionality at any time, without changing the design.

Most important factor hindering the purchase of a modern system for approx. 37% of surveyed companies was too high investment cost. Other factors were the lack of funds (approx. 24%), as well as the reluctance of staff to change (approx. 24%). 22% of companies said they did not have the right knowledge to buy extended support information system for welding (Fig.5). Only 10% of companies considered that there were no such requirements.

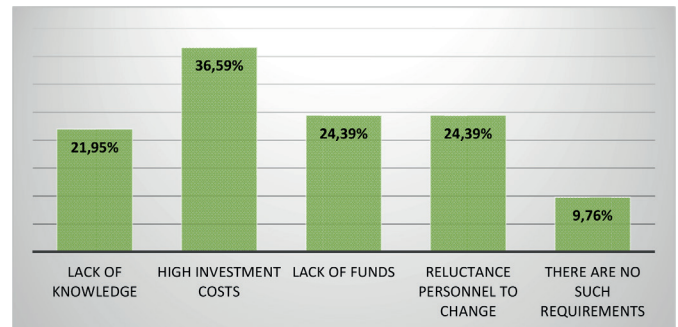


Fig. 5. Factors hindering the purchase of software (%) (source: Instytut Spawalnictwa)

Car production process consists of several stages which should be coordinated with each other in an appropriate way. In this coordination integrated manufacturing CIM (Computer Integrated Manufacturing) can be helpful, developed in accordance with international standards and methods of production control - MRP II (Manufacturing Resource Planning II). CIM combines the areas of design (CAD), manufacturing process control (CAE) and supporting administration (CAA) [11].

4. The area of engineering design, or CAD (Computer Aided Design)

CAD systems allow one to design the geometry of the product, make analysis, and develop product documentation. Creating projects carried out in the area of two-dimensional and three-dimensional (3D) areas. A model having three dimensions can be fully described by its geometry and then it is easier to modify technical and structure documentation during the entire production. Such programs also allow one to simulate working in a virtual environment, outside the machine (off-line). Thanks to the ability to create fast calculations and estimates based on data on the consumption of materials, production costs will be known already in the design phase. Such a facility will enable optimization of production costs. Another task of the CAD software is the transformation from geometrical model to the discrete one, properly prepared for later analysis using finite element method (FEM) [4, 5, 11].

5. The use of CAD systems in the automotive industry in the welding-related processes

In the automotive industry, CAD systems have been used for the design of vehicles and their components, car bodies, drive systems, steering systems as well as, engine and braking systems. Welding is an important stage in the car production and can be also designed by using CAD. In welding processes CAD systems are applied mainly for welding tooling design. A sub-group dedicated to this type of project is CAFD (Computer Aided Fixture Design). Welding personnel, according to the technological documentation, verify the project and planned activities, then determine the coordinates for the appropriate positioning of the elements involved in the process. The position of the handle and its impact on the process is also tested. Each welding device is

subjected to testing in virtual reality in order to verify the occurrence of errors or collisions. In the case of capture an error, the design changes in a virtual environment, which significantly reduces the cost of repair [4, 5, 11].

Research related to the design of welding fixture are also made in the field of virtual reality. Information about the machine, tools and operating parameters are very useful in the implementation of the model to a particular production environment. The newest module is CAFD containing ready components mainly dedicated for the robotized stations eg. robotic arm, heads or handles. Programmers have also performed a huge number of research on the design of complex instrumentation associated with robotics. This may indicate that the development of computer-aiding is moving towards the integration of software in automated welding processes. An example of using CAD software, which is a part of a complex NX system in the automotive industry is Daimler-Benz. NX is an integrated solution, including modules of CAD, CAM and CAE. The software is used to support product development from initial concept, through technical design, its analysis and verification, to tool design and manufacturing process. Application of this system has increased productivity, accelerated work on product development, and also raised the level of quality while reducing costs. The implementation of NX in Daimler-Benz company found reasons in complex terms. Currently, the constructor has the ability to take any model of the tool, which is designed and built it into the system. This simplifies the design process. Unlike other programs supporting engineering, most of virtual fixtures are available for each module which allows one to work on a single document without having to move between modules. Adjusting the software to the needs of Daimler-Benz consisted on improving modular work of several users at the same time, increasing the scope of relation determination and the individual distributing rules in relation to the geometric and dimensional parameters. Noticeable change was the implementation of an optional automatic closing of open profiles. An innovative feature is the ability to choose the region rejected after subtracting the mutual solid elements [6, 11, 13].

The company has full accessibility to modifications in synchronous technology, which means, edition objects by changing the values of the geometrical parameters, as well as the change of the position and shape of objects treated as a set. Objects in the NX environment can be imported with the following file extension `stp` * * `jt` * `igs`, but also `*CATPart` and `*model`. An imported project keeps the parameters with all notes and colour schemes. According to the recent statements NX product has been on the leading place among CAx products currently used in the automotive design industry. Potential number of users oscillates around a few thousands [11, 13].

6. Control of engineering processes, or CAE (Computer Aided Engineering)

The second software group which supports engineering in the early stages of development of the product, i.e. design and structural developing works, is software of CAE class. This is a group of specialized programs operating independently or being an extension of CAD software, enabling engineering

analysis of pre-designed item. Currently, supporting structures of vehicles and their components, probably would have limit in developing and achieving optimum parameters without the numerical modelling of their geometric, material and dynamic features. Computer software from CAE group help control production processes in the field of strength calculations using finite element method and simulation of the operation of the product, its exploitation, in order to solve structural problems. The accuracy of each analysis directly affects the quality. Unfortunately, using this type of software it is possible to perform only a prototype. When using CAE it is very important to correct the correlation model. The need for updating and optimization of the structure is connected with this issue. The operation of standard CAE systems can be divided into three stages, i.e. analysis preparation (also referred to as pre-processing), calculations and interpretation of results. Using software belonging to this group one can make kinematic and dynamic analysis of mechanisms, thermal and flow analysis using FEM and dynamic and static analysis of components and assemblies also using the finite element method. An additional advantage of Computer Aided Engineering is the ability to simulate the production and simulation of mechanical effects [3, 8].

7. Application of CAE systems in the automotive industry for welding processes

By calculation performed with software such as CAE it is possible to create simulation of almost any process, including the welding process. Welding is a very special process in which the resulting quality is not easy to verify. Due to the high demands on the quality of the welds in the automotive industry using process simulation in a virtual environment significantly reduces production costs. For this reason, in the last few years there has been a large increase in the use of numerical methods. In some cases they can replace experimental studies. Still, the errors are made during simulation. It happens because the conditions of welding production frequently differ from the virtual. The difference caused by physical phenomena is too high and in welding processes it is impossible to predict a whole conditions. To further take into account all the „external” factors one must make several simulations. In this way the occurrence of potential errors and differences can be reduced [3, 8].

One of the most popular systems used in the broad structural, thermal, electromagnetic and fluid mechanics analysis is a computer system - ANSYS. Although it does not have a dedicated environment for modelling and simulation of welded joints, but there is the possibility of making model taking into account the thermal and mechanical processes. Due to this possibility, ANSYS is also used to simulate the welding process in industry. One of examples of the use of that software is Audi A8 production. A structure subjected to simulation consists of 5 parts of aluminium alloy (AlMgSi): one cross, and four inserts [1, 7].

Eight joints with a total length of 500 mm was made using robotized welding by metal inert gas method (MIG method, 131). The total time of a welding set, along with the crossing between the joints was approx. 1.5 minutes.

Although deformation after welding were not large it was decided to perform simulations of the process. The construction was fitted for simulation because of the size and conditions of clamping and from an economical point of view. At the beginning it was necessary to determine quantity of heat, and because of that before the virtual simulation several tests under real conditions was performed. During tests the correct parameters were chosen. Thermal and mechanical process simulation reflected the real conditions in 83%. This margin of error is acceptable and can be considered as a successful simulation [7]. Another example of this kind of application is the analysis of thermal endurance prototype of chrome-molybdenum steel frame type A conducted in ESAB company. Fig. 6 shows the stress distribution defined by the respective colours. Red means 80 ksi, green 53 ksi and blue 13 ksi. The thickness and shape of the material has been modified to eliminate the generation of areas of high stresses. Fig. 7 and 8 show the steps of the real production process of the product after the simulation [14].

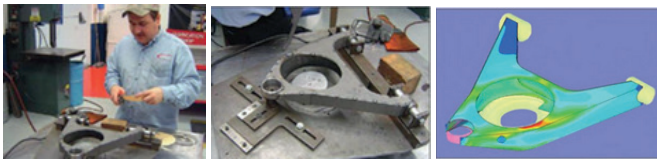


Fig. 6. stress distribution during simulation [14]

Fig. 7 Steel frame type A [14]

Fig. 8 Steel frame type A [14]

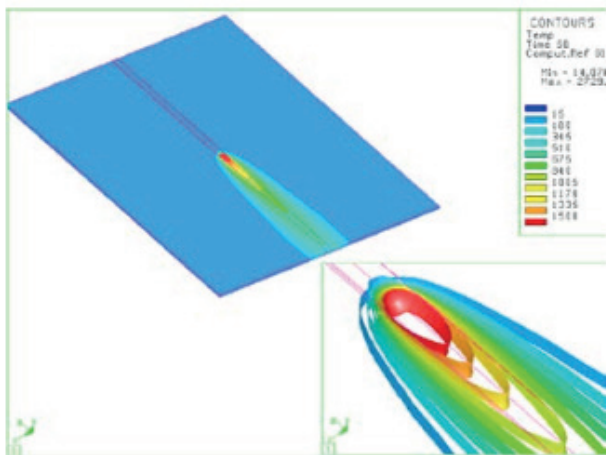


Fig. 9. Simulation in SYSWELD [2]

The next program, which is dedicated to simulating the process of welding, soldering and braze welding is SYSWELD. Thanks to numerical analysis it can determine the temperature field in the process, the participation of the individual phases and the element deformation. By using SYSWELD one can also simulate the formation of stress and strain in the material. Fig. 9 shows an example of the result of thermal analysis. The heat source is located in the middle of the weldment. One can observe distribution of the thermal field with a defined heat affected zone. After thermal analysis the program proceeds to make a mechanical analysis, which will give visualization of distortion caused during the welding process. The maximum displacement value for this analysis is 2 mm [2].

8. Aided Administration, or CAA (Computer Aided Administration)

The main task of CAA systems is integration of all levels of management of the work organization in the company. These systems streamline the circulation of information, including quality management, support planning and testing the scope of their operation. Additional but equally important functions of the software of this type is the financial analysis and marketing analysis. Methods and techniques included in the CAQ (Computer Aided Quality), CAP (Computer Aided Planning) and CAT (Computer Aided Testing) applies to design and planning, as well as the creation of measurement processes and elaborating procedures directly related to quality control. Further functions of the CAA software include creating a task structure, implementing of the cause-effect relation, visualizing scheduling, determining the number of existing solutions, taking into account the type of resource eg. costs. The solutions are generated during the entire time being on the planner disposal [11].

9. The use of CAA systems in the automotive industry, in particular in the welding processes

9.1. Management of welding personnel qualification

Welders records, management of their qualifications and easy registration of employees, generating and printing reports - it all are the functions of software for management of welding personnel qualification. The operation of this type of software is divided into two groups: servicing of courses and students and generation documents (certificates and welder books). Examples of software supporting the above-mentioned field are EVOK and KSOP, i.e. Computer Aided System for Welding Personnel Management. KSOP is an integrated system of „education and certification paths,” allowing access (on-line) to the base of Training Centres according to international standards and allowing to continuously develop of the knowledge through the possibility of asking questions on-line and through the newsletter. In this group of software are also programs that support quality management in welding, mainly by the creation of documents related to the qualifications of welders. Such software is, for example. WelderQual, which is designed to manage and track the qualification of welders according to ASME sec. IX, EN 287 and AWS D1.1. Additionally, using the search tool it is possible to quickly find the welder. The program can be run in LAN and handle multiple welding processes, also allows integration with other programs. Very similar software is WeldSpec. Its functionality is extended with materials selection module, using a database and with the ability to automatically read-out specifications (WPS) downloading information from the PQRS.

9.2. Software supporting welding costs calculations

In the case of this type of programs, support is given for the calculation of costs for different types of weld joints, comparing the cost of welding for the two methods, eg. it can create a spreadsheet calculation for the method 111 and

the second one for the calculation of the 135 (MAG) method. Some of the software compares the costs of welding with manual and robotic methods. Additional features of some software are the possibility of calculating the cross-sectional area based on the geometry of the weld, calculating parameters of arcing, splashes, and the parameters associated with the electricity. A more extensive programs allow one to adjust the cost factors for the region and the company's profile, generate reports, make calculations for exploitation of defined welded joint or the whole structure, and also calculate the probable time of completion time according to the process specification. Examples of such software are: Weld Cost Calc XL, Weld Wizard Estimator Welding, Welding Pro and others.

9.3. Complex solution in one system

Complex solutions in a single system usually have a modular structure. Such software are designed for the

chief welders and technologists. An example of the software in this group is ARC System 3. Each module of this software is designed for a completely different function. With Arc System 3, one can record parameters such as current, voltage, welding speed, wire feed speed and the amount of heat input. The individual modules are responsible for security matters, identification of joints, compliance with EN 1090 standards, control of the welding process, archiving and data analysis, reporting, creation of technological instructions (WPS), cost management and elimination of defects in welding. These features fit in almost every area of CIM (Computer Integrated Manufacturing) which indicates that the one can use such support at every stage of production. There are many complex solutions in supporting welding processes, among others, in the automotive industry. These include programs such as: Welder Expert, Welder Pulse, WeldAssistant and others.

TABLE 2

Software support welding, among others, in the automotive industry [11]

Program names	Type of program	Program functions	Cost (EUR)
SYSWELD	CAE	<ul style="list-style-type: none"> - numerical analysis - defining of the temperature field - simulation of generated stresses and strains - analysis of different types of steel 	-
ANSYS	CAE	<ul style="list-style-type: none"> - strength analysis - thermal analysis - electromagnetic analysis - analysis of fluid mechanics 	-
NX	CAD, CAE, CAM	<ul style="list-style-type: none"> - verification of the design and planning of activities - configuration - verify the operation of a particular device - welding process monitoring - process control - process simulation in a virtual environment 	-
Weldassistant	CAQ, CAP	<ul style="list-style-type: none"> - welders' record - management of welding personnel qualifications - conformity with standards - generating and printing reports - welding cost calculation - database of filler metals - cost comparison engine 	980 EUR (the average cost of a license)
ARC System 3	CAQ, CAP, CAT, CAE	<ul style="list-style-type: none"> - welders' record - management of welding personnel qualifications - development of WPS - conformity with standards - integration with other programmes - generating and printing reports - welding parameter calculation - welding cost calculation - database of filler metals - welding process monitoring - process control 	-
WelderExpert	CAQ, CAP	<ul style="list-style-type: none"> - conformity with standards - generating and printing reports - welding cost calculation - database of filler metals 	200 EUR (the average cost of a license)

WeldPulse	CAQ, CAP	<ul style="list-style-type: none"> - welders' record - management of welding personnel qualifications - development of WPS - reading information from PQRS - conformity with standards - welding parameter calculation - welding cost calculation - database of filler metals - cost comparison engine 	
Weld Cost Calc XL	CAP	<ul style="list-style-type: none"> - conformity with standards - welding parameter calculation - welding cost calculation - cost comparison engine 	70 EUR (the average cost of a license)
Weld Wizard	CAP	<ul style="list-style-type: none"> - welding parameter calculation - welding cost calculation - cost comparison engine 	FREE
Welding Estimator	CAP	<ul style="list-style-type: none"> - conformity with standards - generating and printing reports - welding parameter calculation - welding cost calculation - cost comparison engine - cost factors for a given region 	845 EUR (the average cost of a license)
Welding Pro	CAP	<ul style="list-style-type: none"> - welding parameter calculation - welding cost calculation - cost comparison engine - smartphone application 	FREE
EVOK	CAQ	<ul style="list-style-type: none"> - welders' record - management of welding personnel qualifications - creation of tests and examination reports - development of WPS - conformity with standards - integration with other programmes - generating and printing reports 	-
KSOP	CAQ	<ul style="list-style-type: none"> - welders' record - management of welding and NDT personnel qualifications - creation of tests and examination reports - database of Training Centres - conformity with standards - generating and printing reports - on-line access via an Internet browser - possibility of running a programme on mobile devices 	FREE access to application for centres attested at Instytut Spawalnictwa
Welder Qual	CAQ	<ul style="list-style-type: none"> - welders' record - management of welding personnel qualifications - development of WPS - conformity with standards - integration with other programmes - generating and printing reports 	1395 EUR (the average cost of a license)
Weld Spec	CAQ	<ul style="list-style-type: none"> - development of WPS - conformity with standards - integration with other programmes - generating and printing reports - cost comparison engine 	2235 EUR (the average cost of a license)

10. Summary

The quality of welding processes in the automotive industry is of great importance. A wide range of implementing quality management systems, employment of welding personnel with international qualifications indicate the determination and willingness to implement innovative solutions in the field of production organization. This is also a proof of the high quality of production using welding techniques. Long-term trend in automation and robotization

of repeatable welding processes, including production of vehicles also confirms this tendency. For this reason also different kinds of computer systems aiding this work are being increasingly used. According to the the analysis, company are interested in the implementation of computer support in terms of personnel management welding (23%), documentation and calculation of costs (19%), simulation processes by finite element method (17%), monitoring and recording of parameters (12%), design and manufacturing (10%). Another advantage is the ability to archive data

downloaded from the process, in a user-friendly way. Information systems manufacturers offer a wide range of solutions to support the welding processes in the automotive industry. These include SYSWELD software, ANSYS, NX, WelderQual, ARC System 3, KSOP and many others.

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