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ROBOTIC WELDING APPLICATIONS IN PRESSURE VESSEL MANUFACTURING

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Abstract

The use of industrial robots for welding has hitherto been confined to automobile sector, which predominantly use the Resistance Spot Welding & Gas Metal Arc Welding processes. Primary reasons for the same can be attributed to the mass production and repetitive nature of work involved in the manufacture of components & assembly parts. Pressure vessel manufacturing is a distinctive area where welding and testing requirements change from one job to other requiring customized solutions and associated process developments in each case. This paper discusses some of the advanced Robotic Welding deployed/ developed for Pressure Vessel manufacturing in Heavy Engineering such as:

•Stainless Steel Internal bore weld overlay on Tube sheet cutouts by Flux Cored Arc Welding (FCAW) process
•Stainless Steel Clad restoration of dished end longitudinal seams by FCAW process
•Stainless Steel liner weld buttering of dished end longitudinal seams by FCAW for critical Urea application

Keywords: Robotic Welding, Pressure Vessel, Weld Overlay, FCAW

INTRODUCTION

Industrial robots are essential components of today's factory and even more of the factory of the future. The demand for the use of robots stems from the potential for flexible, intelligent machines that can perform tasks in a repetitive manner at acceptable cost and quality levels. Presently the most active industry in the application of robots is the automobile industry and there is great interest in applying robots to weld and assembly operations, and material handling. For the sake of competitiveness in modern industries, manual welding must be limited to shorter periods of time because of the required setup time, operator discomfort, safety considerations and cost. Thus, robotic welding is critical to welding automation in many industries [1-4]. It is estimated as much as 25% of all industrial robots are being used for welding tasks [5,6]. The three major advantages of using robot welding that are exploited in the automobile industry are repetitiveness, productivity & quality. There are only very few works reported relating to robot welding in the manufacture of pressure vessel [7-9]. The present paper will provide examples of application of robotic welding for manufacture of pressure vessel components in heavy engineering. Two examples of implemented projects and one of the projects for which robotic welding is under development are discussed in this paper.

1) Stainless Steel Internal Bore Weld Overlay on Tube Sheet Cutouts by FCAW Process

Background: The Fly Ash Filter is a stainless steel clad pressure vessel manufactured as per the requirements of ASME Sec VIII Div. 2 [10]. The task in hand was to perform the weld overlay on tube holes of Master Tube sheet. Refer Fig.1 for component details.

The subassembly highlights are shown in Table 1.

Table 1: Subassembly highlights

Tubesheet Dimension	5670 mm OD x 215 thick
Tubesheet Material	SA 387 Gr 11 Cl2 (P4)
Cut-out Dimension	Ø ٨٢٤ mm
Number of Cut-outs	24
Welding Position	Horizontal
Weight of Tubesheet	28 T
Weld deposition	600 kg

The stringent quality requirements to be met during the weld overlay are as shown in Table 2.

Table 2: Quality Requirements

Overlay Thickness	5 mm
Chemistry Requirement	Undiluted weld metal chemistry of SS 308L (3mm from the top surface)
Ferrite	Top layer ferrite after final welding and after PWHT of 5-10 FN
Dye Penetrant Test	After final welding and PWHT

Figure 1: Master Tubesheet of Flyash Filter

It was envisaged that the weld overlay of the cut-outs can be done in one of the three ways; semi-automatic, automatic with track mounted systems or by robotic welding technique. The weight of the tubesheet (28T) was one of the major factors to be taken into consideration, as it was difficult to rotate the heavy tubesheet.

From the initial survey it was concluded that although robot welding for internal bore overlay has never been carried out elsewhere, it was worth *Imagineering* it. A detailed and meticulous program was charted out for the development and implementation phase keeping in mind the tight delivery schedule of the project.

1.1 Development & Implementation: The robot used for the weld overlay is the 6 axes KUKA KR-16 robot (Refer Fig. 2) having maximum reach of 1610 mm with an accuracy level within < ۰٫۱± mm. The robot had a built-in software package "ArcTech Digital" for welding applications. The welding power source used for the application was Fronius TransPuls Synergic 5000, a fully digitized and microprocessor-controlled power source for Manual Inert Gas (MIG), Tungsten Inert Arc (TIG) and Manual Metal Arc (MMA) welding. It can be used for welding at 500 A maximum current and gives 100 % duty cycle at < 360 A, thus enabling it for continuous usage without apprehension of breakdown.

Next stage involved was selection of suitable welding process for the given overlay application. Flux Cored Arc Welding (FCAW) was chosen over other processes in view of its positional welding capability coupled with higher levels of productivity. Welding wire E309LTO-1 was used for barrier layer to minimize dilution followed by E308LTO-1 wire for subsequent layer to meet the ferrite requirement. Welding procedures were qualified accordingly meeting the stringent specification requirements including corrosion test as per ASTM A 262 Practice E.

Figure 2: KUKA KR-16 Robot

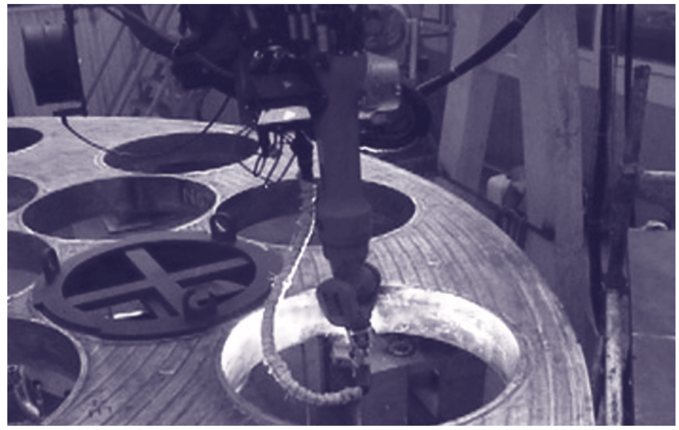


Table 3: Comparison of different methods of internal bore overlay

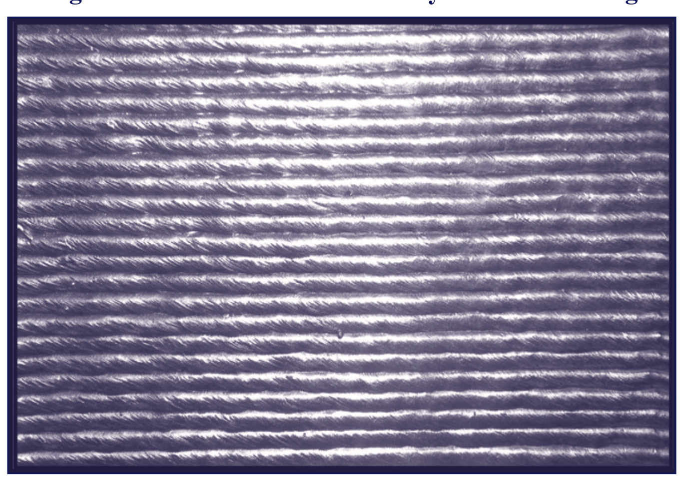
Refer Table 3 regarding the advantages & dis-advantages of each of the evaluated methods. **Method**	**Semi-Automatic**	**Automatic with track mounted system**	**Robotic Welding**
Advantages	Usage of multiple welders possible	Moderate investment	Reduction in cycle time
	No fresh investment needed	Simplicity of operation	Consistent quality
	Use of different welding processes possible	Moderate weld quality	Welding along irregular profile possible
Disadvantages	Higher cycle time	Can weld only perfect circles with consistent radius	High investment
	Inconsistent weld quality	Moderate cycle time.	Programming knowl-edge essential

Numerous trials were taken to arrive at the precise path & motion program. Linear motion was used to move the robot from HOME (a fixed reference position) to WELDSTART position. Circular motion was used to trace a circle by teaching three points with the robot (WELDSTART, AUXILIARY & WELDEND). Increments in vertical plane (z-axis) were done through closed loop programming (FOR loop was used in this case).

1.2 Results & Discussion

Visual Examination: Consistent weld bead shape was achieved with robot welding (Refer Fig. 3). Bead thickness was found to be in the range 2.5-3.0 mm. The total overlay thickness deposited was about 5.5-6.0 mm.

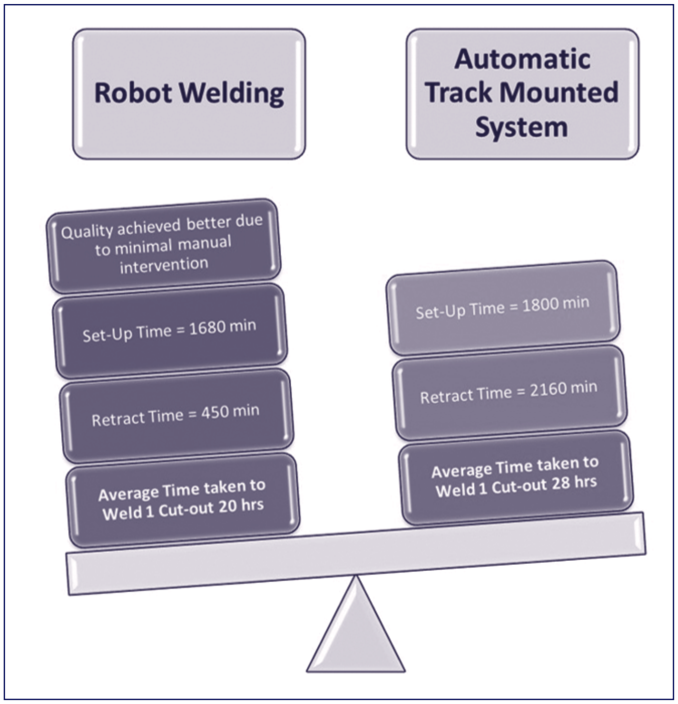
Figure 3: Bead Profile Achieved by Robotic Welding



Chemistry, Ferrite & Dye Penetrant Test: 4 mm Undiluted weld metal chemistry of SS 308L was achieved from the top surface. Ferrite was measured to be in the range 6-7 FN. Dye penetrant test does not reveal any discontinuity.

Comparison of Automatic Track Mounted System & Robotic Welding: In order to catch up the project schedule, a conventional automatic track mounted system was also employed in the same job to carry out overlay of tube holes. Refer Fig. 4 for the comparison between robot and automated track mounted system. It was realized that the advantages of using robot was unique & distinct when compared with conventional methods.

Figure 4: Comparison of Automatic Track Mounted System & Robot Welding



2.) Stainless Steel Clad Restorations of Dished End Longitudinal Seams by FCAW Process

Background: The task in hand was the clad restoration on dished-end petal longitudinal seams of the previously discussed project. The subassembly highlights are as shown in Table 4.

Table 4: Subassembly highlights

Number of Seams	6
Diameter	mm 5850
Length x Width	mm x 60 mm 3200
Section Weight	T 40
Weld Deposition	kg 110

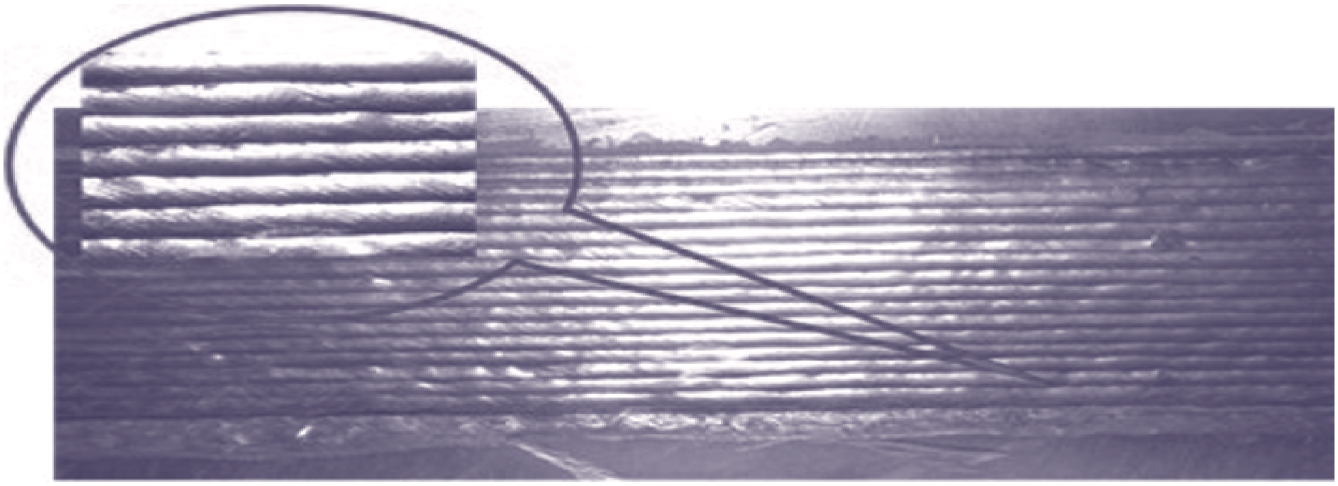
These seams had the same stringent quality requirement as those of the internal bore overlay of master-tube sheet. Clad restoration of dished end petals is hitherto carried out with Manual SMAW or Semi-Automatic FCAW. Both these processes depend a lot on the skill of the welder. Also usage of these processes produces frequent start and stop points. The weld bead profile produced is inconsistent. Deposition efficiency is very less due to less arcing time. There is also a resource constraint of skilled welders. Hence it was decided to automate this task and fully exploit the advantages of robotic welding.

Figure 5: Robotic Clad Restoration in Action

2.1) Development & Implementation: Suitable fixture arrangement was conceptualized, designed and fabricated to facilitate robot positioning. The same was essential to provide for an extension for the reach of the robot within the assembly. In an effort to provide a near identical mock up for the motion programming and parameter checking, an innovative method of conducting trials was discovered. It involved setup of a backing strip directly on the seam with the same radius attached directly on the area to be overlaid. This operation required considerable amount of innovative programming to accommodate for the profile variation in the petals. The petals were found to have up to 19 mm of profile variation along the length of the weld seam. This variation had to be accommodated in a generic program to ease the operators' settings for each petal. All the welding operators were trained on simulated mock-ups before deploying in production. The implementation (Refer Fig. 5) though involved certain hurdles which eclipsed the full efficiency of the robot. The same was due to the seam unevenness along the length and the varying groove depths of the seam. This resulted in manual welding in certain areas prior to deployment of the robot. The other factor leading to non-arcing hours were due to positioning of the equipment, this factor though can be attributed to the size of the section. In case of smaller sections, a single setting of the robot can lead to welding of 2 seams simultaneously without the limitation on the reach of the robot.

2.2) Results & Discussion: Consistent weld bead shape was achieved with robot welding (Refer Fig 6). Bead thickness was measured to be in the range 2.5-3.0 mm. The total overlay thickness was about 5.5-6.0 mm. Ferrite values measured to be 6-7 FN. Dye penetrant test does not reveal any discontinuity.

Figure 6: Bead Profile of restored clad with Robot Welding



3.) SS Liner Weld Buttering of Dished End Longitudinal Seams by FCAW for Critical Urea Application

Background: L&T manufactures urea equipment to most of the Process Licensors. One of the most critical activities in manufacturing of these equipment is the liner welding. In these equipment, liner welding is carried out on the buttering part deposited on the CS/ LAS parent material. Buttering of dished end for liner attachment seams for these Urea equipment has been hitherto carried out with manual SMAW. The process depends a lot on the skill of the welder. Also usage of these process produces frequent start and stop points. Deposition efficiency is very less due to less arcing time. There is also a resource constraint of skilled welders for performing such critical activities. In view of above need was felt for an alternate productive process [11]. First option considered was to perform the overlay with Electro Slag Strip Cladding (ESSC) process. However, with ESSC the buttering operation requires precise control of tilting of the positioner. Mechanical ply of gears etc. may lead to non-uniform weld deposition. For low diameter dished end the tilting speed required will be very high to maintain the required welding speed. Next option worked out was with FCAW process. In this case, fixturing cost involved for set-up and operation was found to be very high. Moreover, each diameter of dished end needs different set of tracks leading to substantial cost. The process also requires manual intervention for positioning of welding torch between passes. In order to counter the identified issues, it was decided to carry out the buttering with Robotic FCAW process. Refer Table 5 for comparison between the present & proposed technique.

Table 5: Comparison between SMAW and Robotic FCAW

Parameter	Present	Proposed
Process	SMAW	FCAW
Technique	Manual	Robotic
Welding Position	Horizontal/Flat	Horizontal
Productivity	2 kg/ Shift/Welder	8 Kg/ Shift
Typical Cycle Time (For dished end having 6 seams of 1.6 m length each)	Horizontal Position – 2 days (2 Welders welding simultaneously) Flat Position – 4 days (1 welder welding)	Horizontal Position – 1 day

Development. Building on previous experience initial trials were taken to establish the welding parameters. Since the process licensor for the equipment is SAIPEM, Italy, the procedure needs to be qualified as per the stringent requirements of SAIPEM specification including corrossion tests. The buttering forms a part of a composite groove joint which is welded with manual GTAW post buttering. A Qualification Testing Plan (QTP) was prepared based on code and SAIPEM specifications. Welding of the PQR block was carried with robotic FCAW buttering followed by PWHT and NDE to Saipem witness. Then manual GTAW of liner was carried out, followed by NDE, destructive and corrosion testing.

Results & Discussion. The welding procedure was successfully qualified to SAIPEM specification and will be implemented on all future urea equipment.

CONCLUSION

Robot welding was successfully developed and implemented first time for pressure vessel application. It was found that there is increase in quality & productivity due to usage of robot welding as compared to conventional automated welding systems. The innovative aspects and business benefits derived in each of the application discussed is summarized in Table 6. The applications discussed attest the fact that robots have a significant role in pressure vessel manufacturing in the days to come.

Table 6: Innovative Aspects and Business Benefits of Robotic Applications

Application	Innovative Aspects	Business Benefits
Internal Bore Overlay	1. Robot used for pressure vessel component fabrication for first time. 2. Experimented with various shielding gas mixtures and zeroed on 80%Ar + 20% CO_2 shielding gas leading to following benefits: a. Self slag detachability leading to continuous operation. b. Elimination of intermittent cutting of wire due to suppression of ball formation. 3. Usage of FCAW in horizontal position for first time. 4. Meticulous robotic programming for vertical torch movement & simultaneous staggering of start and stop points.	1. Benchmark quality leading to 100% FTR joints. 2. 30% reduction in cycle time compared to conventional methods. 3. Helped in On time delivery (OTD) of the equipment. 4. Satisfied internal and external customer. 5. Fresh order received worth Rs 260 cr. based on successful completion & OTD of projects.
Dished End Longitudinal Seam Clad Restoration	1. Innovative robotic programming to counter seam unevenness along the length and varying groove depths. 2. Simulation trials by setting up backing strip directly on the seam with the same radius attached directly on the area to be overlaid. 3. Fixture arrangements to maximize robot envelope in one setting.	1. Entire sub-assembly removed from critical path due to rapid execution. 2. 40% improvement in productivity. 3. 100% FTR quality. 4. Relieving of welder for efficient drum utilization on other jobs. 5. Satisfied internal and external customer 6. Fresh order received worth Rs 260 cr. based on successful completion & OTD of projects

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