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by Erry Rima Wan

Welding Process Improvement in Pressure Vessel Fabrication Approach to DMAIC Methodology case in Small and Medium Industries in Indonesia

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Abstract— The objective of this research is to analyze defect criteria of welding process to decrease defect and rework by using SAW (Submerged Arc Welding) automatic welding machine. The key success of research implementation depends on defect criteria analysis which affecting to quality acceptance requirement and affecting to rework cost also to customer satisfaction, safety standard and financial performance of the organization especially in SMIs (Small and Medium Industries) ini Indonesia. This paper presents an implementation of welding process technology that applied SAW automatic welding machine process. The product object is Pressure Vessel which have AWS (American Welding Society) and ASME (American Society of Mechanical Engineering) standard of mechanical and requirement. This research approach to DMAIC (Define, Measure, Analize, Improve, Control) analysis to achieve customer satisfaction and technical standard requirement, findings of research accomplished via data collecting in vessel manufacturer in manufacturing data report (MDR), defect ratio data, standard requirement and interviews with people in engineering and quality division also top management. This research proved that the benefit of technological improvement in reduce product defect also reduce cost of rework because of defect. This research also improve z level or sigma level of product quality.

Index Terms— Improvement, SMIs (Small and Medium Industries), Welding Defect Criteria, SAW (Submerged Arc Welding), DMAIC (Define, Measure, Analyze, Improve, Control), Z Level.

1 INTRODUCTION

To maintain competitiveness and sustainability of SMI required an improvement in innovation and technology implementation. Innovation and applied technology of improving the efficiency and quality of process mean quality of final product, it is derived from the value of a business, but the method can be applied in the activities of an organization [8].

SMIs have an important function in many countries. They should implement their business to produce high quality product and services to compete and sustain in their business [9].

Small and Medium Industries (SMIs) could not survive if they don't do any improvement or innovation strategy business model. The SMI which has limited resources and manpower should implement the strategy of innovation to keep the sources that is more diverse than the desires of the market and fundamental insights about the external factors compared to prepare all of the resources and capabilities of its own [10].

The involvement of interdependent factors in the process, such as human resources, market conditions and welding machinery, which varies with the type of metals to be welded and the needs of the customer, demand the use of advanced and comprehensive system design and inspection. Designers and manufacturing engineers need to know the full potential of all available welding and joining processes so they can make the best selection of potential manufacturing methods. Scientific knowledge, engineering, and training must be more closely integrated into the welding process if it is to compete with other technologies and fulfill its potential. Another important determinant of the future of welding is the drive to improve efficiency and productivity. For manufactured products to be able to compete, they must be made faster, cheaper, and better than those of competitors [6].

2 LITERATURE REVIEW

The submerged arc welding process, in which the weld and arc zone are submerged by a layer of flux, is the most efficient fusion welding process in plate and structural work such as shipbuilding, bridge building, and pressure vessel fabrication, assuming the work pieces can be properly positioned and the equipment accurately guided. However, when welds must be made out of position or when several short welds are required on many pieces involving frequent moves of the welder or the workpiece, a flexible process such as shielded metal arc welding, gas metal arc welding, or flux cored arc welding should be considered. The optimum process is selected based on a compromise between welding speed (deposition rate), versatility, and portability [6].

Submerged Arc Welding (SAW), or Sub Arc as it's generally referred to, is a unique welding process because there is no visible evidence that a weld is being made. The welding zone is completely shielded by blanket of granular flux. Exposed are eye protection is not normally used since the arc should be completely covered. The welding operator must, however, employes good safety practices to assure protection of the eye and face, by contacting the American welding Society (AWS).

Any arc welding process can produce furnes and gases that could be harmful to health. Always maintain good ventilation in welding area. Use special care in confined apaces. The American Welding Society (AWS) defines Sub-merged Arc Welding (SAW) as follow: "An arc welding process which produces coalescence of metals by healting them with an arc or arcs between a bare metal electrode or electrodes and the work. The arc and molten metal are shielded by a blanket of granular, fusible material on the work, pressure is not used, and filter metal is obtained from the electrode and sometimes form a supplemental source (welding rod, lux or metal granules)". This process has been used successfully for years to produce high quality welds in compliance with such code of agencies as: ASME, AWS, API and the American Bureau of shipping. Submerged arc welding has found usage in nearly all industries [4]

Implementing innovations may require major organisational changes to evolve from closed to open model innovation. For example, implementing an innovative service could mean making changes to organization structure, employee training programmes and company procedures [1].

Sigma is the measurement used to assess process performance and the results of improvement efforts - a way to measure quality. Businesses use sigma to measure quality because it is a standard that reflects the degree of control over any process to meet the standard of performance established for that process [3].

Six Sigma provides a generic quantitative approach that applies to any process. For application, it needs to be tailored to the domain of the process through specific measures and analyses. Basically, it is a high performance data driven approach to analyzing root causes of business problems and solving them. It ties the outputs of a business directly to the customer requirements. The name, Six Sigma, derives from a statistical measure of a process's capability to customer specifications. To most managers and practitioners, Six Sigma is synonymous with Define, Measure, Analyze, Improve and Control (DMAIC) methodology and its associated tool kit. Six Sigma also provides an organizational framework by releasing and training process analysts (called Black Belts and Green Belts) who devote undivided attention to process improvement. User organizations have experienced significant savings by using Six Sigma [7].

3rd of 14 Deming view: "*Cease dependence on inspection*"; Instead of inspecting the product for quality after production, infuse quality at the beginning itself with production quality control, as this will ensure no raw materials are wasted for the sake of quality. All Inspection can do is cull out most of the defective ones, which will be reworked or thrown out. That is too extensive and not satisfactory. Quality comes from relentlessly improving the processes that make the product [2].

3 Research Methodology

The Object of this research issued are defect criteria which have a big affecting Critical To Quality. There are many optional tool for measurement using Non Destructive Test (NDT), in this research limitation of applied NDT referred to NDT requirement as per customer specification and standard examination required and approved by technical association in charge.

The Six Sigma methodology builds on the Six Sigma metric. Six Sigma practitioners measure and assess process performance using DPMO and sigma. They apply the rigorous DMAIC (Define, Measure, Analyze, Improve and Control) methodology to analyze processes in order to root out sources of unacceptable variation, and develop alternatives to eliminate or reduce errors and variation. Once improvements are implemented, controls are put in place to ensure sustained results. Using this DMAIC methodology has netted many organizations significant improvements in product and service quality and profitability over the last several years [3].

This research approach to Six Sigma methodology that known as DMAIC (Define, Measurement, Analyze, Improve, Control). The flow process of DMAIC tools were reflection of actual condition of the fabrication process and defect potential in the fabrication process especially in welding process lines. We determine the sampling 100 units of Pressure Vessel which are process use manual welding / welder, and 100 units of Pressure Vessel use SAW Automatic Welding. From the sampling of both process have any defect quantity which calculate become defect rate ratio then caculate the value of Defect Per Million Opportunity (DPMO) use DPMO calculator and get the Z level of Six Sigma from Z Level table.

4 DMAIC

4.1 Define Defect Criteria

4.1.1 Planar Defects: linear from at least one dimension

i. Cracks may occur in welded materials are caused generally by many factors and may be classified by shape (Longitudinal, Transverse, Branched, Chevron) and position (HAZ, Centre line, Crater, Fusion zone, Parent metal).
ii. Solid Inclusion (Loss of gas shield, Damp electrodes, Contamination, Arc length too large, Damaged, electrode flux, Moisture on parent material, Welding current too low, Slag originates from welding flux, MAG and TIG welding, process produced. Silica inclusions Slag is caused by inadequate cleaning Other inclusions include tungsten and copper Inclusions from the TIG and MAG welding process.
iii. Slag inclusions are defined as a non-metallic inclusion caused by some welding process.
iv. Lack of fusion, poor welder skill, incorrect electrode, manipulation, Arc blow, Incorrect welding, current/voltage, incorrect travel speed, Incorrect inter-run cleaning. An im-

fection at the toe or root of a weld caused by metal flowing on to the surface of the parent metal without fusing to it,

v. Overlap; contamination, slow travel speed, incorrect welding technique, Current too low.

4.1.2 Linear Volumetric Defects, Linear in length with voume;

i. Slag lines,
ii. Lack of fusion with associated slag,
iii. Piping.

4.1.3 Non-planar defects: rounded indications without significant length;

i. Slag inclusions,
ii. Gas pores/blow holes,
iii. Other metallic and non-metallic inclusions

4.1.4 Defects which may be detected by visual inspection can be grouped under five headings;

i. Cracks,
ii. Lack of solid metals,
iii. Lack of fusion,
iv. Lack of smoothly blended surfaces,
v. Miscellaneous.

Mechanical damage can be defined as any surface material damage cause during the manufacturing process. This can included damage caused by grinding, hammering, chiselling, chipping, breaking off welded attachments (torn surfaces), using needle guns to compress weld capping runs. A welding inspector should also inspect the parent material for any visible defects. A weld repair may be used to improve weld profiles or extensive metal removal, repairs to fabrication defects are generally easier than repairs to service failures because the repair procedure may be followed. The main problem with repairing a weld is the maintenance of mechanical properties, during the inspection of the removed area prior to welding the inspector must ensure that the defects have been totally removed and the original joint profile has been maintained as close as possible [5].

All the types of defects noted average almost caused by man / welder travelled factor always appears as one of the causes. On the basis that the researcher decided to do improvement by replacing the Man (Welder Manual) using the Automatic Welding Machine SAW (Submerged Arc Welding).

4.2 Measurement

This research measure 100 units of pressure vessel tank using manual welding and 100 units pressure vessel tank using automatic welding, measurement varian are incomplete Penetration by Ultrasonic Test (UT), undercut by penetrant test (PT), Magnetic Particle Investigation (MPI), porosity, crack, pinhole by Radiography Test (RT).

There are many optional tool for measurement using Non Destructive Test (NDT), in this research limitation of applied NDT referred to NDT requirement as per customer specification and standard examination required and approved by technical association in charge.

4.3 Analyze

Process 1 (manual welding) compared with Process 2 (automatic welding) analyze defect ratio average between process, Defect Per-Million Opportunity (DPMO) and define Six Sigma Level.

PROSES - 1 (MANUAL WELDING GTAW+SMAW)

DPMO Calculator

This template calculates the DPMO using the number of defects.

Total number of units:	100
Number of defects:	26
Opportunities for Error in one unit:	5
DPMO =	52000
Sigma Level=	3.13

PROSES - 2 (AUTOMATIC WELDING GTAW+SAW)

DPMO Calculator

This template calculates the DPMO using the number of defects.

Total number of units:	100
Number of defects:	3
Opportunities for Error in one unit:	5
DPMO =	6000
Sigma Level=	4.00

The table assumes a 1.5 sigma shift because processes tend to exhibit instability of that magnitude over time. In other words, although statistical tables indicate that 3.4 defects / million is achieved when 4.5 process standard deviations (Sigma) are between the mean and the closest specification limit, the target is raised to 6.0 standard deviations to accommodate adverse process shifts over time and still produce only 3.4 defects per million opportunities.

Conversion Calculator – Sigma Conversion Table

DPMO	Sigma Level (With 1.5 Sigma Shift)*	Cpk (Sigma Level / 3) With 1.5 Sigma Shift*
933,200	0.000	0.000
915,450	0.125	0.042
894,400	0.250	0.083
869,700	0.375	0.125
841,300	0.500	0.167
809,200	0.625	0.208
773,400	0.750	0.250
734,050	0.875	0.292
691,500	1.000	0.333
645,650	1.125	0.375
598,700	1.250	0.417
549,750	1.375	0.458
500,000	1.500	0.500
450,250	1.625	0.542
401,300	1.750	0.583
354,350	1.875	0.625
308,500	2.000	0.667
265,950	2.125	0.708
226,600	2.250	0.750
190,800	2.375	0.792
158,700	2.500	0.833
130,300	2.625	0.875
105,600	2.750	0.917
84,550	2.875	0.958
66,800	3.000	1.000

Conversion Calculator – Sigma Conversion Table

DPMO	Sigma Level (With 1.5 Sigma Shift)*	Cpk (Sigma Level / 3) With 1.5 Sigma Shift*
52,100	3.125	1.042
40,100	3.250	1.083
30,400	3.375	1.125
22,700	3.500	1.167
16,800	3.625	1.208
12,200	3.750	1.250
8,800	3.875	1.292
6,200	4.000	1.333
4,350	4.125	1.375
3,000	4.250	1.417
2,050	4.375	1.458
1,300	4.500	1.500
900	4.625	1.542
600	4.750	1.583
400	4.875	1.625
230	5.000	1.667
180	5.125	1.708
130	5.250	1.750
80	5.375	1.792
30	5.500	1.833
23	5.625	1.875
17	5.750	1.917
10	5.875	1.958
3	6.000	2.000

Fig.1. DPMO & Z Level calculator value

4.4 Improve

Using SAW was prooved more better than using SMAW, refer to quality standard requirement, welding procedure specification and procedure qualification record from material laboratory test. Combination welding may required and become good optional if using GTAW (Gas Tungaten Arc Welding) for root then using SAW for filler and capping. Invest and use SAW automatic welding machine is the one of the technological innovation that researcher and enterprises approve and sponsored to applied and implementing the research. The benefit analysis especially in break event point analysis should be submitted and propose as an organization improvement approval.

4.5 Control

To sustaining the quality performance of the process and product it very important have to implementing control strategy and planning also maintenance activity to prevent and sustain the reliability and availability of the equipment and operating procedure standard.

At any point in the course of welding tacking, root pass, filler pass or capping pass, but particularly for the root and cap, a detailed inspection may be required. British Standard BS EN 970 (BS 5289:1976) gives guidance on tools and responsibilities together with sketches of typical defects. The inspector at this point must observe, identify and perhaps record (measure) the features of the weld and decide whether the weld is acceptable in terms of the particular levels that are permitted; defect levels may be 'in-house' or national codes of practice. When the defect size is in excess of the permitted level then either a concession must be applied for (from a competent person), or the weld rejected.

TABLE 1
PROCESS MAPPING CONTROL CYCLES PLAN

No	Description
1	**DESIGN Phase** ; - Define and collecting voice of customer, QFD, FMEA, design feature, design data and mechanical calculation of thickness under pressure as per ASME IX Ug27-28, Inspection Test Plan and measurement methode requirement, drafting in CAD, cost & pricing analysis,
2	**APPROVAL Phase** ; - Vendor drawing approval, - Listing & prepare of document (legal, drawing, mill certificate, WPS-PQR, welder certificate), Safefy procedure,
3	**MATERIAL Requirement Planning** ; - Drawing analysis and cutting plan, bill of material review, spesification code & requirement, supplier selection assesment,
4	**MATERIAL Order** ; - Inquiry (Request For Quotation), catalog / document check, price comparison analysis, negotiation & Purchase Order,
5	**INCOMING Material** ; - Certificate & heat number check, visual check (sharp edge, critical defect, crack, etc), dimension check (length, width, diagonal, diametre outside/inside, wall thickness), document acceptance,
6	**TOOL PREPARATION** ; - Cutting tool, welding machine, consumable, safety equipment, welding rotator jig
7	**BRAINSTORMING** ; - Meeting & briefing of process plan, safety induction, schedule and achieving target, start collect material from warehouse & tool preparation on working area,
8	**CUTTING** ; - Marking material as per plan drawing of cutting plan dimension, - Cutting torch check, LPG-O2 gas check, fire protection check, safety tool check, clearing area check, cutting process, chipping, deburring & grinding sharp edge, deliver WIP to next process, cleaning cutting area,
9	**SETTING PREPARATION** ; - Head forming, shell rolling, grinding & bevelling (shell, head, pipe, cap, flange & other fitting), deliver WIP to setting area,
10	**SETTING** ; - Assemnly shell to shell, assy shell to head, assy fitting nozzles and manhole, deliver to welding Area, cleaning setting area,
11	**WELDING** ; - Weld shell to shell (RFC), weld shell to head (RFC), weld fitting nozzles (RFC), finishing and cleaning HAZ & cleaning preheater, - deliver to inspection & testing, cleaning welding area,
12	**INSPECTION & TESTING – NON DESTRUCTIVE TEST** ; - Visual check & re-check final dimension overall, - Liquid Penetrant Test, Radiography Test, Report analysis & Defect review, defect repair & re-test after accepted, delivered to hydrotesting area,
13	**HYDROTESTING** ; - Tool preparation (test pump, pressure gauge, valve, fitting, water storage, pressure recorder), install outlet valve to blind outlet side or blind use blind flange+gasket, connecting inlet side to water pipe header, water supply to header, pressure test to test pressure requirement on plan design, dwelling pressure time, and decrease pressure after testing acceptance, review & repair if any leak and re-test, Delivered to Painting Area,

5 CONCLUSION

The result of this research were create an improvement that measured by defect ratio using DPMO analysis. This typical research model could be implement in several type of improvement depend on goal and resources capacity and organization policy.

Human factor in defect analysis are the most critical issued that affecting to process and product quality. It shown in defect ratio report and root defect caused analysis. Qualified welder would make high quality product even though low in consistency to make continuous in quality because of humanity factor and others affecting caused. This problem countermeasure and solved by enhancing and implementing innovation and technology of automatic Submerged Arc Welding (SAW) machine. The offorts of quality record are not shown in this research cause it review in manufacturing data report of product which contain of ITP (Inspection Test Plan), drawing, mechnical calculation, mill certificates, WPS (Welding Procedure Specification), PQR (Procedure Qualification Record), NDT (Non Destructive Test) report, visual report, dimension check report, hydrostatic pressure test report, goverment and third party witness and approval.

This technological improvement help Small and Medium Industries to compete, sustain and stay in their business and motivate to create more improvement especially in technological improvement to increase quality of product and in the end increase sustainability and business opportunity.

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