Architecture for Implementing Robotic Arc Welding in SMEs

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Abstract

The content of this article is based on a study regarding robotic arc welding of steel structures and the complexities involved in implementation of robotic arc welding in small or medium sized enterprises (SMEs) with changing product variants and small volume productions. The need for automation is steadily increasing, but for smaller companies that primarily produces one of a kind products, it can be difficult to implement robotic automation in a feasible way. A series of steps are presented in this article which have the purpose of simplifying the implementation of robotic arc welding. The steps are developed based on analytic and experimental work executed at the robotic welding cell at Aalborg University. Including in the steps are different perspectives that must be taken into account when implementing such a solution. The experiments includes producing a series of fillet welds in order to determine typical characteristics of the welds in relation to process parameters, and the development of a weld database. A documentation system which can aquire data during welding is presented, because thorough documentation of the welding parameters is important in the industry.

Keywords: Robot, Automation, Robotic arc welding, Low volume production, SME

1. Introduction

Implementation of robots in industrial productions has been a topic, since the first robots were developed in the early 1960s. Back then, robots were primarily used for material handling but also for spot welding. Throughout the 1970s, the first robots were equipped with arc welding equipment. This induced problems, however, since the robot should not only move to an exact location, but also follow a straight or circular path in order to lay a weld bead [1].

Robot manipulators with multiple DOF have been developed after the 1970s, so that parts can be orientated in multiple ways allowing for the executing of welds on parts that are not possible without rearranging the part [2]. Since then, robots and manipulators have been optimised for higher precision and repeatability combined with new programming methods such as off-line programming.

2. Implementation in small series productions

Robotic automation is used widely throughout the industry such as in automotive, electronics manufacturing, and inspection work where robots are used to execute specific, repeatable tasks [3]. The programming of the robot is simpler, because a single robot program can be used for all the repetitions. The robot does therefore not have to be reconfigured between every produced part. This is the basis in high volume manufacturing of standardised products [4].

The product variety can however be extensive for SMEs working in the manufacturing industries. This is often caused by the limited amount of mass production work, because SMEs often produces a wide variety of one of a kind products. These are under the group customised products produced in low volumes [4]. These low volume productions introduce a problem in relation to automation, because of the large product variety and customised work leads to extensive programming tasks for each product. The challenge is therefore to implement automation in low volume areas in a successfull way [4].

In order to make it profitable to implement robotic automation in SMEs with low volume productions, the changeover and execution time must be as low as possible, and not exceed the manual changeover and execution time. This statement is relevant for multiple automation tasks, but this article is based on the implementation of robotic arc (MIG/MAG) welding in SMEs.

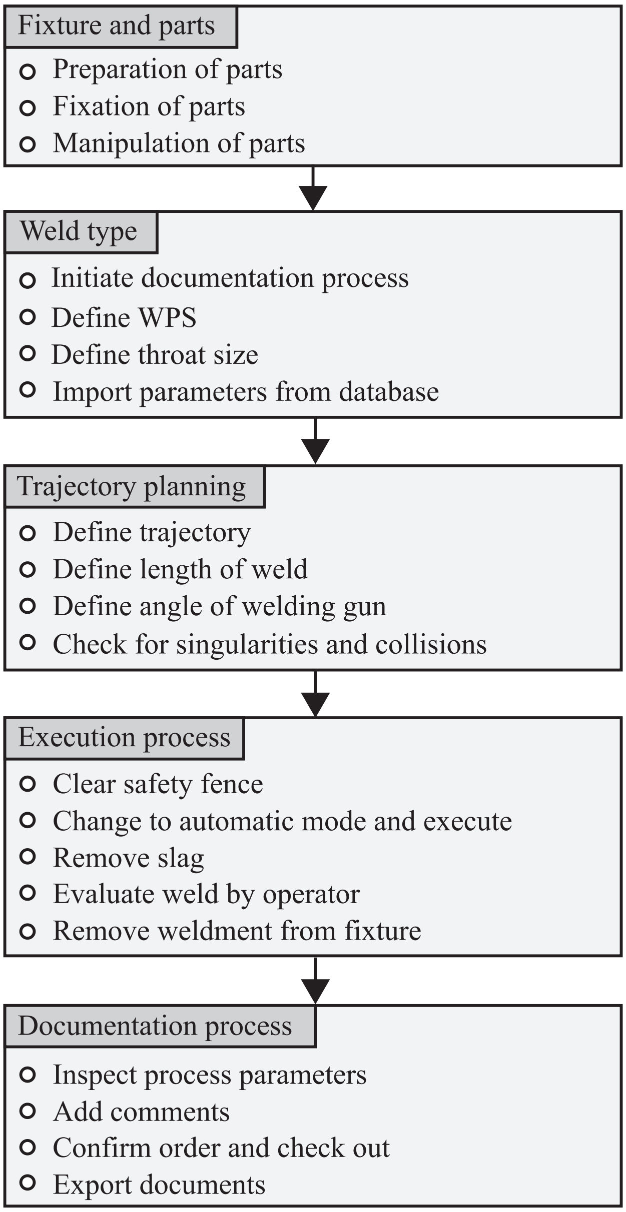

Fig. 1 Flowchart illustrating the architecture.

To implement this in an organised manner are five guidelines presented in this article which have been defined as essential for the implementation of robotic MIG/MAG welding. The topics of the guidelines are:

- Fixture and parts
- Weld type
- Trajectory planning
- Execution of the process
- Documentation of the process

The purpose of the developed architecture is to simplify the implementation for MIG/MAG welding in SMEs by following the five steps which have been defined through analytic work, and the experiments executed at the robotic arc welding set-up on Aalborg University. The experiments are done to test the abilities of the robot and to execute a number of fillet welds in order to determine weld characteristics in regards to welding parameters. In Fig. 1 is a flowchart of the architecture for implementing robotic welding cells presented.

The flowchart in Fig. 1 includes additional points at every step in the architecture. These points outlines what is necessary to define or to be aware of in every step seen from an operators point of view. The points will be elaborated further throughout the article.

3. Experimental set-up

The robotic arc welding of the fillet welds have been executed, at the set-up in Fibigerstraede 14 at Aalborg University. This set-up consists of a fixture, parts, robot, tool, robot controller, and a welding machine. The set-up can be seen in Fig. 2.

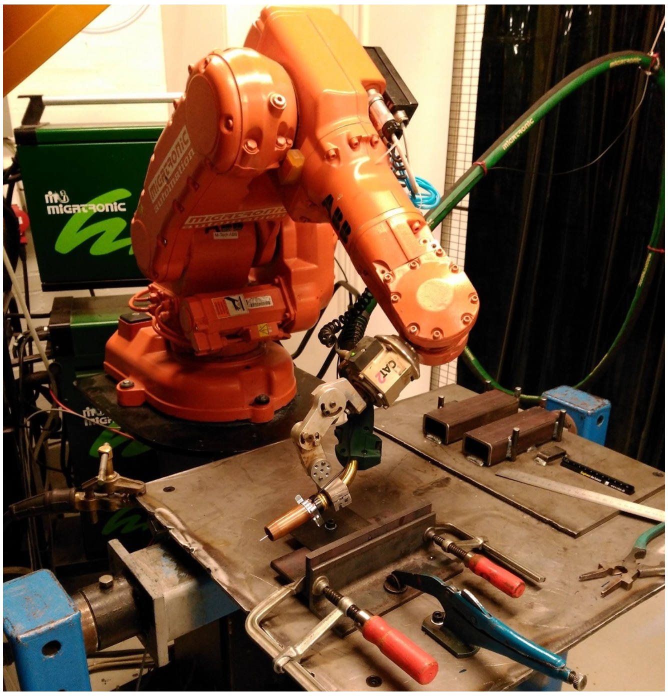

Fig. 2 The robotic arc welding cell at Aalborg University.

The different parts of the set-up shown in Fig. 2 consists of:

- ABB IRB 140 M2000 industrial robot with a S4Cplus robot controller
  - ABB IRB 6400 teach pendant
  - Reach of 5th axis: 810 mm
  - Handling capacity: 6 kg
  - Number of axes: 6
- Migatronic FLEX 4000 welding machine

- Current: 400 A
- Wire speed: 1.0 - 24.0 m/min
- Consumables: Flux and solid wire 0.8 - 1.6 mm

- Shielding gas: MISON® 18
  - Ar + 18 % CO_2 + 0.03 % NO
  - Gas flow: 15 l/min
- Welding wire: Bohler Ti52 T-FD 1.2 mm flux core

4. Fixture and parts

The test parts are made by cutting a 200x10x6000 mm S235JR steel flat bar into parts of lengths of 100 mm, 70 mm, and 50 mm on a cold cutting metal band saw. A number of parts are bevelled to 45° through 5 mm of the thickness in order to execute horizontal compound welds. The parts are ground smooth and cleaned after cutting to remove rust and lubricants.

The preparation of parts includes cleaning and edge bevelling of the parts, if it is necessary as pointed in Fig. 1. The parts are then fixated in a fixture that is capable of clamping the parts sufficiently to reduce distortion by welding but also to reduce the possibility of misaligning the part. The risk of misaligning the part is important, if the robot's trajectory is programmed beforehand. The preprogrammed trajectory will then deviate from the actual path, which the robot must follow in order to weld a misaligned part.

In Fig. 3 is the simple fixture used for the experiments shown. The fixture consists of a 90° angle steel with clamps for fixating the vertical part, and a plate with a bolt for fixating the horizontal part. This fixture has been sufficient for welding on the small 200 mm wide parts.

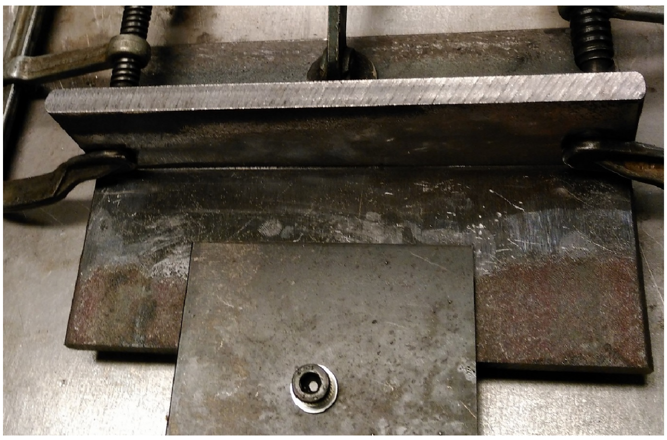

Fig. 3 Simple fixture for fixation of the parts.

For a larger geometry is a manipulator often used to orient the part. A manipulator can increase the opportunities for welding different objects at the same robot cell [2]. However, a manipulator increases the programming complexity, because additional coordinate systems for the manipulator are introduced. The complexity is dependent on the number of axes on the manipulator. In addition to the purchase cost are there extra expences from the increased programming time used for programming the manipulator. A tool such as off-line programming is feasible when the complexity becomes higher than what on-line programming can handle [5].

5. Weld type

Fillet welds are chosen as the type of welds for the experiments in this article, because fillet welds are the most commonly used in the industry and therefore most important to implement [6, p. 494]. The goal of the experimentation is to evaluate the automatability of the three different fillet welds; single pass fillet welds, compound welds, and multiple pass welds.

The experiments are done to determine a methodology for transforming the welds from theory, welding procedure specifications (WPS), to practise. The macroscopic assessments are done to uncover the surface defects, while the microscopic assessments are done to uncover defects in the cross section of the weldment. The method for adjusting the welding parameters from the WPS to a practical welding is shown in Fig. 4. Firstly are the initial parameters set to the lowest possible according to the WPS such that all parameters initially only can change in one direction. A weldment is produced with the initial parameters, and an assessment is done to determine the parameter that needs to be adjusted to eliminate the macroscopic defect. Weldments are produced until the macroscopic defects are eliminated, and the weldment is then examined microscopically. Adjustments are done until the microscopic defects are eliminated, and a final evaluation is then done to ensure that the parameters repeatably can be used to produce welds of sufficient quality.

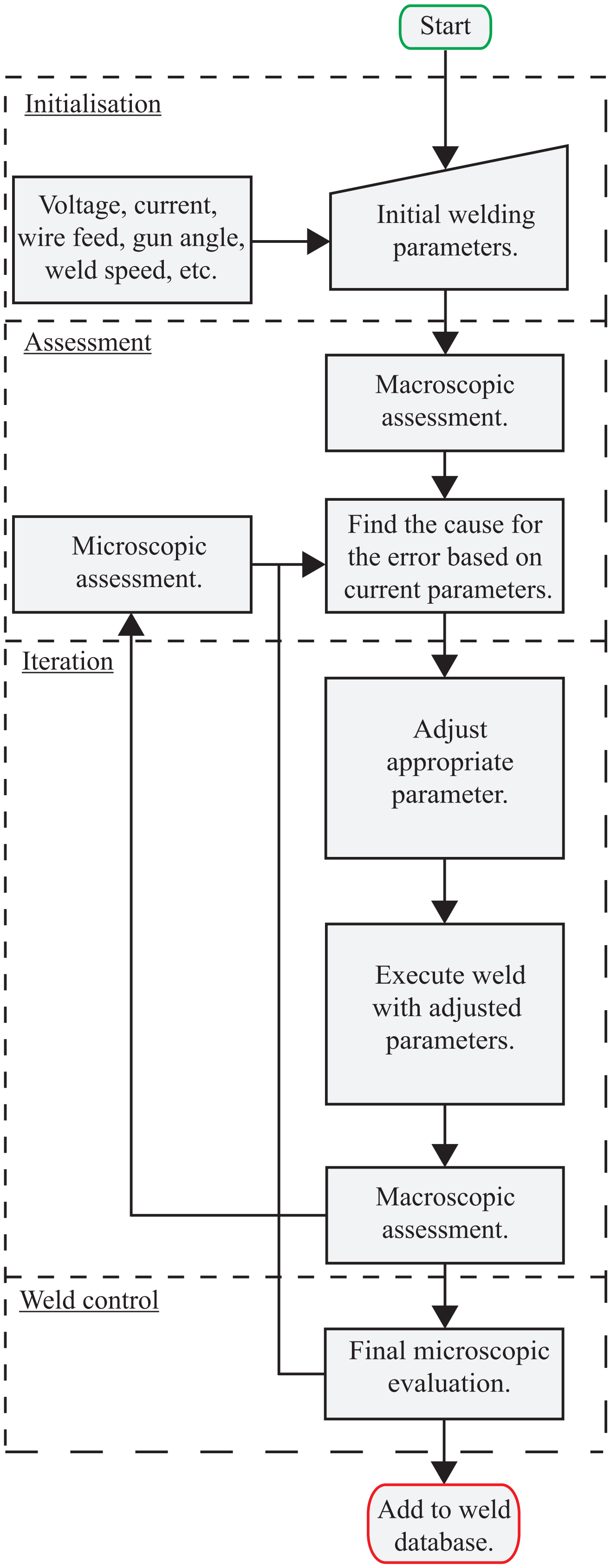

Fig. 4 Flowchart of the method for adjusting the welding parameters, and how acceptable welds are chosen for the weld database.

Fig. 5 Macroscopic image of a multiple pass weld sample. This initial visual inspection of the weld determines, if large surface defects are present in the weld.

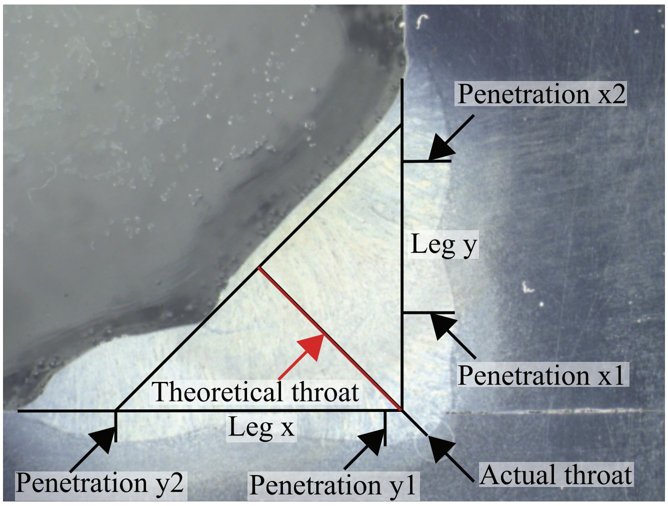

Fig. 6 Microscopic image of a multiple pass weld sample with lines indicating the measurements of the weld.

In Fig. 5 is a macroscopic image of a multiple pass weld shown. The initial inspection of the welds are done from a view such as this, where it is possible to identify severe surface defects in the weld. A microscopic image of a multiple pass weld is shown in Fig. 6. The lines in the figure shows how measurements are taken of the weld, in order to analyse the quality of the weld. The microstructure of the weld is furthermore analysed for cracks and porosity to ensure that the weld is of sufficient quality, before it is incorporated in the weld database.

6. Trajectory planing

Programming of the trajectory is a time-consuming process which especially is difficult for small series productions, since the programming takes up a larger part of the overall production time. On-line programming can be implemented in SMEs with succes, since the on-line programming can realatively easily be taught to traditional welders. Traditional welders have the advantage of already being experienced in welding, and the welders can therefore use their practical knowledge, when they program a robot. On-line programming is only recommended for welding without the use of a manipulator, since the manipulator considerably increases the time used for programming [2]. Off-line programming has the advantage that the operator can develop programs without using the robot, and the productivity of the robot is therefore not reduced. An identical model of the set-up is needed for off-line programming, and this hinders off-line programming compared to on-line programming, where simple parts easily can be welded without modelling the workspace.

In the experiments performed for this article are the trajectories programmed with on-line programming, because the parts can be welded without the use of a manipulator. To increase the robustness of the system is the welding equipment SmarTac from ABB implemented. The system is used to search for the parts before a welding is produced. This search works by having an electric charge run through the nozzle of the welding gun. The SmarTac system can be seen in Fig. 7, where a planar search is shown, and in Fig. 8 is the search out of the plane shown. The parts are detected, when the nozzle comes into contact with the part and short-circuits the nozzle and ground. The sensitivity of positional and geometric error can be reduced with systems such as these. The system can furthermore be used for seam tracking such that the system directly searches for the seam instead of indirectly finding the seam through searching for the part. By searching directly for the seam are geometrical errors in the part bypassed, because this method does not depend on whether the seam is positioned correctly in relation to the outer edges.

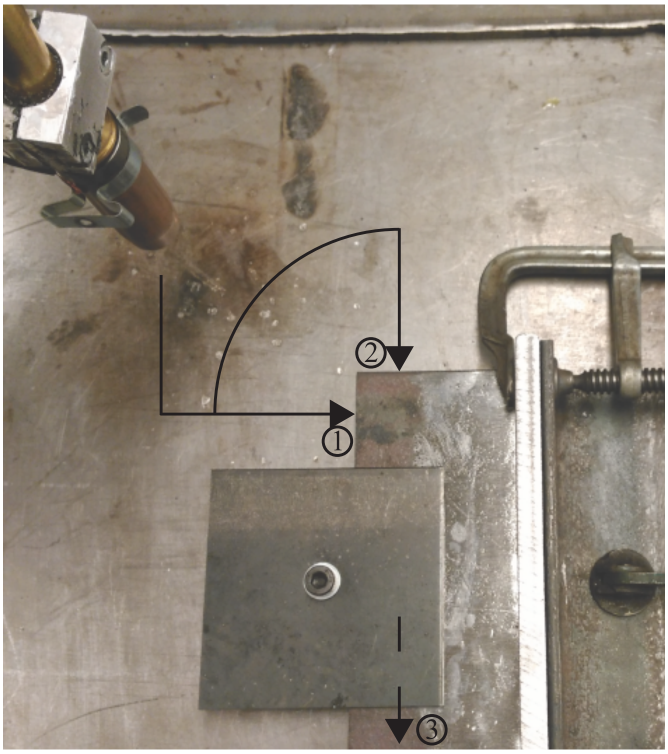

Fig. 7 Image of how the SmarTac system is used to search in the plane. The dashed arrow is movement out of the 2D plane.

Off-line programming also facilitates the incorporation of sensor inputs such that the programming can be adjusted for geometric or positional errors. The entire programming can in addition be automated by the use of sensors. In [7] is an edge detection algorithm developed for fillet welds. This algorithm is based on a sobel image processing that is filtered such that noise is reduced. From this image processing are seeds detected in the image. These seeds are then connected with a seam line growing algorithm.

In [8] is a butt weld recognition system developed. The system takes a region of interest from the captured image and segments it with a sobel process. Unwanted points are filtered from the image by subtracting the background. The weld path is generated from the remaining points. By use of methods such as those presented in [7] and [8] is it possible to design a fully automated robot welding cell, and this is especially useful for SMEs, since this method can greatly reduce the time used for programming the trajectory of the robot.

In [9] is a real-time seam tracing control system developed based on passive vision sensors. The seam is detected by an improved Canny algorithm, and a PID controller is implemented to track the seam during the process. It is possible to increase the weld quality by increasing the seam tracking accuracy with a system like the one presented in [9].

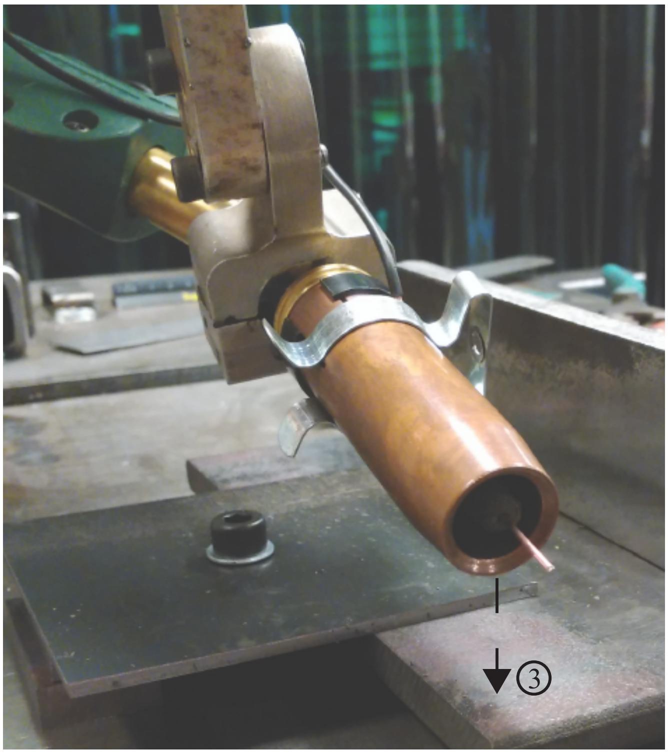

Fig. 8 Image of how the SmarTac system is used to search out of the plane. The dashed arrow is movement out of the 2D plane.

7. Execution

The experiments have been performed at the robotic arc welding set-up shown in Fig. 2. The points noted below "Execution process" in Fig. 1 shows the practical steps in the execution of a weld at the set-up. The weld types are all performed as horizontal fillet welds and performed according to WPSs. These includes:

- Single pass fillet welds
- Compound welds
  - Produced as butt welds combined with fillet welds
- Multiple pass fillet welds
  - Three passes are stacked

The purpose of the experiments is to identify typical characteristics between welding parameters and macro- and microscopic appearances. The welding parameters of acceptable welds will be included in the weld database as previously mentioned. Welding parameters can then be imported from the weld database to decrease the changeover time.

The repeatability of the welding set-up is evaluated to ensure that future welds made from the database are of sufficient quality. This is done by executing four multiple pass fillet welds (three passes) with identical welding parameters. The four welds are then cut and assessed through microscope in order to detect potential failures, or deviations between each weld.

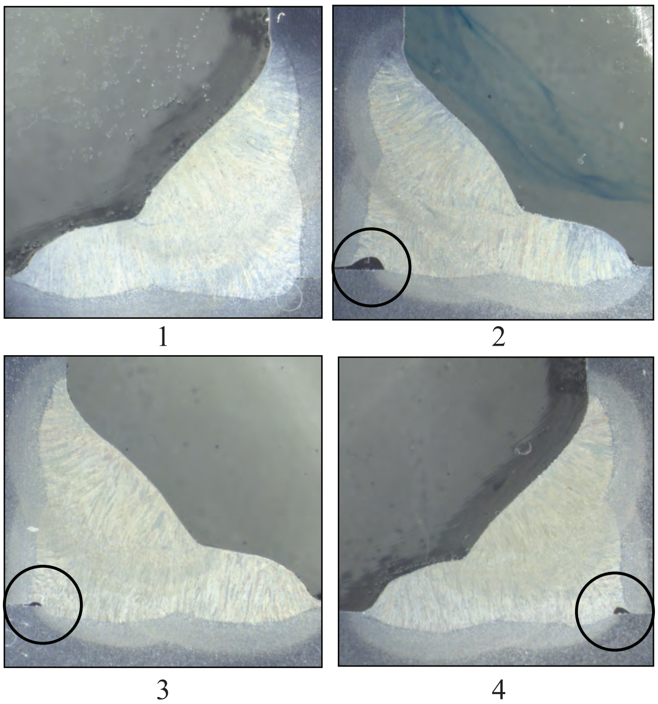

Fig. 9 Microscopic images of the four multiple pass repeatability welds. The circles indicates the areas of root failures.

In figure 9 can it be seen that three of the four repeatability welds have root failures in the form of incomplete root fusions. This could be caused by variations in the output of the welding machine during executing. However, the outputs of current and voltage have been measured for the four welds, and these output fluctuate around approximately the same mean for all of the welds. The cause of the root failures can therefore be:

- Preparation of the parts
- Flux inclusions
- Gas coverage

The causes are based on [6, p. 557]. The preparation work on the parts was done manually on a belt grinder in order to remove surface rust and cutting oil. Geometrical variation can therefore occur on the parts which in turn will cause the arc length to vary between the four repeated welds. Flux inclusions can occur since a flux core is included in the welding wire. The shielding gas coverage may not have been sufficient, since the gas flow has been set at approximately 15 l/min instead of the minimum of 18 l/min as stated in the WPS. This was caused by a faulty valve in the experimental set-up. These problems can occur on other geometries or in other welding cells, so attention must be paid to avoid problems such as root failures.

In order to transfer the experiences gained from the experiments, to a more general set-up, must the weld database be completed. The concept of process parameters in a weld database can be used in other set-ups to shorten the changeover time. Certain weld types are simpler to implement in an automated welding set-up than others. This includes single pass fillet welds, since cleaning and removal of slag does not have to be included in an automated solution. Compound welds and multiple pass welds are more complex to be included in an automated welding cell than single pass fillet welds, since cleaning and slag removal must be done between every pass. This has been done manually in the experiments, but an automated solution for cleaning and slag removal must be developed in order to increase the degree of automation.

8. Documentation

The welder is close to the process in a manual welding environment, and the welder can monitor the process and take actions based on the observations. The operator in an automated robotic welding cell is often at a distance because of safety measures, and the operator can therefore not adjust the welding parameters continuously [10]. Real-time data acquisition is therefore important to reduce time consuming post-weld repairs of the welds.

The weld quality is directly linked with the process parameters, and it is therefore important to monitor the parameters during the process. The process parameters for a specific weldment are usually determined by a WPS, where the parameters have to be within an interval of allowable values, and the process must follow industry standards.

The developed data acquisition and documentation system in this article is capable of monitoring the voltage and current. This system is presented in a flowchart in Fig. 10. The data are captured through a multifunctional I/O device with a frequency of 1000 Hz.

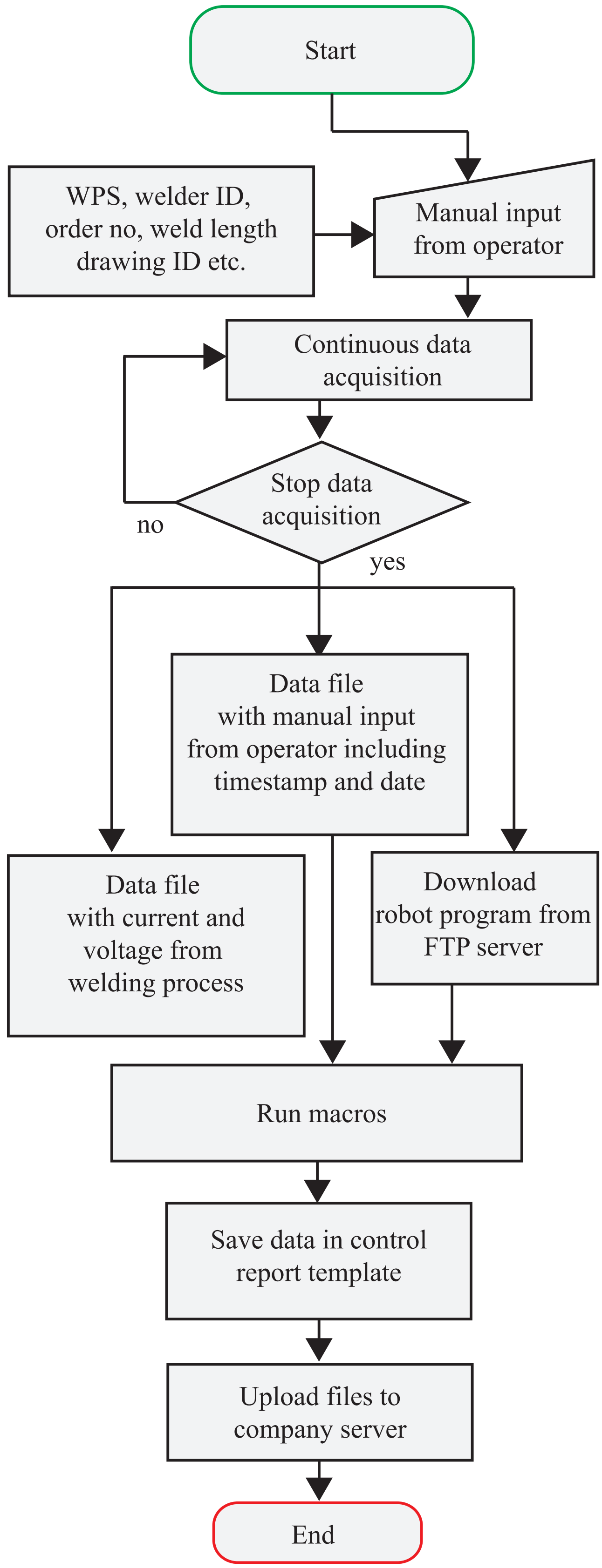

Fig. 10 Flowchart of the method for documenting the welding process.

The operator types in which WPS is used along with the desired throat thickness, before the process is started. The operator also types in the welder ID, the welding wire, drawing ID, and the order ID. The WPS and throat thickness are especially important, since these input define which welding parameters are imported from the weld database. The operator can add comments regarding to the weld, if something unexpected has happened. The system prints a timestamp, when the welding has been executed, since some welds have to undergo a relaxation phase, before the quality can be inspected.

After the welding process has completed is the robot program downloaded manually from the FTP server of the robot controller. The process parameters such as wire feed and welding speed are exported to a control report. The operator checks and confirms the order, when the documentation process is completed. The control report along with the file containing the measured current and voltage can then be uploaded to a database, and attached to the customer.

Previously captured data can be used for improving the weld quality by building a database containing information about weldments that have been accepted by an inspection team. The monitored process parameters can be compared to preset nominal values, and an alarm could be implemented to be triggered when the difference between the values exceeds a certain limit. This limit can be designed from WPSs in combination with previously captured data for products which have been approved by an inspection team [11]. One way of implementing such an alarm threshold could be accomplished with statistical quality control by implementing control charts with upper and lower control limits. The alarm will be triggered, when a value is exceeds one of the control limits. One essential advantage of implementing an automatic documentation system is the reduced production cost, since the time spent on manual documentation has been reduced [11].

9. Conclusion and future works

In this article has five guidelines for implementing robotic arc welding in SMEs been presented. The presented guidelines should be seen as the foundation which can be used as a starting point for further development. In the following are the five guidelines concluded upon and put into perspective.

The fixture is important in the sense that this can be a factor in regards to the limitations of the robot cell. The robot needs to be able to handle different parts, but this can also increase the complexity of the programming, if a manipulator needs to be programmed. In order to design a general robotic welding cell for SMEs must some kind of manipulator be incorporated, and the increased programming workload must be handled appropriately.

The process of validating the welds for the weld database is a complicated process. The experimental work have shown that it is difficult to follow the requirements from the WPS, and get an acceptable welding quality. Further work must therefore be done to ensure the WPSs are followed.

The programming of the robot trajectory is an important part in the incorporation of robots in SMEs, since the robot cell mainly is going to produce small series. The system must therefore be able to easily plan the trajectory such that the programming of the robot does not make the robot cell uneconomical. This can be done by incorporating some combination of the proposed methods for detecting the weld path.

The experiments showed that the execution of welds from the same weld parameters could deviate. This problem needs to be addressed, before the overall plan for implementing robotic welding cells in SMEs can be used. It has been found in the experiments that the automatability of welds with multiple passes are lower, because the weldments must be cleaned thoroughly between each pass. It is therefore recommended to first focus on automating single pass welds.

Documentation of the process is important in regards to fulfilling requirements from the authorities and customers. The documentation of the process is furthermore important from a production aspect, because the data can be used for monitoring the process. Data acquisition during the process is especially important, because the operator can not monitor the process directly and is therefore reliant upon the data in analysis of the robot cell.

The weld database must contain all the necessary weld types to translate the method used in the experimental work at Aalborg University to a general set-up. The welds in the database must be devised from the appropriate WPSs. With this system are the process parameters automatically found based on the WPS and the throat size. This ensures that the changeover time is reduced. The future work for a SME is to establish their own weld database based on their own experimental work, since changing equipment can cause deviations.

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