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Flaw Reduction in Low Alloy Steel Butter Welds for Productivity Improvement Using Six Sigma

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***Abstract*: In this paper, a study on ultrasonic testing on fusion welded joint of ferrite steels for Oil and Gas refinery application. The weld defects are major concern leading to rework, higher costs and thus affecting the delivery schedule of the job. The process starts with long and circular seams in the job and subsequently carrying out the NDT to find any defects in weld area. A number of defects are being observed in the welding process. Defects in welding may be found out in different methods at surface and subsurface levels, i.e. by Ultrasonic Testing, Penetrant Testing and Magnetic Particle testing. This deals with an application of Six Sigma Define-Measure-Analyze-Improve-Control methodology is an integral part of a Six Sigma initiative, improves the process performance leading to better utilization of resources, decreases variations and maintains consistent quality of the process output.**

***Keywords*: DMAIC, Ferrite Steels, Non-Destructive testing (NDT), Six Sigma.**

1. Introduction

Ultrasonic Testing involves the inspection, testing, or evaluation of materials, components, assemblies for material discontinuities, properties and machine problems without further impairing or destroying the parts serviceability. Ferrite steel with Compression or shear wave velocity is used for analysis. It deals with an application of Six Sigma and DMAIC methodology in an industry which provides a framework to identify, quantify and eliminate sources of variation in an operational process to optimize the operation variables. Six Sigma improves the process performance of the critical operational process, leading to better utilization of resources, decreases variations & maintains consistent quality of the process output.

2. Non-Destructive Testing (NDT)

Ferrite Steel materials are inspected for its reliability and quality. Generally fabricated parts undergo different means of inspection.

A. Ultrasonic Testing
B. Liquid Penetrant Test
C. Magnetic Particle Testing

A. Ultrasonic Testing

Ultrasonic Testing (UT) uses high frequency sound energy to conduct examinations and make measurements. Sound is transmitted in the material to be tested. Testing is the distance sound traveled can be displayed on the Flaw Detector, the screen can be calibrated to give accurate readings of the distance, the instrument produces the sound energy called probe and the echoes are shown on the cathode ray tube (CRT).

B. Liquid Penetrant testing

LPT is surface testing method for detecting surface breaking defects (opened to surface) applicable to all materials except for excessively porous (absorbing) materials.

C. Magnetic Particle Testing

Magnetic field induced in component Defects disrupt the magnetic flux Defects revealed by applying ferromagnetic particles.

3. Six Sigma

Six Sigma is an innovative approach to continuous process improvement. Six Sigma has become a much broader umbrella compared to Total Quality Management. [1] DMAIC is a closed-loop process that eliminates unproductive steps, often focuses on new measurements, and applied shown in fig. 1. [2]

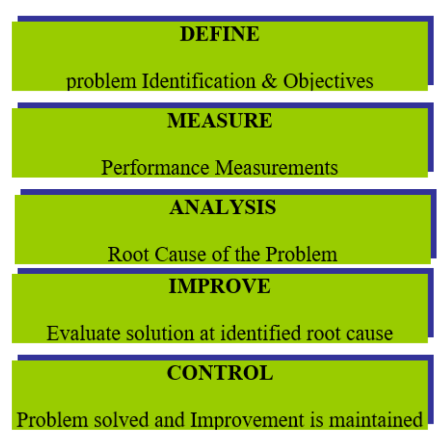

Fig. 1. DMAIC process flow

Implementation of DMAIC Methodology took place in five different phases as outlined earlier. Problem identification and definition takes place in define phase. After identifying, performance is calculated in measure phase with the help of data collection. Root causes of the problem are found out in analysis phase. Solutions to solve problem and implementing them are in improve phase. Finally, improvement is maintained in control phase [3].

A. *Define Phase*

In this phase, define the purpose of project. And also scope, process for both internal and external customers.

There are a different tools which is used in define phase like SIPOC, Voice of the customer. Hence, identify the customer(s), the project goals, and timeframe for completion are major role.

Table 1
DMAIC Project Charter

Department Name	**Mechanical Eng and TQM**
Project Location	Large Manufacturing Unit, Johr Bohr, Malaysia
Business Case	Improvement in fusion welded butted joint repairs in manufacturing section. By decreasing the welding repair rate overall project quality, productivity would be improved, cost will be saved and customer satisfaction level will be improved.
Project Title	Flaw Reduction in Fusion Welded Joint of Ferrite Steels for Productivity improvement using Six sigma
Project Scope	Welding Section, NDT Section, Procurement, Quality Control and store department should involve during different phases of the project
Goal	Defect rate should be reduced.
Phases of Project	1. DEFINE 2. MEASURE 3. ANALYSIS 4. IMPROVE 5. CONTROL

1) *Project Charter*

It is given by visiting welding facility. Production and Quality departments helped in understanding current performance of the facility.

2) *Welding Processes*

To identify the root causes efficiently welding Process Flow Chart were established by Six Sigma Team.

3) *SIPOC*

The following figure shows the relationship between Supplier Input Process Output Customer.

4) *Voice of Customers*

Customers have been identified by coordinating with Six Sigma team and quality engineering department after elaborated discussion with the internal and external customers.

From the view point of customers, proper welds made according to the specific standards, Trained Personal (TP), Qualified welders (QW), Quality Consumables (QC), Codes Standards (CS), Proper Testing Lab (PTL), Good Welding Equipment (GWE), Proper Storage for Consumables (PSC), Identification of Welds (IW), Proper Grained Welds (PGW), Qualified Welding Procedure (QWP) that are key to the customer satisfaction.

Define Outcomes:

The company follows codes and standards of American welding society and American society of mechanical engineers for proper execution and documentation of welding different projects. The welding facility is well equipped with modern welding technologies and welds testing labs.

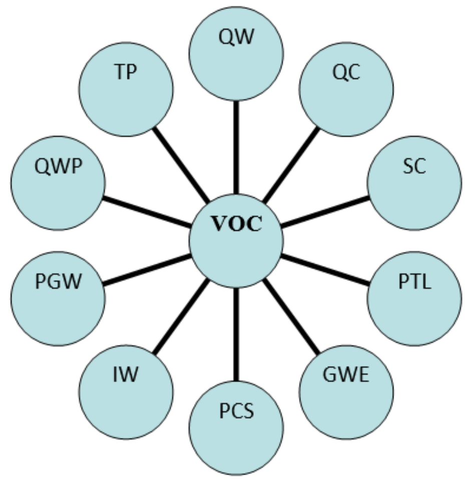

Fig. 2. Voice of customer

B. *Measure Phase*

This is data collection chart, evaluation of the existing system, assessment of the current level of process performance.

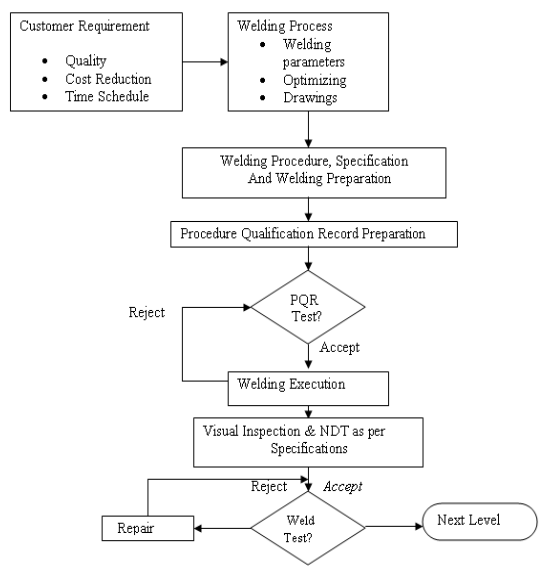

Fig. 3. Welding process flow chart

The goal of the Measure phase of a Six Sigma DMAIC project is to get as much information as possible on the current level.

Pareto Chart will help to identify areas of improvement and bench mark the quality levels to be achieved by bringing improvements.

Supplier	Input	Process	Output	Customer
Eng Department	Drawings/Specifications	Weld Preparations	Details Of Weld Joint	Production Department
Welding Engineer	Materials and Welding Requirements	Filler wire selections	Filler wire compatible with base metal according to Weld procedure specification	Weld Dept
Fabrication	Welders, Machines and detail welding requirement	Selected welders & welding job according to specification	Defect free weld	NDE
QC/NDE	Operators & Machines	Testing using NDE Techniques	Inspection Reports Evaluation no of defects	Fabrication shop/Quality Control/Third Party Inspection
Fabrication Shop & Welding Eng	Plan & Welder	Repair Welding	Repair Cleared	Machine shop

Fig. 4. Supplier input process output customer

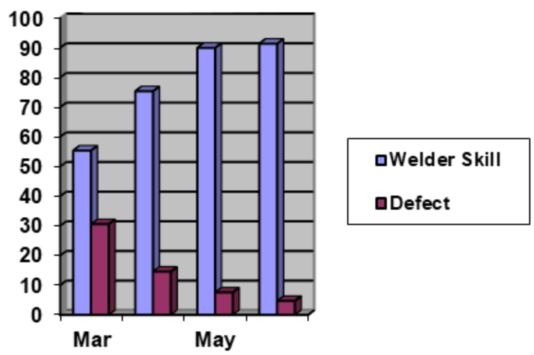

Fig. 5. Pareto chart of defect level

SIPOC diagram was also used as an input for this session. After conducting many sessions with different stake holders the cause and effect analysis was made and three critical variables consumables, tool and equipment and welder skill found.

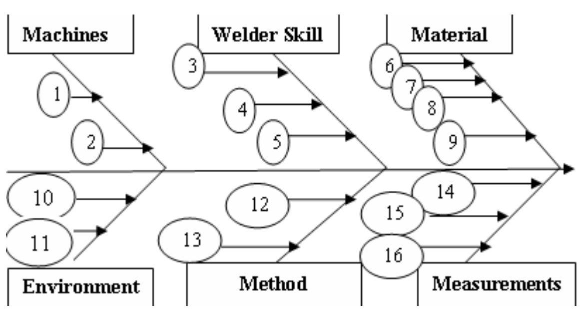

Fig. 6. Cause and Effect Matrix

From the Matrix, 1. Equipments, 2. Tools, 3. Skill, 4. Training, 5. Qualification, 6. Electrodes, 7. Filer wires, 8. Filers, 9. Base & Filler defects, 10. Electrodes Storage Environment, 11. Base metal storage Environment, 12. Drawings and Specifications, 13. Weld matrix, 14. NDT 15. Non NDT, 16. Visual Inspection.

To identify the repair rate, defect length is the most important factor. NDT level II are responsible to review the NDT (UT) Report to identify the defects length of the respective type of the defect. Each inspector viewed the UT and then collected data is used to perform the following analysis.

Measure Outcomes:

Data was collected; slag Inclusions and porosity are highest frequency of occurrence.

Measure phase outcomes:

- Base materials welded in previous are mostly different grades of stainless steel and carbon steel and plate and pipe welding were usually performed. So these types of welding are chosen for experimental purpose.
- Shielded metal arc welding is the process with lowest sigma value so this process is selected for further analysis.
- Slag inclusions and porosity are the most frequently occurring defects so efforts will be made to minimize these defects.

Table 2
Sigma values for welding process

Technique	Weld Length (cm)	Repair Defects (cm)	DPMO	Yield	Sigma
SAW	1875	5	2666	99.87	4.3
SMAW	17832	598	33535	96.35	3.2
GTAW	125000	300	2400	99.72	4.3

SMAW: Sub merged Arc welding; GTAW: Gas Tungsten Arc welding; SAW: Submerged Arc welding

An approach is available to obtain the overall sigma level of an organization based on weighting each of the critical processes. The quality function deployment (QFD) tool is to prioritize various processes based on the importance ratings obtained as a result of customer satisfaction.

Consider xi (i = 1, 2, n) are the 'n' critical processes identified by the organization of interest. Then k_1, k_2, k_n are the sigma levels of the processes x_1, x_2, x_n respectively. Extensive study on the importance of these processes may reveal specific weights for the critical processes. Let w_1, w_2, w_n be the weights assigned to the respective processes.

$$\sum_{i=1}^{n} w_i = 1$$

This implies that the process xi assumes a weight w_i to each unit produced, either defective or non-defective. Now the overall sigma level of an organization with regard to all 'n' critical processes is obtained. The total weighted-DPMO from all the processes put together is obtained as:

Weighted-DPMO = (w) x (DPMO)

$$\sum_{i=1}^{n} w_i p_i$$

The overall sigma level is now obtained for this combined DPMO either from the available tables or using the NORMSINV function available in Microsoft Excel. This sigma level is compared with following table to determine the category in which the organization falls.

Sigma Level	DPMO	Category
6	3.4	World Class
5 4 3	230 6,200 67,000	Industry Average
2 1	310,000 700,000	Non competitive

In a given set of critical processes that are used to determine the organization's overall sigma level, all critical processes may be in the equally-valued category or few may be in the higher-valued category. Without loss of generality that in case of equally-valued 'n' processes the weights are equal (1/n) and hence a weight 1/n is assigned to each unit produced by any of these 'n' processes.

All the three processes are treated as equally important and hence each process is assumed a weight 1/3. The overall sigma level is calculated using the data provided from the following table.

Table 3
Equally-valued Processes

Technique	W_t (w)	DPMO (p)	Weighted –DPMO w*DPMO
SAW	1/3	2666	888.6
SMAW	1/3	33535	11178.3
GTAW	1/3	2400	800

Therefore, total weighted-DPMO is given by,

888.6+11178.3+800=12866.93

Let q =12866.93/1000000 =0.01286

The sigma quality level,

k =1.5 + NORMSINV (1 – 0.01286)
= 1.5 + 2.230 = 3.73

The organization has achieved an overall sigma level of 3.73 and this falls in to the category of industry average.

$$\text{DPMO} = \frac{\text{No. of Defects} * 1,000,000}{(\text{(No. of Defect Opportunities/Unit)} * \text{Number of Units})}$$

= 598*100000/17832*1
= 33535.2

From standard Yield to Sigma Conversion Table, achieved Sigma Value is 3.2.

C. Analyze Phase

The third phase includes the definition of the root causes of the problem or defects and a root cause analysis criticality of each cause using a tool such as failure mode effect analysis.

1) Process Analysis

The result of the cause and effect diagram, Pareto analysis of the causes is which identify the root causes of the defects/problems detail activity flow chart as shown in fig 3. Repair Data collected and maintained in the form of standard reports and carrying out NDT process.

Identification of ferrite steel butt material
Rolling and make shell
Welding of butt joint
Carrying out NDT of butted weld joint
Repair the defects found if any
Two weld butted joints being joined
Grinding of two weld joints
Carrying out PT, MPT & UT
Repair the defects found if any
Clear NDT
Job is released

Fig. 7. Activity flow chart

2) Root-Cause Analysis

Root Cause Analysis is a method used to correct or eliminate the cause, and prevent the problem form recurring and immediate corrective action. It is simply the application of a series of well known, common sense techniques which can produce a systematic, qualified and documented approach to the identification, understanding and resolution of underlying causes.

3) Failure Mode Effect Analysis (FMEA)

It is methodology for analyzing potential reliability problems early in the development cycle where it is easier to take actions to overcome issues, thereby enhancing reliability through design. It is precisely an analytical methodology used to ensure that potential problems have been considered and addressed throughout the product and process development cycle. In this work, various discontinuities or defects are analyzed on welded joints.

a) Severity:

The following procedure shall be used to determine length of indication which has Decibel (db) rating more severe than for class D indications as per American Welding Society standards. The length of such indication shall be determined by measuring the distance between the transducer centerline locations Where indication rating amplitude drops 50% (6 db) below the rating for the applicable discontinuity classification. The procedure shall be repeated to determine the length of class A, B and C discontinuity. This shall not apply if the weld joint is back gouged to sound metal to remove the root face and MPT used to verify that root face has been removed.

This shall not apply if the weld joint is back gouged to sound metal to remove the root face and MPT used to verify that root face has been removed. Discontinuities detected at scanning level which exceed 50 mm in length shall be suspected and shall

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Table 4
Statistical Loaded Non Tubular Connections

Acceptance-Rejection Criteria Statically loaded Non Tubular Connections								
Weld Size in inch or mm and Search Unit Angle								
Severity	[8-20]	[20-38]	[38-65]		[65-100]		[100-200]	
	70°	70°	70°	45°	70°	45°	70°	45°
Class A	+5	+2	-2	+3	-5	0	-7	-1
Class B	+6	+3	-1	+4	-4	+1	-6	0
Class C	+7	+4	+1	+6	-2	+3	-4	+2
Class D	+8	+5	+3	+8	+3	+5	+3	+4

Table 5
Cylindrical Loaded Non Tubular Connections

Acceptance-Rejection Criteria (Cylindrically loaded Non Tubular Connections								
Weld Size in inch or mm and Search Unit Angle								
Severity	[8-20]	[20-38]	[38-65]		[65-100]		[100-200]	
	70°	70°	70°	45°	70°	45°	70°	45°
Class A	+10	+8	+4	+9	+1	+6	-2	+3
Class B	+11	+9	+5	+10	+2	+7	-1	+4
Class C	+12	+10	+7	+12	+4	+9	+5	+10
Class D	+13	+11	+9	+14	+6	+11	+3	+8

be further evaluated with radiography.

b) Detection

The type of discontinuities will be evaluated based on the following characteristics; one is height and pattern of the echo and second is the location of the discontinuity. The size of reflectors shall be estimated by 6 db drop for length of defects and 20db for width of defect. Other methods of sizing defect such as maximum amplitude technique. The parent metal shall be examined manually by pulse echo technique using a compression single or twin crystal normal probe. Probe size and frequency shall be within 10 mm to 25 mm diameter and 2 MHZ to 5 MHZ.

The scanning sensitivity shall be set on parent metal in an area free from imperfection such that the second back wall echo (BWE) is displayed at full screen height 100% FSH. Any discontinuity indication that because total losses of second back wall echo reflection shall be investigated. The location, depth and size of discontinuity area shall be recorded using Sona test site scan 150S.

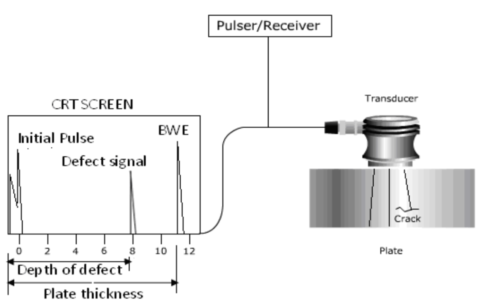

Fig. 8. Scanning sensitivity level

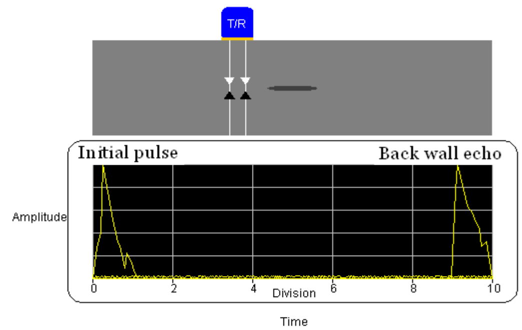

Fig. 9. Initial vs. Backwall echo

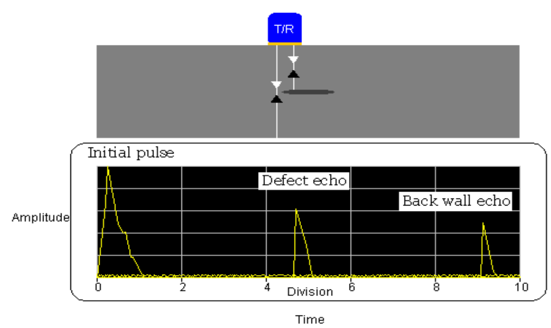

Fig. 10. Initial, Defect vs. Backwall

Table 5
Velocity of sound in common materials m/sec:

Material	**Compression**	**Shear**
Aluminum	6320	3080
Steel	5900	3245
Copper	4700	2260
Brass	3830	2050
Perspex	2730	1430
Water	1483	------
Air	330	------

The weld shall be examined manually by pulse echo technique using shear wave probe and compression wave probe. Probe size and frequency for angle probe should be 8 mm*9 mm crystal size and 2 MHZ to 5 MHZ, while normal probe size and frequency should within 10mm to 25 mm diameter and 2 MHZ to 5 MHZ.

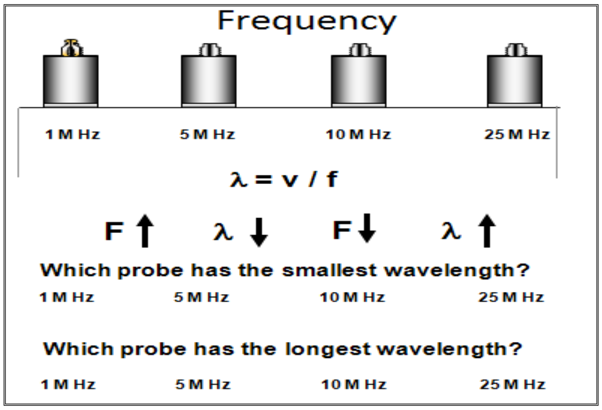

Fig. 11. Probe frequency variations

From the analysis point of view, Submerged Arc Welding depending up on welding arc length, welding electrode diameter, welding travel speed, welding electrode size.

Table is shown, describes testing plate of 3/8 inches' fusion welded fillet weld joint was tested against different input variables.

Table 6
Factors for screening experiment

1	**Electrode Length 9, 12 inch**
2	Electrode Diameter 3/32, 5/32 inch
3	Welding Travel Speed of Electrode 20, 40 inch/min

It is clear that Electrode thickness and Arc length are the significant factors. Thus it is recommended to use thin electrode with proper arc length to reduce defects.

The Experiments were performed on Fusion welded butted joints with 30 mm thickness.

c) Acceptability

Each weld discontinuity shall be accepted or rejected basis of its indication rating and its length in accordance with AWS D 1.1 section. All discontinuities which are rejection need to be recorded. [4]

Large discontinuities (Class A) in this category shall be rejected regardless of length. Medium discontinuities (Class B) having a length greater than ¾ in or 20 mm shall be rejected. Small discontinuities (Class C) having a length 50 mm middle half shall be rejected. Any indication in this Class D Category shall be accepted regardless of length or location in the weld.

Analysis Outcomes:

From the Results obtained by Analyze Phase Analysis it is recommended to use ¼ inches arc length with less diameter electrode for reducing the defect percentage and Arc length used during welding and thickness of electrode highly affect the defect rates.

4) Improve Phase

Practically, the improvement must investigate necessary knowledge based on brainstorming to create the best solution in design stage with proper drawings. The phase focuses on fully understanding the top causes identified in the Analyze phase, with the intent of either controlling or eliminating those causes to achieve breakthrough height.

Reports shall be accompanied with sketches of part being tested, surface condition, equipment used, sensitivity settings, drawings and location of indications if any welds found unacceptable shall be repaired and retested by the same ultrasonic testing technique with results. The accept or reject criteria tell what size and type of defects to report or which defects render the component is rejectable.

Improve Outcomes:

From the data, improved submerged arc welding technique company will continue to save cost in future projects depending upon the length of welding performed.

5) Control Phase

The last phase of DMAIC is control, which is the phase in which we ensure that the processes continue to work well, produce desired output results, and maintain quality levels.

4. Conclusion

Operational Six Sigma methodology was selected to solve the variation problem in a welded area. This Six Sigma improvement methodology, viz., DMAIC project shows that the performance of the company is increased to a better level as regards to: enhancement in customers' (both internal and external) satisfaction, adherence of delivery schedules and reorganize a process with a view to reduce or eliminate errors, defects; and more better overall process performance, creation of continuous improvement in productivity. The Root causes, effects and the preventive measures all the possible failures are given along with the priorities or classes.

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