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Reduction in Repair rate of Welding Processes by Determination & Controlling of Critical KPIVs.

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Abstract: Six Sigma is being Implemented all over the World as a successful Quality Improvement Methodology. Many Companies are now days are using Six Sigma as an Approach towards zero defects. This article provides a practical case study regarding the implementation of Six Sigma Project in a Welding Facility and discusses the Statistical Analysis performed for bringing the welding processes in the desired sigma Limits. DMAIC was chosen as potential Six Sigma methodology with the help of findings of this Methodology, Six Sigma Team First Identified the critical Factors affecting the Process Yield and then certain Improvement Measures were taken to improve the Capability of Individual welding Processes and also of Overall Welding Facility. Cost of Quality was also measured to Validate the Improvement results achieved after Conducting the Six Sigma Project.

Key words: Statistical Process Control (SQC), Process Capability Indices, Six Sigma, Variable control chart, Pareto charts, Standard deviation, Critical to Quality (CTQ), Analysis of Variance (ANOVA), DMAIC, Total quality Management.

1. Introduction

In this Era of changing customer needs and demand of highly reliable products have pushed many Manufacturing companies to adopt Total Quality Management (TQM) principles. Globalization and extension of Product Market has also increased the need of Quality Products at Reasonable cost to Customers. To respond to these Demands many Companies are implementing different Quality Management Principles at their manufacturing facilities such as ISO 9000, Just in Time (JIT), Lean Manufacturing, and Kaizen etc. A new and improved Quality Improvement Approach called Six Sigma is also becoming Popular in Controlling the Defect rate and managing the Quality as overall Process Function.

2. Six Sigma as an Improvement Approach

It is the set of practices originally developed by Motorola to systematically improve process by eliminating defects. Defect is defined as non-conformity of a product or service to its specification. Like its previous quality improving methodologies six sigma focuses on the following points.

- A continuous effort to reduce variation in process outputs is essential to business success.
- Manufacturing and business processes can be Measured, Analyzed, Improved and Controlled.
- In order to achieve best Quality Improvement results, role of upper management is very critical.

The term Six Sigma refers to a highly capable process that can produce products within specifications. Process that achieves Six Sigma levels produces only 3.4 defective Products per million opportunities. Main focus of Six Sigma is to improve all key processes of manufacturing setup and takes quality as a function of Processes Capability to produce items with in specification.

2.1. DMAIC Overview

Define, Measure, Analyze, Improve and Control (DMAIC) is a Six Sigma Methodology mainly used for improving quality of already established Processes and Manufacturing Systems. Basically this methodology comprises of following five key points.

- Define the process improvement goals that are aligned with the customer demands and company's strategy.
- Measure the current process and make a strategy for making further improvement.
- Analyze to verify the relationship and causality of factors. Determine what the relationship is and attempts to ensure that all the factors have been considered.
- Improve and optimize process based on findings of analysis phase using different techniques.
- Control to ensure that any variances are corrected before they result in defects.

In this research DMAIC is used as Potential Six Sigma Methodology to bring Quality Improvements in Manufacturing Company.

2.2. Case Study

2.2.1. Company Profile

The Pakistan Welding Institute (PWI) is a Pakistan based Professional institution devoted to maintain and promote standards of excellence in Welding Technology. PWI provides industry with technical support through advice & information, consultancy, Research and Development (R & D) and training & qualification. Its services and expertise cover all areas of welding & joining technology and materials engineering for metals and non-metals alike. PWI has the capacity of welding almost all commercially available engineering materials ranging in thickness from 0.1mm to 300mm.

2.2.2. Problem Statement

The Head manufacturing at Pakistan Welding Institute was not satisfied from the current welding Repair rate. From the last few months he was receiving the complaints from the ASME Authorized Inspector and the client's inspector that in a number of welding jobs due to a higher repair rate the quality of the product is suffering; and there level of confidence is decreasing on the production-welding process. Head Manufacturing also showed the concern with reference to the last financial review; showing that the manufacturing is bearing a larger amount due to the welding repair work.

2.2.3. Research Methodology

To overcome the Welding Problem defined previously, Companies Upper Management decided to launch a Six Sigma Quality Improvement Study. As Six Sigma further Comprises of different Methodologies so by studying the nature of Problem it was decided to choose DMAIC methodology which consists of sequential identification and controlling of root Causes of Problem to bring the process under control and in desired quality level.

3. Data and Results

3.1. Define Phase

(What the problem is and what customer Wants)

Define phase of the project helps to identify the problem according to the demand of customers. In this phase of Project, Quality Problems and future roadmap for the project are defined. The project started with the investigation of the problem. This was evaluated in greater depth with the help of process map and other tools. Findings of Define Phase are given as.

Table 1. DMAIC Project Charter.

Project Title	**Minimization of Welding Repair Rate by using DMAIC Approach**
Business Case	Welding is one of the most critical processes in the PWI equipment manufacturing Area. Higher repair rate Increases the cost and decreases the productivity. By decreasing the welding repair rate overall project quality and productivity would be improved and cost will be saved moreover all the interested parties including internal/external (Execution team, Authorized Inspectors, Clients Inceptors) customer satisfaction level will be improved.
Goal	Repair rate to be minimized up to 0.25% age.
Metrics (CTQ's)	**Primary Metric** (% age of repair rate), **Cost of Quality** (Rupees)
Project Scope	Welding Section, NDT Section, Procurement, Quality Control and store department should involve during different phases of the project

3.1.1. Project Charter

A project charter is established by visiting welding facility. Production and Quality Departments helped in understanding current performance of Facility. Table 1 gives details of Project`s Charter.

3.1.2. Welding Processes Flow chart at PWI

To understand the details of Welding Processes and to identify the root causes efficiently welding Process Flow Chart was established by Six Sigma Team. Figure 1 describes the welding Flow Chart.

3.1.3. Supplier Input Process Output Customer (SIPOC)

To understand the relationship between different departments at PWI the SIPOC diagram was made. Table 2 shows the findings of SIPOC Diagram.

3.1.4. Voice of Customers

The needs of customers have been identified by coordinating with Six Sigma Black Belt and quality engineering department after elaborated discussion with the internal and external customers. From the

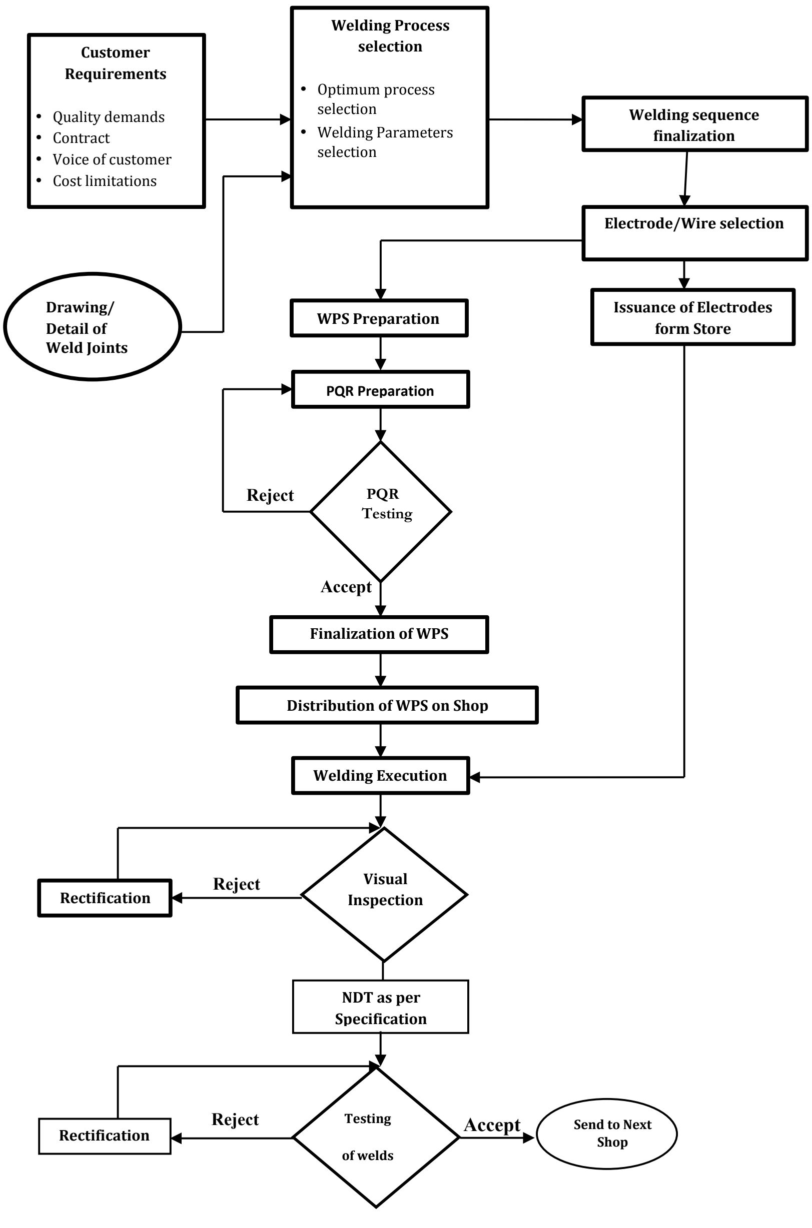

Figure 1. Welding processes flow chart at PWI.

Table 2. SIPOC Diagram.

Supplier	Input	Process	Output	Customer
Engineering Department	Latest Drawings/ Specifications	Weld Map Preparation	Details Of Weld Joints Drawing	Production Department
Production Department	Details Of Weld Joints And Design Requirements	Preparation Of Weld Matrix (WPS & PQR)	Weld Matrix	Welding Department & Quality Control
Welding Engineer	Materials And Welding Requirements	Electrodes/ Filler Wires Selection & Requirements	Electrodes/ Filler Wires Compatible With Base Metal According To The WPS	Welding Department
Welding Engineer	All Welding Parameters And Their Qualification Reports	Lab Testing (Mechanical Testing) According To Design / Code Requirements	Test Reports	Welding Department & Quality Control
Project Engineer	Detail Welding Requirements	Welder Selection	Selected Welder Capable Of Welding Sound Weld & WPQR	Welding Department & Quality Control
Welding Engineer	Welding Requirements, Joint Number And Applicable WPS	Welding Execution	Welding Of Job According To Weld Matrix	Fabrication Engineer/ Area Supervisor
Project Engineer/ Welding Engineer	Production Test Plate Requirement And Process	Lab Testing (Production Test Plate)	Test Reports Values According To Design/ Code	Welding Department & Quality Control
Project Engineer	All NDT Requirements	Visual Testing NDT (R.T., U.T., D.P.T. & M.P.T.)	Inspection Reports, NDE Reports	Quality Control/ Third Party Inspector/ Client

view point of customers it is clear that proper welds made according to the specific standards and codes is key to the customer satisfaction. Figure 2. Elaborates quality of welds according to the view point of customers.

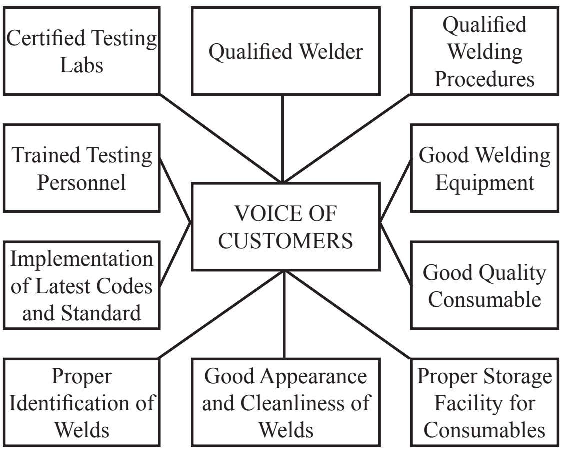

Figure 2. Voice of Customers.

3.1.5. Define Phase Outcomes

Welding is one of the most critical processes in the Pakistan Welding Institute equipment manufacturing Area. Higher repair rate Increases the cost and decreases the productivity. By decreasing the welding repair rate overall project quality and productivity would be improved and cost will be saved moreover all the interested parties including internal/external (Execution team, Authorized Inspectors, Clients Inceptors) customer satisfaction level will be improved. Project Goal is to reduce Repair rate up to **0.25 %age**. The welding Facility has up to date and a well-controlled Quality Management System to ensure Proper Quality of Welds. The Welding 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.

3.2. **Measure Phase** (Establishing the base line for the DMAIC Project)

After studying the nature of problem in the define phase, the six sigma team started collecting the data in order to measure Project outputs in more detail and from different angles. The Measure Phase now focuses to get a bit more information about the welding processes by measuring the Yield of different projects performed in past and calculating current sigma levels. This will help to identify areas of improvement and bench mark the quality levels to be achieved by bringing improvements. Some Tools of Measure Phase are given in the following.

3.2.1. Defining Project Inputs and Outputs (X`s and Y`s)

For defining the critical inputs and outputs of the six sigma project variables a brainstorming session involving the Six Sigma team, Authorized Inspector, Clients Inspectors and Internal Quality Control Inspectors was conducted. 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. Cause and Effect Diagram is shown in Figure 3.

Here WPS stands for Welding procedure specification a WPS is a written procedure prepared to provide direction for making production welds according to code requirements. PQR is an abbreviation of procedure qualification record a PQR lists what was used in qualifying the WPS and test results.

3.2.2. Cause and Effect (C & E) Matrix

Based on the findings' of process X's and Y's and Rating of Importance to Customers the Cause and effect matrix is developed. Table 3 describes the cause and effects of different input process variables on the critical process output variables in form of highest and lowest scores.

On the basis of the Cause and Effect matrix; Project team concluded three critical X(s) that influence the output variables the most. These three variables are defined as:

Welder Skill: Capability of the welder to produce sound weld (i.e. Weld according to WPS &should be defect free)

Tool & Equipment: Tool & Equipment includes welding machines, Welding Holders, Welding Torches.

Consumables: Consumables includes Electrodes and Filler wires used for welding purpose.

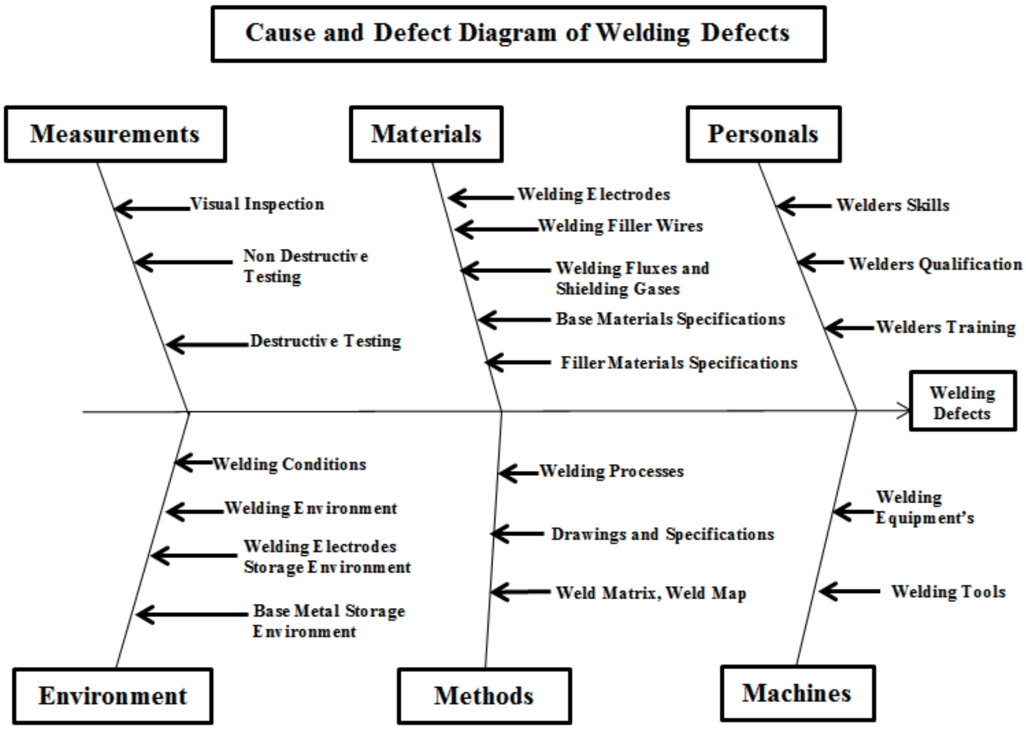

Figure 3. Causes and Effect Diagram of Welding Defects.

Table 3. Cause and Effect Matrix.

	Rating of Importance		Key Process Output Variables (KPOV`s)						
			6	6	3	9	9	9	
Sr. No.	Key Process Input Variables (KPIV`s)	Priority rating	Visual Appearance	Welding Size	Proper Cleaning	Internal Defects	External Defects	Mechanical &Chemical Properties of weld	TOTAL
1	Drawing/Specifications	3	0	3	0	0	0	3	45
2	Weld Matrix	6	0	0	0	3	0	6	81
3	WPS/PQR	6	0	0	0	3	3	6	108
4	Welder Skill	9	9	9	9	9	9	9	378
5	Tool & Equipment	6	3	0	6	3	6	3	126
6	Consumable	9	9	3	3	9	9	9	324

3.2.3. Measurement System Analysis and Gage R&R study

To identify the repair rate, defect length is the most important factor. Quality control personnel (NDT level II) are responsible to review the NDT (radiography)

Report to identify the defects length of the respective Type of the defect. Six Sigma team selected the three radiographic films and three quality inspectors (NDT Level- II). Each inspector viewed the radiographic films three times and then collected data is used to perform the following analysis.

Table 4 shows that Gage R&R % is **0.59%** which is less than 1%. According to MSA standard if total gauge R&R is between **1** and **9** the measurement system is acceptable and if it is less than 1 the system is highly acceptable. Total study variation is **7.70%** which is less than 30% of the MSA standard the distinct category is **18**, which is greater than the minimum requirement 5 of the MSA standard. Therefore According to above conclusions the six sigma team agreed that the measurement system for the welding repair work is acceptable.

Table 4. Two-Way ANOVA Table with Interaction.

Source	DF	SS	MS	F	P
PART	2	1352.29	676.143	511.95	0.000
OPERATOR	2	2.77	1.384	1.05	0.431
PART * OPERATOR	4	5.28	1.321	2743.03	0.000
Repeatability	18	0.01	0.000		
Total	26	1360.34			

Gage Repeatability and Reproducibility (R&R)

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.4476	0.59
Repeatability	0.0005	0.00
Reproducibility	0.4471	0.59
OPERATOR	0.0070	0.01
OPERATOR*PART	0.4401	0.58
Part-To-Part	74.9802	99.41
Total Variation	75.4278	100.00

Source	StdDev (SD)	Study Var (6 * SD)	%Study Var (%SV)	%Tolerance (SV/Toler)
Total Gage R&R	0.66901	4.0140	7.70	20.07
Repeatability	0.02194	0.1317	0.25	0.66
Reproducibility	0.66865	4.0119	7.70	20.06
OPERATOR	0.08371	0.5022	0.96	2.51
OPERATOR*PART	0.66338	3.9803	7.64	19.90
Part-To-Part	8.65911	51.9547	99.70	259.77
Total Variation	8.68492	52.1095	100.00	260.55

Number of Distinct Categories = 18

3.2.4. *Welding Defects Data Collection*

Data was collected for all the projects which were executed during November 2012 to April 2013.Total Projects are 20 in number. The 100% of the last 6 months projects data was collected by the six sigma team. From Figure 4 it is clear that Slag Inclusions have the highest frequency of occurrence.

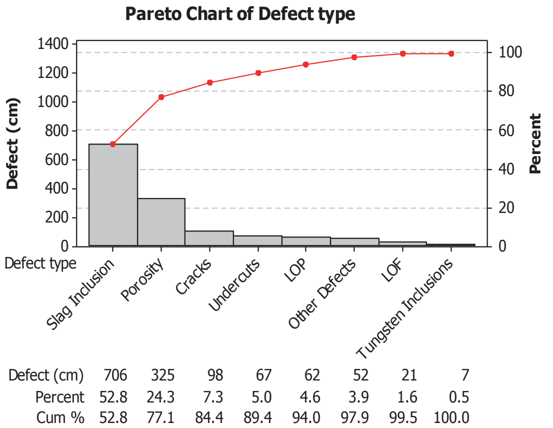

Figure 4. Pareto chart of Defect Type repair (Note: LOF=Lack of Fusion, LOP=Lack of Penetration, Other defects=Root Concavity etc.).

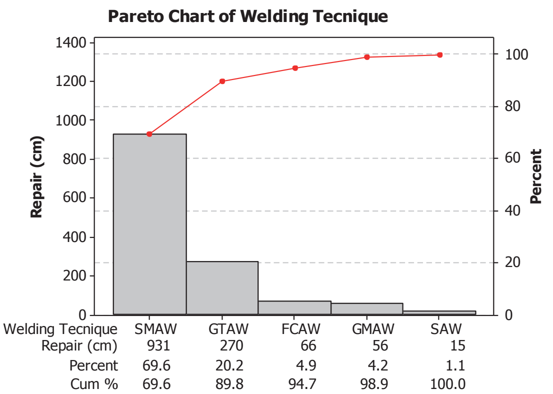

Figure 5. Pareto chart of Welding Processes (Note: SMAW=Shielded metal Arc Welding, GTAW=Gas Tungsten Arc Welding, SAW=submerged Arc Welding, FCAW=Flux Cored Arc Welding, GMAW=Gas Metal Arc Welding).

Figure 5 shows that Shielded metal Arc welding has also highest contribution in defect or repair rate where Gas tungsten Arc Welding has the second most impact. It is hence cleared that major improvements can be brought in Quality of welds by targeting Shielded metal arc welding and Gas tungsten arc Welding and factors contributing to the occurrence of Slag inclusions and porosity.

3.2.5. *Calculation of Sigma Values*

Six Sigma team calculated the Sigma values for the minimizing welding repair work project. Table 5 Represents the Calculated Sigma values of each Welding Process and overall Welding Facility.

3.2.6. *Measure phase outcomes*

Major conclusions that can be drawn from Measure Phase of the Project are:

- Significant X(s) (KPIVs) have been found. Welder skills, Consumables and welding Equipment are found to be critical input variables that influence the Quality of Welding.
- Shielded Metal Arc Welding and Flux cored Arc Welding are the processes with lowest sigma values so these Processes are selected for further Analysis.
- Slag Inclusions and Porosity are the most frequently occurring defects so efforts will be made to minimize these defects.
- Base Materials welded in previous projects by shielded Metal Arc Welding process are mostly different grades of Stainless steel and carbon steel and Plate and Pipe Welding were usually performed in those Projects. So these types of welding are chosen for experimental scheme In Further Project Phases.
- Target is to minimize the Welding Repair rate up to **0.25%.**

Table 5. Calculation of Sigma values of Welding Processes.

Sr. No.	Welding Technique	Weld Length (cm)	Repair Defects (cm)	Defect %	DPMO	Yield	Sigma	Cpk
1	SMAW	21778	931	4.2749	42749.5	95.72	3.2	1.07
2	GTAW	123853	270	0.2180	2180	99.78	4.3	1.43
3	FCAW	1921	66	3.4357	34357	96.56	3.3	1.1
4	SAW	7415	15	0.2022	2022	99.79	4.3	1.43
5	GMAW	41921	56	0.1335	1336	99.86	4.5	1.5
	Total	196888	1338	0.70	7049.69	99.30	4	1.33

3.3. **Analyze Phase** (Analyze Source of Variation)

After Measurement Phase and establishing the baseline and target level, the team analyzed the causal relationships in detail. This phase involved identifying and validating possible X's and prepare for the design of experiment for the improve phase.

3.3.1. Analysis of Welding Processes with low Sigma Values

The findings of Measure Phase show that two welding Processes i.e. Shielded metal Arc welding and Flux cored Arc welding have the low sigma values of 3.2 and 3.3 consecutively. Based on the facts shown in measure phase, Flux cored Arc welding is a semi-automated arc welding process that is rarely used in the execution of projects at the welding Facility. Table 5 describes that FCAW technique is used to weld only 1921 cm of welding length, Reasons behind this fact is limitations of this welding technique because of high cost associated with its operation. So the decision here is to remove Flux cored Arc welding from the investigation list and Focus of Improvement will now be on Shielded metal Arc welding due to its lowest sigma values and High Repair rate.

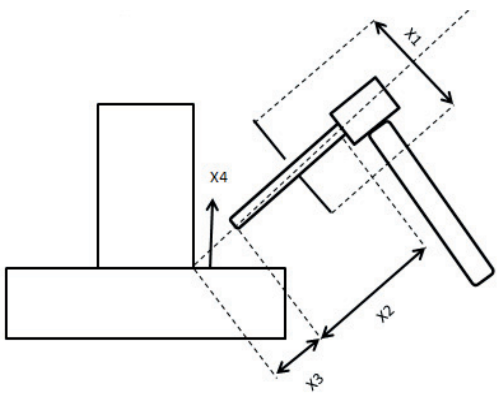

Figure 6. Experimental setup for Fillet weld by Shielded Metal Arc welding.

3.3.2. Screening Experiments

To analyze the sources of Variation in Shielded Metal Arc Welding it is necessary to first Ensure the Smooth Welding Process that is not influenced or affected by the Process Parameters. For this purpose a brain storming session was conducted with the Welding Engineer and Welding Literature was consulted to identify the Primary Source of Variation in Shielded Metal Arc Welding Process. Few Factors that were identified are Welding electrode Diameter, Welding Electrode Length (Size), Welding Arc Length, Welding Travel speed. A multilevel Factorial Experiment was designed to analyze effect of different Values of these factors on Response variable. The Response Variables selected are the Defect % of Slag Inclusion or Porosity. Experimental Scheme is given in Figure 6 is shown, it describes Testing plate of 3/8 inches Stainless steel with fillet weld joint was tested against different input variable settings.

Table 6 shows the different Variables Values used for experimental scheme. Welding material used here is AISI 304L stainless steel and electrode Type used is 308L.

Table 6. Factors settings for Screening Experiment.

S.NO.	Factors	Levels
01	X1= Electrode Diameter	3/32, 5/32 inches
02	X2= Electrode Length	9, 12 inches
03	X3= ARC Length	Buried, 1/4 inches
04	X4= Welding Travel Speed of Electrode	20, 40 inches/min

The Analysis of Variance Results are shown in Table 7 and Figure 7; it becomes clear that Electrode thickness and Arc length are the significant factors with P-Value of 0.007 and 0.069. Other two factors have not the significant effect and can be treated as redundant Factors for further Analysis. Thus it is recommended to use thin electrode with proper arc length to reduce Slag inclusions and Porosity.

Table 7. ANOVA Results for Screening Experiments.

Analysis of Variance for Defect %, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
X1	1	0.254898	0.254898	0.254898	45.31	0.007
X2	1	0.000480	0.000480	0.000480	0.09	0.789
X3	1	0.043218	0.043218	0.043218	7.68	0.069
X4	1	0.003960	0.003960	0.003960	0.70	0.463
Error	3	0.016877	0.016877	0.005626		
Total	7	0.319434				

S=0.0750033 **R-Sq**=94.72% **R-Sq. (adj)**=87.67%

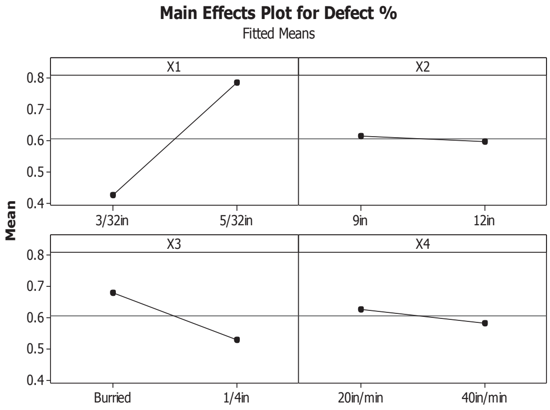

Figure 7. Main Effect Plots for Factors used in Screening Experiments.

3.3.3. Analysis of Variance of Critical KPIV`s

With reference to the short listed Process Input Variables i.e. X(s), Sigma team designed the experimental scheme by using Design of experiment concepts. Three factors chosen for analysis are welder skills, tool and equipment and Consumables used for welding sample welding plates of Stainless steel grade 304L materials by Shielded Arc Welding Process. Test plates of 30mm thickness were welded in Butt weld Profile and were tested by Visual inspection and Radiographic tests. Inspector of Quality, NDT Level II was appointed to view Test reports. The response variable here is Slag inclusions and Porosity whose defect rate is measured against different settings of Input Variables. Three level of Operator skills and two levels of other two factors were used for Variation Analysis. Table 8 shows the data obtained from experimental settings of different variables

3.3.3.1. Analysis of Variance Results

Using the Results shown in Table 8 a dot plot Figure was created which showed greater variation in welder Skills and Consumables and showed lesser variation in Tool and Equipment. Figure 8 shows the Dot Plot. Tool and Equipment`s are removed from further Investigation.

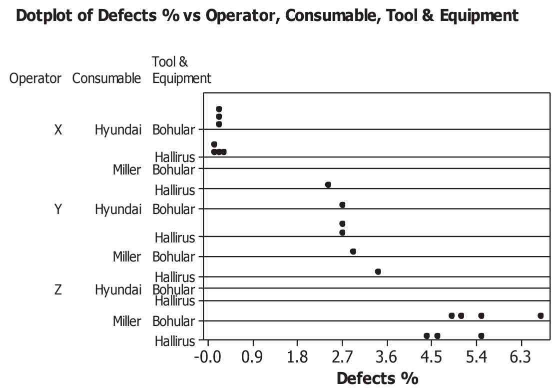

Figure 8. Dot plot of Defect% versus three factors

Table 8. Experimental data for Analysis of Effect of different Variables

Sr. No	Operator	Consumable	Tool & Equipment	Defects % of Slag Inclusion and Porosity
1	Z	Miller	Bohular	5.10
2	Z	Miller	Hallirus	4.393
3	Y	Miller	Hallirus	3.358
4	X	Hyundai	Bohular	0.2022
5	X	Miller	Hallirus	2.388
6	X	Hyundai	Hallirus	0.128
7	X	Hyundai	Hallirus	0.310
8	Z	Miller	Hallirus	5.45
9	Z	Miller	Bohular	6.66
10	X	Hyundai	Bohular	0.199
11	X	Hyundai	Hallirus	0.147
12	Y	Hyundai	Hallirus	2.651
13	Y	Miller	Bohular	2.922
14	Z	Miller	Bohular	4.916
15	Y	Hyundai	Hallirus	2.708
16	Y	Hyundai	Bohular	2.74
17	Z	Miller	Bohular	5.513
18	X	Hyundai	Hallirus	0.1995
19	Z	Miller	Hallirus	4.623
20	X	Hyundai	Bohular	0.170

In Figure 9, Interaction plot shows that welder X with Hyundai consumable is producing least defect% as compare to the welder Y and Z with Miller consumable. It is hence clear that Hyundai Company Manufactured Consumables are the most Appropriate for decreasing the Defect %, thus decision here is to use Hyundai Consumables in Further Welding and to Improve Welder Skills in Improvement Phase.

Figure 9. Interaction Plots of Two Factors versus Response variable.

3.3.4. Analyze Phase Outcomes

From the Results obtained by Analyze Phase Analysis it is clear that Arc length used during welding and thickness of electrode highly affect the defect rate of Slag Inclusions and Porosity, so it is recommended to use ¼ inches arc length with less diameter electrode for reducing the defect percentage. Furthermore Project team has short listed the following two KPIVs:

- Welder Skill
- Consumable

In Consumables the Hyundai manufactured consumables are producing good quality of welds while the reason why variation is being caused by welder skills will be analyzed and Improved in next Phase of the Project.

3.4. Improve Phase (Making Changes)

This phase involved identifying solutions, select best choice, and carrying out experimentations to validate solutions and relations between the effects and causes.

3.4.1. Analysis of Variance for finding Factors affects

For further Improvement in Shielded Metal Arc Welding Process a multi-level Factorial Experiment as designed to analyze variance of different factors suggested by Six Sigma Team that can cause variation. For this Purpose Three factors were selected with two levels of each. The three factors Selected are:

Factor 1 = Shift Timings, Level 1 = Morning, Level 2 = Evening

Factor 2 = Heating time of Electrode in Electrode oven, Level 1 = 3 hours (normal), Level 2 = 5 hours (suggested) at 250 degrees Centigrade Temperature.

Factor 3 = Electrode Composition, Level 1 = Electrode with low flux deposition Rate (Flux Deposition Rate of 2 lb/hour), level 2 = Electrode with high flux deposition Rate (Flux Deposition Rate of 4lb/hour).

Table 9 shows the Data Collected for the before mentioned Experimental Scheme.

Table 9. Experimental scheme used for Analysis of Variance.

Run Order	Shift	Electrode	Heating time	Defect %
1	Evening	High Flux deposition	3 Hours	0.90
2	Morning	High Flux deposition	3 Hours	0.87
3	Evening	Low Flux deposition	5 Hours	0.10
4	Evening	High Flux deposition	5 Hours	0.30
5	Evening	Low Flux deposition	3 Hours	0.20
6	Morning	High Flux deposition	5 Hours	0.28
7	Morning	Low Flux deposition	3 Hours	0.19
8	Morning	Low Flux deposition	5 Hours	0.12

In Table 10 and Figure 10, 11 the effect of each factor is are shown. The Experiments were performed on 304L Pipes with 30 mm thickness in 6G Position by Shielded Metal Arc Welding Process.

Table 10. Results of Multilevel Factorial Experiments.

Analysis of Variance for Defect %, using Adjusted SS for Tests

Term	Effect	Coef	SE Coef	T	P
Constant	0.3700	0.002500	148.00	0.004	0.000
Shift Timings	–0.0100	–0.0050	0.002500	–2.00	0.295
Electrode Type	0.4350	0.2175	0.002500	87.00	0.007
Heating Time	–0.3400	–0.1700	0.002500	–68.00	0.009
Shift Timings×Electrode Type	–0.0150	–0.0075	0.002500	–3.00	0.205
Shift Timings×Heating Time	0.0100	0.0050	0.002500	2.00	0.295
Electrode Type×Heating Time	–0.2550	–0.1275	0.002500	–51.00	0.012

S=0.00707107, **PRESS**=0.0032, **R-Sq** = 99.99%, **R-Sq(pred)** = 99.57%, **R-Sq. (adj)** = 99.95%

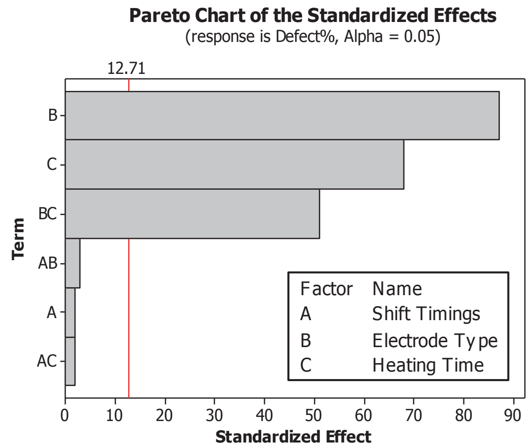

Figure 10. Pareto chart of Standardized effect.

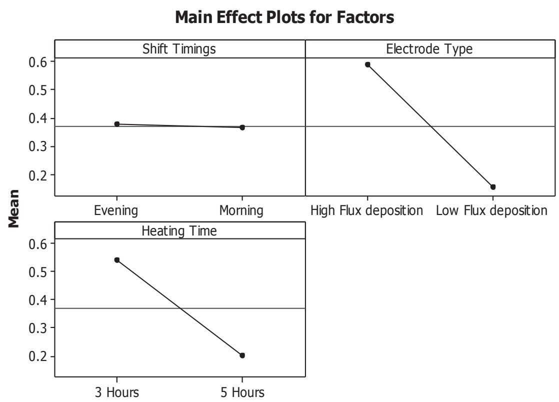

Figure 11. Main Effect Plots for Defect %.

3.4.2. *ANOVA Conclusions*

- From the values obtained by analysis of variance of three before mentioned factors it is clear that shift Timings of welders have little or no effect on defect rate of welding process, P value of 0.295 is high enough to support this claim.
- Electrode and heating timings of electrode in oven have P values of 0.007 and 0.009 respectively, so conclusion can be drawn that both of these factors have significant effect on the defect rate. Interaction effect of both these factors is significant because p value of 0.012 is much lesser then the alpha value of 0.05.
- From the factorial plots it is clear that by increasing the heating time of electrode in oven the defect rate drops significantly and using low Flux deposition rate electrode also cause reduction in defect rate of welding.
- Shift timings effect is not significant and remains almost constant over the range of morning and evening as shown in plots.
- Interaction plot of the three factors also support the fact that interaction of shift timings with other two factors do not bring significant changes in the defect rate, while interaction of heating time along with Electrode type gives reduced defect rate of welding.
- From all these results it can be conclude that using Low Flux deposition electrode along with the more heating time will be set as final setting for the Shielded Metal Arc Welding Process.

3.4.3. *Further Improvement Changes*

For Improvement Purpose two main changes were suggested by the Welding Engineer in The general welding Process of the welding Facility. Welder skill is a strong factor identified previously in Analyze Phase to bring Quality Improvement in the welding process. For this purpose Proper Testing of the welders before execution of any new welding project was necessary to be done. In most of the welding companies in the word this testing of welders is being done and called welding operator performance qualification test (WPQ).

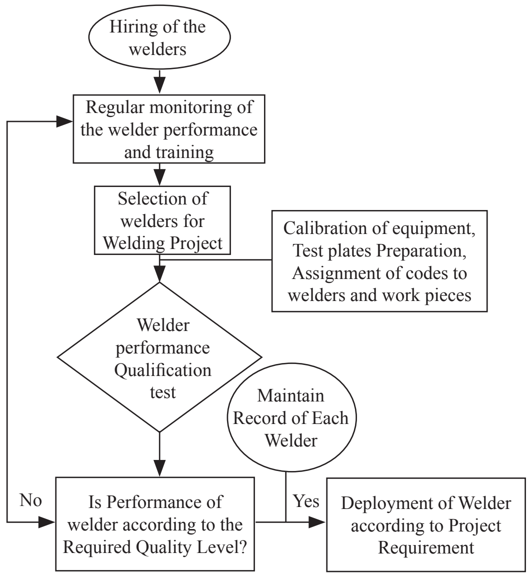

Figure 12. Welder Performance Qualification Process

In Figure 12 details of the processes inducted to bring quality improvement in welder skill area are given. This process explains that how welder ability to perform satisfactory welds will be enhanced and the welder best in performance will be chosen to perform Welding on a specific Project.

According to changes implemented, only the best performance giving welder would be chosen regardless the capability of the welder and his reputation. The record of test plates would be used to analyze the performance and selection of welder for further projects.

3.4.4. Improvements from the Six Sigma Project

Table 11 shows the results from two of the recently completed Jobs by Shielded Metal Arc Welding Process. Slag Inclusions and Porosity were taken as Responses variable to be calculated.

Cost of quality was also calculated based upon the factors identified in the measure phase. Clearly here Sigma value of shielded Metal Arc Welding given in table 11 is 4.30. Improved Sigma value of Overall Facility is summed up in table 12.

It is clear that SMAW process has improved from 3.3 sigma to 4.3 sigma which has also improved combined Sigma Value of overall Facility from 4.0 to 4.3 sigma Level.

From the data shown in Figure 13 it is clear that by improving Sigma value of Shielded Metal Arc Welding Process from 3.3 Sigma to 4.3 sigma a cost of Rs. 1,000,000 is saved initially and Company will continue to save Cost in future projects depending upon the Length of welding Performed by SMAW Process.

Table 11. Results of Quality Improvement.

Sr. No.	Project No.	Project Description	Weld Length (cm)	Slag (cm)	Porosity (cm)	Repair (Defects) (cm)	Defects (%)	DPMO	Yield	Sigma
1	TK-25	RWST Tank	5055	7	3	10	0.20	1978	99.8	4.30
2	S-925	Generator Cooler	4233	5	3	08	0.19	1890	99.81	4.30
	TOTAL		**7065**	**13**	**6**	**19**	**0.27**	**2689**	**99.73**	**4.30**

Table 12. Process Capability Calculations.

Sr. No	WeldingTechnique	Defect %	DPMO	Yield	Sigma	Cpk
1	SMAW	0.27 (Improved)	2689	99.73	4.3	1.43
2	GTAW	0.2180	2180	99.78	4.3	1.43
3	FCAW	3.4357	34357	96.56	3.3	1.10
4	SAW	0.2022	2022	99.79	4.3	1.43
5	GMAW	0.1335	1336	99.86	4.5	1.50
	TOTAL	**0.2235**	**2235**	**99.74**	**4.3**	**1.43**

Table 13. Six Sigma Project Control Plan.

Sub Process	Specification Characteristic	Specification Requirement	Measurement Method	Who Measures	Where Recorded	Decision Rule/ Corrective Action/Reference Documents
Qualification of WPS	ASME Sec- IX & Code of construction	ASME Sec VIII div.-I & Supplementary Requirements	Mechanical and Radiography Results	Approved Laboratory	PWI Performance Record Sheets	Must be Approved by the NDE Level-III & client
Qualification of Welder	ASME Sec- IX & code of construction	ASME Sec VIII Div-I & Supplementary Requirements	Radiography Results	Radiography lab test reports	Welder Certificate	HRD/SOP-06
Selection of WPS & Welders	Specification of the Material	ASME Sec VIII div.-I & Supplementary Requirements	Radiography Results	NDE Level- III Personnel	Radiography test Reports	Verification by Level-III or Level-II
Selection of Consumable	ASME Sec-II Part-C	WPS & QPR	Chemical & Mechanical Results	Internal Inspector & Testing Lab	Accepted Material Reports	QA&QC/MS-01
Welding Execution	ASME Sec V-III Div.-I & ASME Sec-VI	Drawings & Client Specifications	Visual & Radiography Results	Welding Engineer, NDE Level-II & III	Welder Performance Sheet	Inspection Reports

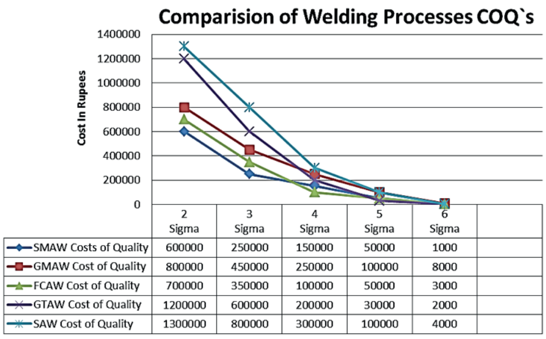

Figure 13. Welding Processes Cost of Quality Analysis

3.5. Control Phase (Control the Improved Process)

Table 13 shows the welding process control plan that was developed to ensure the consistent and to effectively implement the control measures.

After satisfaction from the project outcome and achievement of its main objectives, the project was closed. Conclusions that can be drawn From Six Sigma Project are the following

4. Conclusions

PWI is the welding Facility that is equipped with modern and up to date welding technologies. A quality of welds being produced in the facility are the prime concern for the Upper management of the Company, because that defines the Overall Quality of welding Facility and also explains how reliable are the welds. From the past one year this Company is facing quality defects in its welding projects, due to which a Six Sigma Project was selected for Implementation. The Five Phases of Six Sigma were implemented and results were obtained to Bring Quality Improvement in Welding Processes. Shielded Metal Arc Welding was found to be at lowest Sigma level so efforts were made to Analyze Source of variation for SMAW process. After obtaining optimum process Settings for SMAW process these were implemented and results were analyzed.

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