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Quality Improvement in Shielded Metal Arc Welding Process by Six Sigma Approach using DMAIC Methodology

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***Abstract:** Shielded metal arc welding (SMAW) is the easiest, least costly, and extensively used arc welding process. It is usually stated as 'stick welding' or manual metal arc welding (MAW). It yields permanent joint of metals by heating them with an electric arc between a flux coated metallic rod and the work piece. Shielding is provided by decomposing of the electrode covering. The key role of the shielding is to guard the arc and the hot metal from chemical reaction with elements of the atmosphere. The electrode outer layer contains fluxing agents, scavengers, and slag formers (1). Pressure is not used in the process, and the filler metal is obtained from the electrode. All ferrous metals can be welded in all positions using SMAW.*
***Keywords:** Shielded Metal Arc Welding, Manual Metal Arc Welding, Permanent Joint, Pressure, Filler Metal, & Heat.*

I. INTRODUCTION

A. Welding

It is an everlasting joining method utilized in the direction of connecting diverse resources like metals, combinations or plastics, collectively at their reaching faces by use of heat and pressure application. Amid welding, the materials to be fused are liquefied at the interacting edges and later hardening as a lasting effect can be seen. The assembled pieces that are fused by welding are called a weldment. It is mostly utilised in metal pieces and its alloys. Welding operations are categorized into two key groups:

1) *Fusion Welding:* In this practice, base metal is liquefied by means of heat. Frequently, in fusion welding processes, a filler metal is provided to the melted pool to aid the operation by preventing contaminates hence provides resistance and hardness at the joint. Frequent types of welding processes used are: arc welding, resistance welding, oxyfuel welding, electron beam welding and laser beam welding.
2) *Solid-State Welding:* In this practice, uniting of the pieces takes place by the use of pressure only or a grouping of both heat and pressure. Filler metal can or cannot be used here as per the need. Frequently used solid-state welding processes are: diffusion welding, friction welding, ultrasonic welding. Against the heat source it can be classified as below: Arc Welding, Gas Welding, Resistance Welding, High Energy Beam Welding, and Solid State Welding.

The figure 1 below provides the flow chart for better visualization of the process in brief:

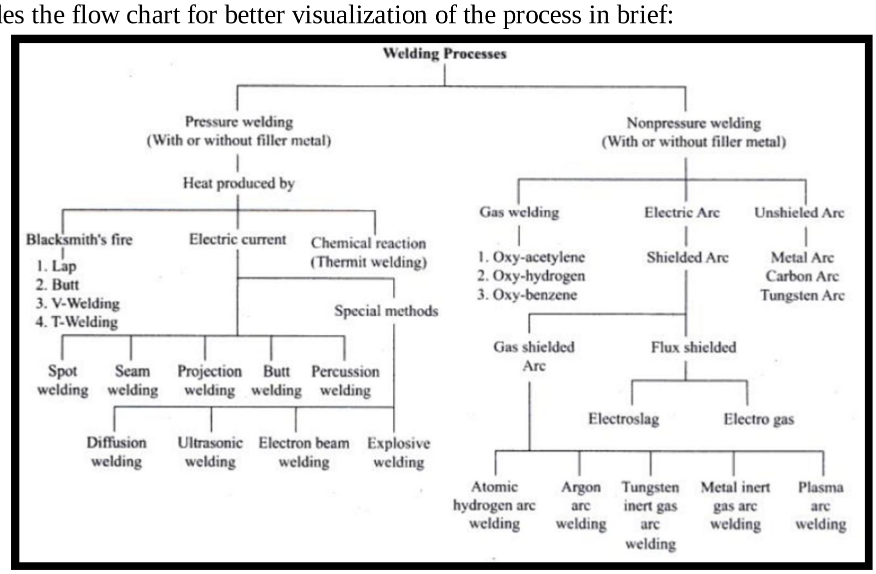

Figure 1: Classification of Welding Processes

B. Six Sigma

It is a quality improvement tool, utilized in almost every firms, striving for excellence. Overall it is disciplined and database managed approach methodology. It is centred on removing the flaws in any operation. It can be utilized in both area scope of product manufacturing and service providing businesses. The point here is to attain and keep up the 6 standard variations between the mean and nearby details constrain so as to limit the defect rate at the end of any operation. In standings to the statistical representation, we can say that it defines about how the whole work is actually acting. The operational work done essentially not yield more than three point four DPMO for any process to attain better Sigma Level. Any exterior work done against the desired client details is called as a defect.

The overall number of odds for a deformity can be stated as an opportunity. We will utilize these parameters to calculate process sigma. The usage of the technique that centres on operational advancement and variety control is the basic aim of the technique. This is going to be accomplished by methodically utilizing the elementary sub-methodologies which are DMAIC and DMADV. The DMAIC stands for - Define, Measure, Analyse, Improve, Control - It is a transformed framework for present forms coming under the desired purpose and examining for improved advancement.

The DMADV stands for - Design, Measure, Analyse, Design, and Verify - It is an enhancement framework utilized to create modern forms in the whole process. In our case we will be using the DMAIC approach. We will be working under six sigma DMAIC technique.

II. LITERATURE REVIEW

A. Tushar N Desai and Dr. R L Shrivastava (2008) [1]

They talked about the quality and yield enhancement in an industrial venture through an event taken under research work. These research works on the application of Six Sigma DMAIC tactic in an organisation which offers a system to distinguish, assess and dispose of causes of variety in an operating practices, in address to enhance the process factors, progress & maintain execution viz. operational output with fine implemented control tactics. The method outcome was moved forward as an outcome of executing this technique. It has impact on progress and is way superior in use of the assets & controls most of the varieties in the process. It moreover helps to maintain consistent quality in the method yield as an output result.

B. Adan Valles et. al (2009) [2]

He has utilized Six Sigma DMAIC technique in a semiconductor industry devoted in production of the cartridges of inkjet printers. They actually have verified it through electrically within the last phase of the method evaluating electrical properties to acknowledge or dismiss the same. Amid data collected they found out that the Electrical problems were almost 50% of all faults. Hence it was needful to lessen the range of faults by setting up the most issues, sources and activities. They decided the main variables, distinguished the optimal ranks or tolerance limit and advancement chances. The advancement was lessening within the electrical faults of about 50%. The comes about appeared that with appropriate use of this technique, & backing for the groups present in the company, a worthwhile effect on the quality & added highlighting points vital to the client fulfilment can be attained in best way.

C. Prof. Dr. Vidosav MAJSTOROVIĆ, et. al (2010) [3]

He has utilized DMAIC technique in definite Serbian metal treating producing business. What actually he accomplished over his work was the lessening of operational variations, hence decreasing the amount of non-conformity items. It is driven to extend of the process sigma level for the watched industrial scheme or practises & client fulfilment.

D. E. V. Gijo, Johny Scaria and Jiju Antony (2011) [4]

Talk about the Six Sigma in reference to the event taken under research of Grinding Operations. The foremost objective of DMAIC methodology is to unravel the basic issue of lessening operational variability and progressing the method productivity output. It concisely explains about how a production operations can be benefited through an efficient utilization of DMAIC technique to proceed to topnotch quality state. The use of the technique brought about the reduction of the defect rate within the fine grinding operations from 16.6 to 1.19%. Moreover, it provided a noteworthy money related effect on the benefit of the organization. The improvement seen due to the saves found from preventing rework, decrease in the waste- scrap value, labor-hour drop, & better yield. This venture stated a saving of around US$2.4 million per annum.

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E. Hsiang-Chin Hung and Ming-Hsien Sung (2011) [5]

He make use of the DMAIC technique in a food corporation well established around Taiwan. Utilizing the technique, he unravelled a basic issue of reducing process variation. In this way he seems to reduce high imperfection or the defect rate related with it. The outcome seen are lower imperfection rate of little custard buns by 70% from the reference line up to its due. He has moreover shared his knowledge w.r.t the aspects that are mindful for realisation of Six Sigma.

III.OBJECTIVE

The objective here is to prevent the defect to happen and improve the overall quality of the SMAW process and its outcome. It can be understood in brief as:

A. To control and prevent the defect rate in the welding process.
B. To advance in the quality and productivity of the SMAW operations.
C. To improve knowledge and technical skillsets of workers and labours involved in the process regarding the Japanese quality concepts of Six Sigma DMAIC technique.

IV. RESEARCH METHODOLOGY

DMAIC is applied in the SMAW process to improve the overall quality by going through the welding operations in the local workshop setup. The process is elaborated stepwise as per DMAIC sequence in below for better understanding:

A. Definition Phase

Herein these point, define the aim, scope and operational background for both interior and exterior clients. There is a diverse instrument which is utilized to characterize stages like SIPOC, Voice of Client & Quality work execution. SIPOC utilised here is actually a statistical method used give brief information about flow of process. 6σ is a business improvement approach which concentrate on reducing the defects &/or reducing the cycle time and improving the customer-oriented quality. The data of components which was collected initially before application of 6-sigma instrument is utilized to calculate standard deviation and hence process capability.

Table 1 SIPOC Table for the SMAW process

Supplier	Input	Process	Output	Customer
Ador	Welding Electrode	SMAW	Welding Joint	Welding shop
3M & Krishna Trading	Emery Paper	Deburring	Plane Surface	Machine shop
Orion	DP Spray	NDT	Defect observed	Fabrication shop
BOSCH	Grinding Wheel	Grinding	Finished Surface	Machine shop
Smart Cut	Cut Rod	Cutting	Cut out workpiece	Welding shop
SAIL	MS Plate	Fabrication	Desired Welding Work	Fabrication shop

Defining of the specific requirements of the raw materials utilised in SMAW process undergoing:

1) Work piece Material Details

a) Material: MS Plate – Scrap Sample Plates – L x B x H = 70x50x8 mm (Approx.)
b) Full Plate Size: 5000 x 1250 x 8 mm (Length X Width X Thickness) {Standard}
c) Grade Specification: IS: 2062/2011, Mild Steel, E250, Quality C, ASTM-A-36
d) Application: Utilised for general structural works

2) Process Variables of Welding Operations

a) Current (I) = Variable (As per process need and requirement the current can be varied)
b) Voltage (Vfixed) = 415 V, Phase = 3, Frequency = 50 Hz, Current Range = 40 to 400 A

3) Welding Rod Details

1) Welding Rod - 3.15 x 350 mm (B x L), E6013 Bond MS Welding Electrode (Ador)
2) Ultimate Tensile Strength from welding rod - 430 to 540 MPa
3) Workable Grade - IS: 2062 & equivalent grades up to 20 mm thick work pieces
4) Quantity - 3 nos. required in the process (Max.)
5) As per BIS Coding - AWS A/SFA 5.1 = E6013 & IS 814 = ER 4211
6) General Purpose Electrode - For Welding Mild Steel and Low Carbon Steels (MSGP)
7) Classification: AWS A/ SFA 5.1: E6013
8) IS 814: ER 4121
9) APPROVALS: BIS

After the specification is briefed we have gone through SMAW process on five MS plates for which the outcome can be seen in below figure for better visualization of its physical state and its defect rate is further calculated afterwards.

Figure 2 - Five Welding Samples

Note: Data collected here is for the fourth sample out of the five for below analysis. Fourth is selected as it has significant variety of defects over five of the lot and we can only work out one at a time for major improvement in the process and respectively do the comparative study in the further upcoming stages of DMAIC. The data collected are as follows:

Table 2 – Defects found on the selected work piece

Sr.	Defects	Quantity of defects observed over selected work piece
		Selected Sample No. 4 - Physical Observations
1.	Spatter	56
2.	Blow holes	7
3.	Welding undercut	4
4.	Weld Burn	3
5.	Welding incomplete	1

Table 3 – Cumulative % of each defects considered for the experimental phases

Problem	Frequency	Cumulative frequency	Cumulative %
Spatter	56	56	79%
Blow holes	7	63	89%
Welding undercut	4	67	94%
Weld Burn	3	70	99%
Welding incomplete	1	71	100%
Sum total	71	-	-

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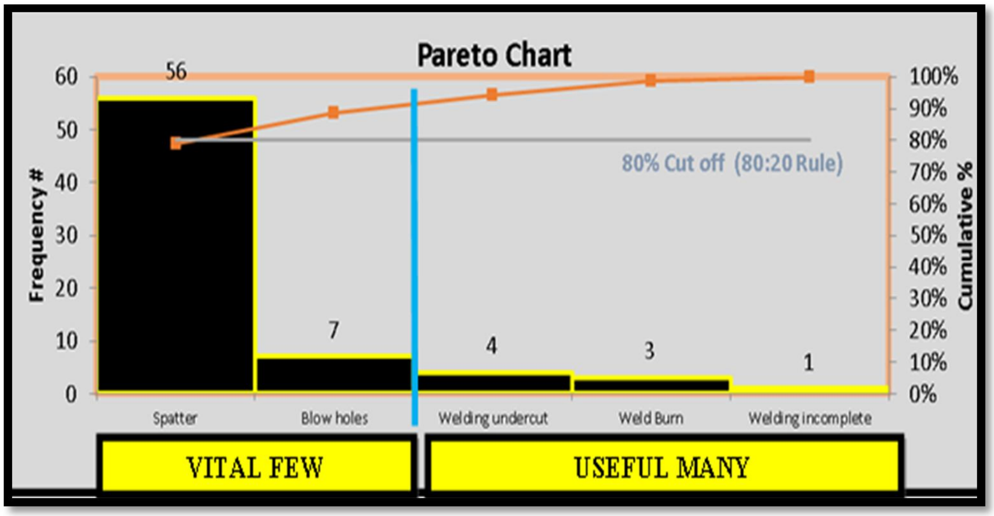
Figure 3 – Pareto Analysis for the above defects



We have utilised the pareto tool above as shown in figure 4.11, here the Pareto principle proposes that, for various occasion's, about 80% of the effect seen comes from 20% of the causes. In above, we observe that around 80% of the welding problems comes from 20% of the problem causes. As easily seen from the above pareto chart, it is clear that there are more severe and prioritized 80 % cases of spatter & somewhat blow holes conditions in the welding operations from above. It provides us with 80:20 partition or VITAL FEW: USEFUL MANY priority categorisation. If we workout to prevent the spatter and blow holes we can achieve better results as both are responsible for 80% of the overall defect problem here. Now as far as define phase goes, we have defined the basic raw materials, process parameters & other needful things. Now we can move forward to the 2nd step of measurement phase of DMAIC technique to measure the process rating accordingly to its physical conditions observed after SMAW process completion. So, we can say that in overall samples taken the significant defects which needed to be controlled on priority as per 80:20 principle is:

a) Spatter, &
b) Blowholes.

B. Measurement Phase

This stage grants the thorough operation mapping, process explanation, data collection plan, assessment of the present scheme, evaluation of the present level of operational yield, etc. The aim of this stage of 6σ DMAIC technique is to find the abundant data as likely on the current variable. Before moving on further we should know about Defects per Million Opportunities (DPMO) which can be characterized as the avg. no. of imperfections per unit seen amid an avg. generation course divided by the no. of chances to form an imperfection on the work piece taken into studying amid that work normalised to one million. We will measure & evaluate the process efficiency, productivity and quality by calculating its process sigma level. It will help us to further evaluate the welding work quality condition i.e.; on comparing step 2 (Measure phase) with step 5 (Control phase - last step). It will help us to assess the DMAIC technique on the SMAW process. A table is shown below having sigma level w.r.t DPMO. Further below you can see the formula to calculate DPMO against the SMAW process.

Table 4 – Sigma performance level (1 to 6) [8]

Sigma Performance Levels - 1 to 6 Sigma		
Sigma Level	DPMO	Yield %
0	9,34,000	6.6 %
1	6,90,000	31 %
2	3,08,000	69.2 %
3	66,800	93.3 %
4	6,210	99.4 %
5	230	99.977 %
6	3.4	99.99966 %

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Above table 4 shown is the basic chart which shows all six sigma levels wrt DPMO & its yield % respectively. One can only improve their sigma level & improve the yield % by reducing the respective DPMO seen within the process. 6,90,000 or above can be considered as of 0^{th} sigma level while DPMO in between 3,08,001 to 6,90,000 can be considered as of 1^{st} level and vice versa for other. DPMO can be calculated as per the formula provided below for reference:-

1) Defect (D) = Total no. of defected samples out of the process
2) Opportunity (O) = Total no. of sample size for the process
3) Defects per Opportunities (DPO) = D/O
4) Defects per Million Opportunities (DPMO) = (D/O) x 10^6 = DPO x 10^6
5) Final Yield % = (O-D)/O x 100

C. Six Sigma Level for Each Component

Now we have to evaluate & assess the welding process sigma level with its yield %. To do that we have evaluate the sigma levels of the selected sample pieces undergone welding work. It is observed that four were rejected out of five because of welding imperfections severity rate found in the work piece as it is not as per the quality standard specification and weld inspection report checklist. The quality is evaluated on the basis of checklist briefed in below in a tabulated manner: -

D. Checklists Followed for Rejecting Welded Material on Basis of Quality Checking:

Table 5 – Welding Inspection Quality Checklist

Weld Inspection Report									
PROJECT:			LOCATION:			DATE:			
Quality Inspection of Welded MS Sample Plates			Bhilai, CG			20.12.2019			
CODE OR SPECIFICATION:			BASE MATERIAL			WELDING ROD:			
Indian Standard (IS) - 2062/2011 & 814			Mild Steel, IS: 2062/2011, E250, ASTM A 36			MSGP - AWS A/SFA 5.1 = E6013 & IS 814 = ER 4211			
WELDING WORK:			Operator SKILL:						
Shielded Metal Arc Welding Operation			Welding & Cutting skill						
Weld Id. & Location	Accept	Reject	Spatter	Weld Burns	Incomplete Welding	Welding Uppercut	Blowholes	Total Sev. Score	Remarks
Before									
Sample piece 1		No	3	0	0	1	1	5	4 out of 5 is rejected due to high severity score rate ie; above value 4
Sample piece 2		No	2	0	1	1	1	5	
Sample piece 3		No	3	1	1	1	0	6	
Sample piece 4		No	3	1	1	1	1	7	
Sample piece 5	Yes		2	1	0	1	0	4	
Additional Notes/Comments:		a. Total Severity Level = Sum total of all five defects b. Here 0 – 4 rating stands for: 0= none, 1= trace, 2= minor, 3= marginal, 4=rejectable							
DPMO 1 = (4/5)*10^6 = 8,00,000		0 - None – Total Deformities = 0							
		1 - Trace - Total Deformities - Range is from 1 to 30							
		2 - Minor - Total Deformities - Range is from 31 to 50							
		3 - Marginal - Total Deformities - Range is from 51 to 60							
		4- Rejectable - Total Deformities - Range is from 61 to more							
		Note: If Total Severity Score is less than 5 then accept or else reject the weld sample							

Above is the general weld inspection checklist that are referred and followed during the welding work to check quality and find the imperfection severity of the finished good fabricated at workshop floor. It aids in inspecting the product & with it the concerned person can judge the SMAW work for accepting or rejecting the same. Ongoing through the above checklist table - 5 it is observed that there were four rejections out of the five sample work pieces. So, we are now going to calculate the actual SMAW process sigma level sigma as: -

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Table 6 – DPMO & Sigma performance level

Sr.	Component	Defects founds (D)	Sample Size (O)	DPO= D/O	DPMO = DPO X 10^6	Process Sigma Level		Yield %
						Excel Cal.	From Table 4.11	
1.	Work piece Samples	4	5	4/5 = 0.8	8,00,000	= - normsinv(0.8)+1.5 = 0.65838	1. 8,10,000 2. 0.60	20%

Figure 4 – Defects Observed in Rejected Welding Samples (S1) Taken (without paint)

To calculate the process sigma level more properly we can do it manually in a proper manner:

1) Process Sigma Level Can Be Calculated By Two General Methods

1st Method :-
Excel Formula Calculation :
= - normsinv(.33)+1.5
= 0.65838

2nd Method :-
Table Reference Calculation :
1. **For 8,10,000 – 0.60** (Near to 8,00,000)
2. For 7,80,000 – 0.70

2) Process Yield % Can Be Calculated For The Process As

Yield % = (O-D / O) X 100 = (5-4)/5 X 100 = 1/5 X 100 **= 20%**

3) Process Output

0th or 0.66 (To be exact) Process Sigma Level achieved without quality control work or 6 sigma application

1. PROCESS SIGMA LEVEL = 0.65838
2. PROCESS YIELD % = 20 %
NOTE: THE VALUES HERE IS WITHOUT 6 SIGMA APPLICATION)

Now we move further towards the step 3rd (Analysis Phase) after completing current step.

E. Analysis Phase

The 3rd stage of the technique contains the description of the key roots of the flaws & a RCA utilizing one of the tools such as the fishbone analysis signifying the priority of each causes using the tools such as the FMEA, WHY-WHY Analysis. Fishbone analysis is used here for discovering out the chief causes and its effects causing issues of spatter and blowholes. Further to analyse we need something to experiment & study so for it we used trial & error method on the MS plates; where we actually vary the welding parameters until we get the separate results out of the process for our study to analyse the causes through C&E and fishbone diagram. The basic parameters are defined below: -

Table 7 – Analysis of welding parameters during the welding process

Sr.	Welding Current (A)	Weld Length (mm)	Welding Voltage (V)	Polarity	Welding Gap (mm)	Phase	Frequency (Hz)
1	100	70	415 (± 10%)	Reverse Polarity	2 to 3 mm	3	50
2	105	70					
3	108	70					
4	110	70					
5	115	70					
6	118	70					
7	120	70					
8	125	70					
9	128	70					
10	130	70					

For analysing we have taken set of ten different current variables within working range of 3.15 mm rod as provided in the Table – 7. As seen from the relation it is clear that higher the current more will be the feed rate of rod which means directly proportional relation between the variables. We have fixed the gap, frequency, phase, polarity, and voltage factors here for our experimental study. Now we start our welding experiment i.e.; trial and error over the face of straight flat plate to check the best output out of the fixed range of current 100-130 A. Now here we observe the weld arc patterns over various current as allotted in table 7, then we check the time to cover the fixed length and respectively calculate the welding rod feed rate on further note.

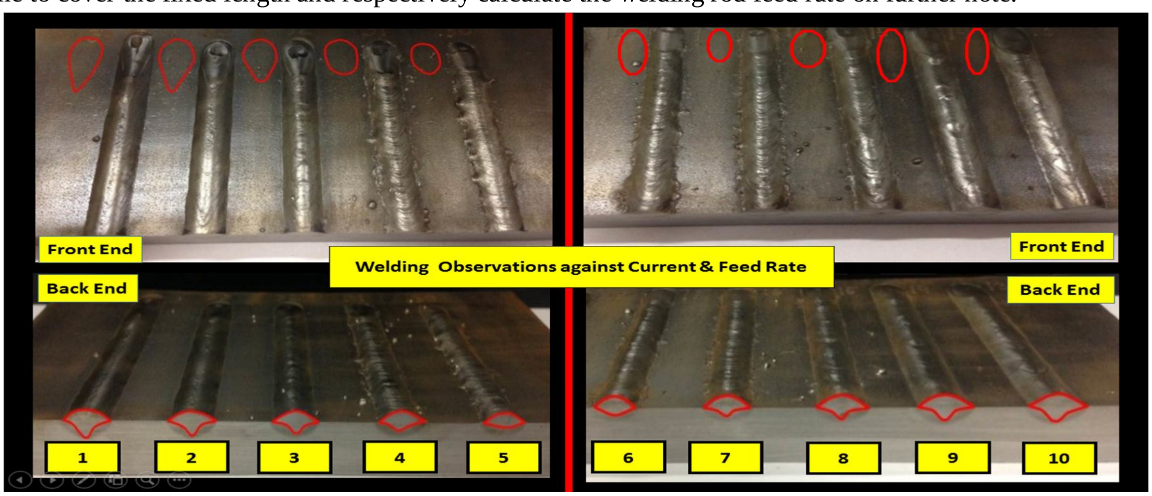
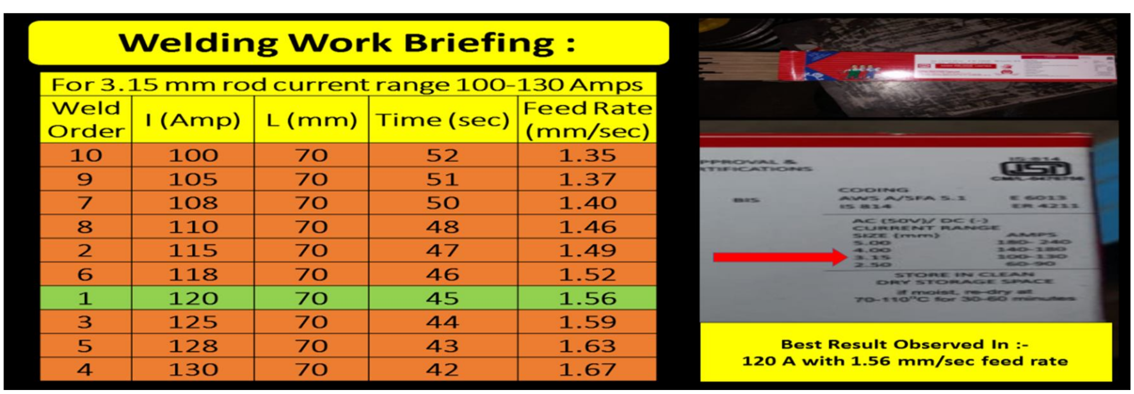


Figure 5 – Ten weld arc observations out of the SMAW trial & error method on MS flat plate



For 3.15 mm rod current range 100-130 Amps				
Weld Order	I (Amp)	L (mm)	Time (sec)	Feed Rate (mm/sec)
10	100	70	52	1.35
9	105	70	51	1.37
7	108	70	50	1.40
8	110	70	48	1.46
2	115	70	47	1.49
6	118	70	46	1.52
1	120	70	45	1.56
3	125	70	44	1.59
5	128	70	43	1.63
4	130	70	42	1.67

Figure 6 – Calculation of the specific feed rate with respect to set of ten variables of current and respective time duration taken in the welding experimental work

Based on process set ten current parameters the physical observations found are shown and depicted in figures 5 and 6 above. From the experiment we see that the weld arc seen is better in serial weld order 1st in the flat plate. Now we can lock the parameter 120 A and 1.56 mm/s feed rate for the next improvement phase by looking over the quality result.

Accordingly, the fishbone and Cause & Effect analysis for the defects observed above can be worked out for finding the causes to control, prevent and eliminate the issues associated within the welding process. The steps will be:

1) First we will start with the fishbone diagram for analysing the five common defects seen namely: spatter, weld burn, welding incomplete, welding undercut and blow holes.
2) Secondly, we will analyse the cause and effect on basis of personal, material, measurement, environment, method, and machine.
3) After finding the significant causes we will control and prevent it from happening repetitive or in a recurring manner. By tracking and tracing each of the causes we will going to rectify the bad effects in each of the cases one by one on a later improvement & control phase.

The fishbone diagram of each is depicted below:-

Figure – 7 - Fishbone Diagram for Spatter

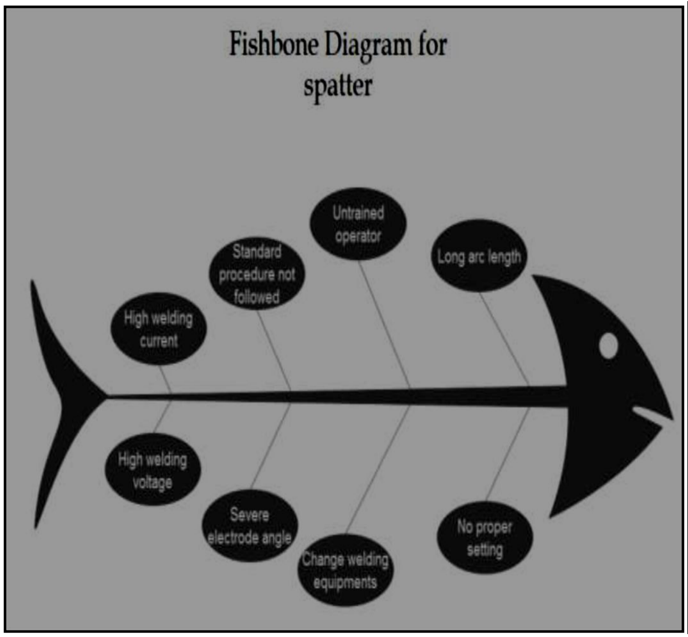


Figure – 8 - Fishbone Diagram for Weld Burn

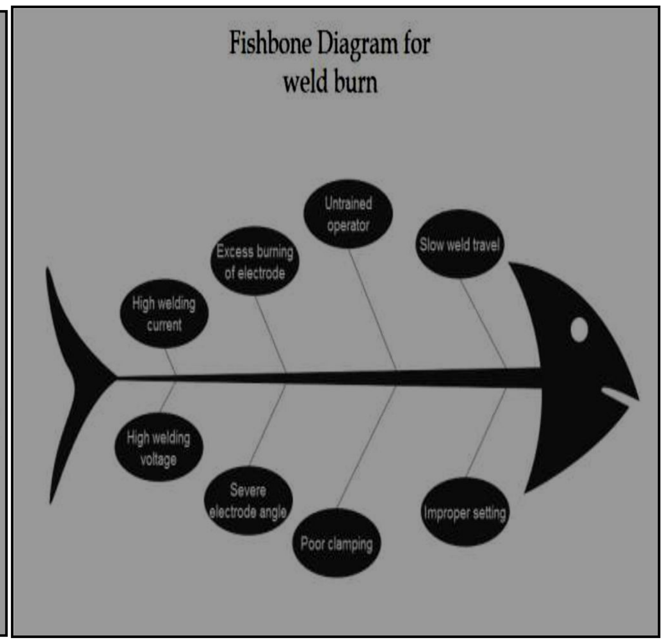


Figure – 10 - Fishbone Diagram for Weld Burn

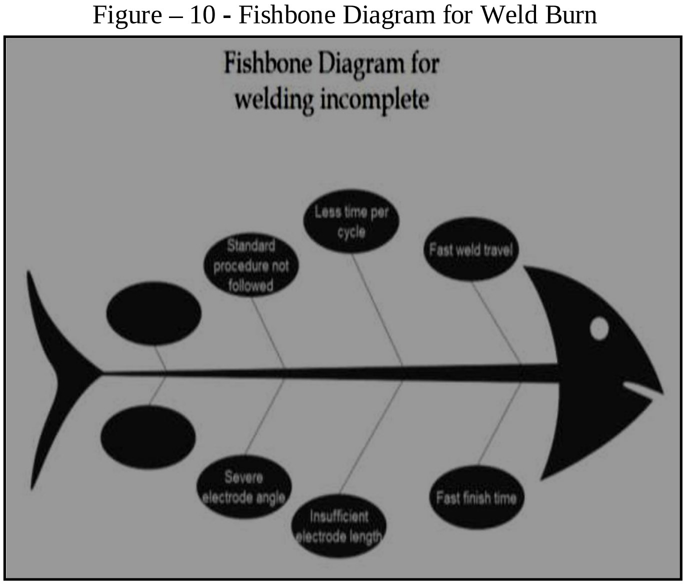


Figure – 11 - Fishbone Diagram for Weld Burn

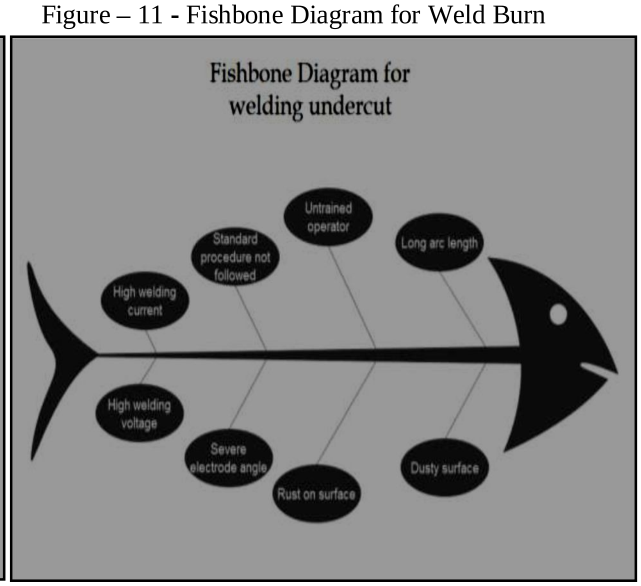


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Figure – 12 - Fishbone Diagram for Weld Burn

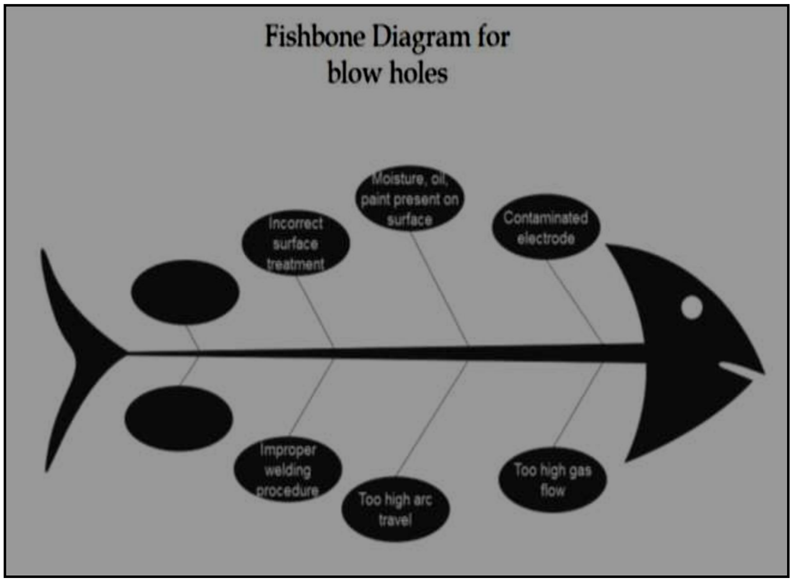
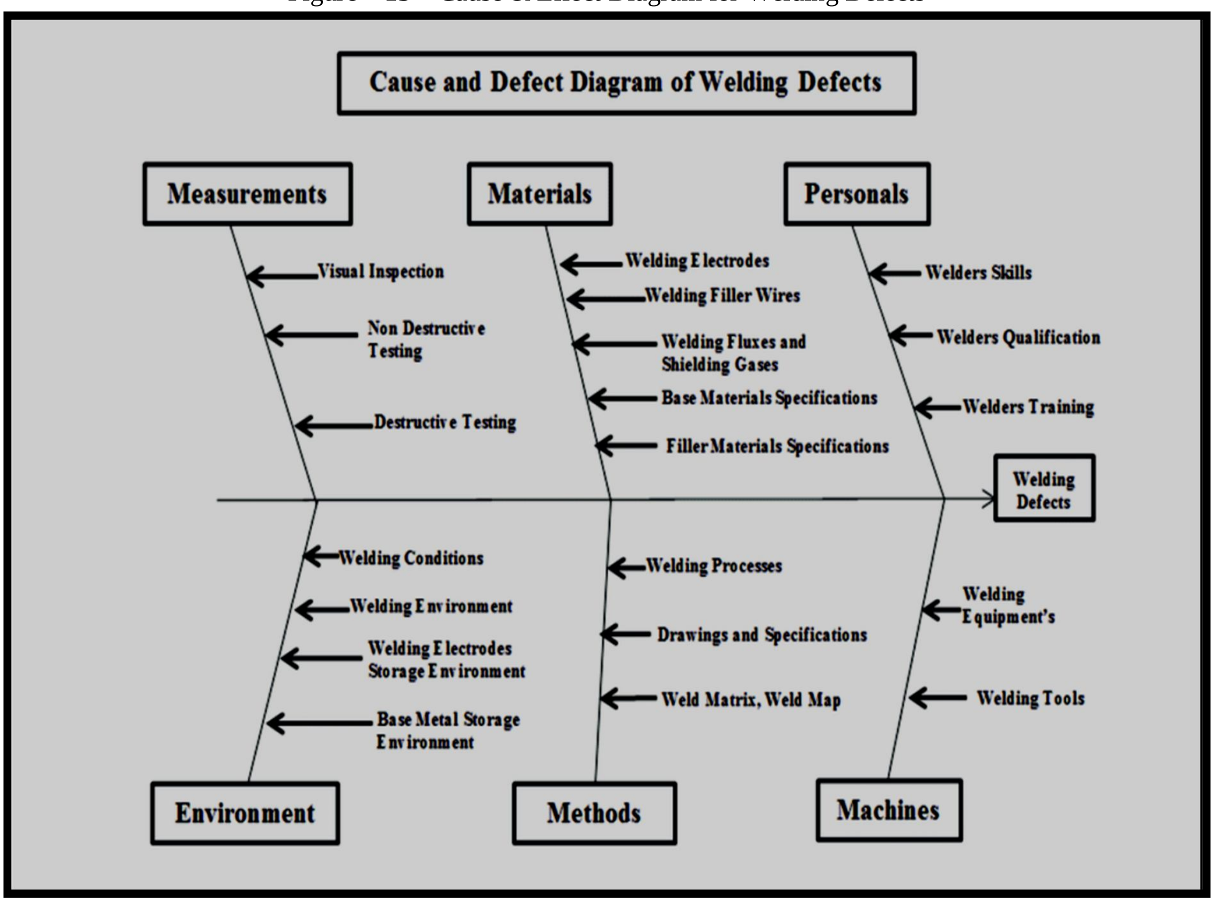


Figure – 13 – Cause & Effect Diagram for Welding Defects



We have analysed the causes associated with man, method, machine, environment, material, & measurement into care, other than fishbone defect analysis. It will help in finding the root cause on further level for eliminating worse effects to happen repetitively. To analyse the changes before & after DMAIC we have used further the FMEA method which provides us the score to assess the process output before & after as: -

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F. Failure Mode Effect Analysis (FMEA)

FMEA is a way for analysing possible issues prematurely in the progress cycle where it is much easy to execute work to resolve these problems, thus advancing reliability, productivity, efficiency & respective process sigma level through it. It is actually a logical approach utilized to guarantee the possible issues that has been well-thought-out & sorted out properly on the product and process development cycle. Let's discuss the three basic parameters before calculating the scores further: -

1) *Step 1:* Occurrence or Probability of failure

Here it is essential to seek the causes of an issue means & the no. of times it happens. It can be work out by viewing at alike goods or operations & the failure means that is recorded for them in the past. The failure source is viewed as a design flaw. Entire possible reasons for a failure means should be known & recorded properly. The failure means w.r.t intensity or impact factor is specified as occurrence (O) ranking from 1–10. Work here needed to be recognized if the occurrence is very high, high, moderate, low & remote. It is grounded on goods produced and client desired description.

Table 8 – Occurrence Matrix Chart

Probability of Failure	Failure Occurrence or Probability	Ranking
Very High: Failure is almost inevitable	>1 in 2	10
	1 in 3	9
High: Recurring failure	1 in 8	8
	1 in 20	7
Moderate: Infrequent failure	1 in 80	6
	1 in 400	5
	1 in 2,000	4
Low: Comparatively few failure	1 in 15,000	3
	1 in 150,000	2
Remote: Failure is unlikely	<1 in 1,500,000	1

2) *Step 2:* Severity

Finding the entire failure means centred on the useful necessities & its impacts. Ex. of it are: short circuits, deformation etc. A failure means in single piece can results into the failure means in additional piece, thus each issue means it must be registered in technical manner & for the respective purpose. Henceforth the vital outcome of each fail issue means it required to be addressed properly. A fail impact can be briefed as the outcome of a failure means on the task done as seen by the end operator. So, in a manner it is suitable to set these impacting causes in a way as per the end person might realise it or feel it. Ex. are: lower yield, wound to a worker etc. Every outcome is specified a severity no. (S) From 1 (no danger) to 10 (critical). The no. aids a user to rank the failure means and their out coming impact. In case the sensitivity of an effect has a no. 9 or 10, activities are reflected to vary the design by rejecting the fail means, if possible, or shielding the person from its impact. A severity range of 9 or 10 is usually kept for hazardous or harmful impact as shown in below table.

Table 9 – Severity Matrix Chart

Effect	SEVERITY of Effect	Ranking
Harmful lacking warning	Very high severity it is seen where the potential failure means can affect the safe working processing without warning	10
Harmful with warning	Very high severity it is seen where the potential failure means affect the safe working processing with warning	9
Very High	Operation unworkable with damaging failure without compromising safety	8
High	Operation unworkable with equipment damage	7
Moderate	Operation unworkable with minor damage	6
Low	Operation unworkable without damage	5
Very Low	Operation workable with substantial degradation of yield	4
Minor	Operation workable with some degradation of yield	3
Very Minor	Operation workable with minimum interference	2
None	No effect	1

3) Step 3: Detection

After suitable activities are decided, it is vital to check their usefulness. Additionally, the design confirmation is required. The right evaluation strategies got to be chosen. To begin with, we ought to see at the current parameters of the related context, that avoids the fail means from occurring or which identify the fail means some time recently it comes to the client. In the future one ought to recognize testing, investigate, observe & further methods that is utilized on same frameworks to identify the fail cases. The controls here for the end-user can be utilised for the failure so as to get recognized or identified. Every combo from the past two phases gets a detection no. (D). It prioritizes the capacity of arranged checks & assessments to eliminate flaws or identify fail means. The allotted detection no. events the danger that the fail case gets to escape from the detection range. A higher detection no. shows that the odds are more for the failure to escape the detection, or in other words, that the odds of detection is lower.

Table 10 – Detection Matrix Chart

Detection	Likelihood of DETECTION by Design Control	Ranking
Absolute Uncertainty	Design control cannot identify the possible reasons & consequent failing means	10
Very Remote	Here there is a very remote possibility of the design control that it will sense possible reasons & consequent failing means	9
Remote	Here there is a remote possibility of the design control that it will sense possible reasons & consequent failing means	8
Very Low	Here there is a very low possibility of the design control that it will sense possible reasons & consequent failing means	7
Low	Here there is a low possibility of the design control that it will sense possible reasons & consequent failing means	6
Moderate	Here there is a moderate possibility of the design control that it will sense possible reasons & consequent failing means	5
Moderately High	Here there is a moderately high possibility of the design control that it will sense possible reasons & consequent failing means	4
High	Here there is a high possibility of the design control that it will sense possible reasons & consequent failing means	3
Very High	Here there is a very high possibility of the design control that it will sense possible reasons & consequent failing means	2
Almost Certain	Here it will certainly sense the possible reasons & consequent failing means	1

Now we move further to compute RPN (Risk priority number) score from above three parameters defined. The main purpose here was to reduce RPN score & improve the welding process here. The plan was depicted in the below figure: -

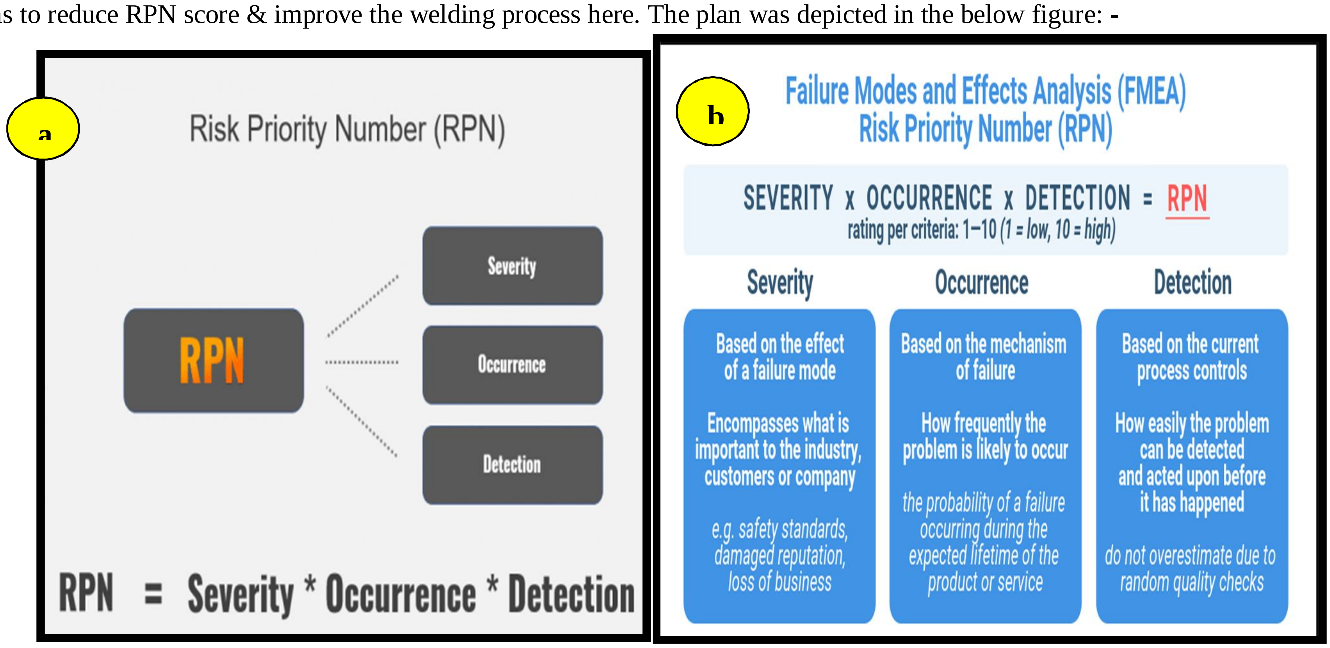

Figure 14 – RPN Mapping Process (a & b)

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Table 11 – FMEA Matrix for Welding Process (Before)

Cause Effect Matrix 1						
Work Catg.	Sr	Cause(X)	Severity	Occurrence	Detection	RPN Score
Welding Process	1	Work piece quality	5	4	5	100
	2	Cleanliness	3	5	2	30
	3	Quality of burr/ polish/grinding wheel	6	6	4	144
	4	Gas Cylinder Purity (LPG, Oxygen)	6	7	5	210
	5	Welding rod quality (E6013)	7	8	5	280
	6	White/Banyan cloth for cleaning	3	5	4	60
	7	Holder Angle	4	3	2	24
	8	Holder Condition	4	3	3	36
	9	Shielding & trailing line quality	5	3	3	45
	10	Arc Blow	7	2	6	84
	11	Change in current	9	5	2	90
	12	Voltage Fluctuation	9	5	2	90
	13	Manual Adjustment of Holder	4	5	2	40
	14	Feed rate	9	3	4	108
	15	Welder Skill	8	5	4	160
	16	Grinding quality	5	4	3	60
	17	Wire Brush Cleaning	3	4	3	36
	18	Welding Gap	6	3	4	72
	19	Weld penetration depth	4	1	8	32
Sum Total Score =						1701

By utilising the above chart, we can find the overall score of the welding process by: -

1) RPN Score = Severity X Occurrence X Detection
2) RPN Score 1 = 1701 …………… (Score 1) (Sum of scores from Table 13 - Before)

In here we need to focus on lowering the RPN score 1 further by reducing the above relative causes i.e. occurrence & detection. Here we have analysed all these to prevent and control defects rate further during the welding operations. More score results into lower quality rating and lower score results better quality results. By using these we can overall improve the operation efficiency and quality in a better way. Now we have to move towards the next step i.e.; improvement phase where we take the necessary measures towards the analysed factors of causes found out in: -

a) Cause & Effect Diagram – Fig. 13,
b) Fishbone Diagram - Fig – 7 to 12, &
c) Failure mode effect analysis – Table – 11.

The factors mentioned here are such that if we work into it, the overall RPN scores will get reduced and further quality can be improved respectively so as to improve the process sigma level further at the end.

G. Improvement Phase

These stage has a purpose to discover & execute actions that would resolve the in-hand issue. Here objectives of this stage are to choose issue solution, identify the danger & execute the chosen solution. Essentially, the advancement must examine fundamental information grounded on brainstorming to form the leading solution. The stage centres on completely finding the main reasons recognised within the Analyse stage, with a resolution of any control or disposing of the reasons to attain revolutionary yield. Here we utilize inventive steps to determine improved tactics to do work way improved manner, low priced or quicker. Variations within the operations are done in a manner to keep the factors within the specified bounds. The values seen of the process parameters taken into study were found to be improper for the manufacturing process. Further studies about defects revealed that the defects occurring during manufacturing can be minimized by changing the process parameters to some extents. Table below gives the modified & improved values of the welding process parameters taken with reference to experiment done in analyse phase where we have found better output results.

Table 12 – Changes made for improving in the welding processes

Sr.	**Parameters**	**Specifications**
1	Welding Current (A) – $\mathbf{I_{fixed(Analyse\ phase)}}$	**120**
2	Welding Voltage (V) - $\mathbf{V_{fixed}}$	415 (± 10%)
3	Polarity	Reverse polarity
4	Welding rod travel feed rate (mm/sec) – $\mathbf{N_{fixed\ (Analyse\ phase)}}$	**1.56**
5	Welding Gap (mm)	2 to 3
6	Phase	3
7	Frequency (Hz)	50

Here we have taken following steps for quality improvement phase: -
Changes in welding parameters done as per above weld bead quality observations,

1) Followed & taken care of the identified sub-causes in Fishbone analysis for controlling spatter, weld burn, incomplete welding, undercut and blowholes defects,
2) Detailed specified diagram, SWP, checklist, quality safety measures, FMEA defined and followed during the current operations for improved work efficiency,
3) Worked out C&E diagram & resolved each points here for measurements, materials, personals, environment, methods, and machines related all certain variables.
4) To execute with safety specific safe working procedure is defined & followed for the whole welding process for overall improvement work without any incident or near miss during the work execution period.

The SWP for welding & cutting work has been defined & followed as mentioned in below to prevent any mishap during the SMAW work: -

H. Safety Operating Procedure (SOP)

1) General Safety

a) Workforces executing welding and/or cutting actions should be competent to do so.
b) Welding, soldering, and brazing workforces frequently are open to a no. of hazards, comprising the intense light created by the arc, poisonous fumes, and very hot materials.
c) Wear proper safety shoes, goggles, hoods with protective lenses, and other PPE's intended to avoid burns and eye injuries and to protect user from the falling objects. It is vital that the welders wear appropriate protective clothing, counting leather gloves, a closed shirt collar to protect the neck (especially the throat), a protective long sleeve jacket and a suitable welding helmet to prevent retinal damage or ultraviolet burns to the cornea, often called arc eye.
d) Welding cables shall be of good quality and maintained properly. A welding cable shall be terminated properly and more than one joint shall not be allowed in its entire length. The joint shall be made through proper junction box or lugs and properly insulated.
e) Carry out welding activity in well-ventilated areas to limit exposure to fumes. For welding and cutting in confined spaces, adequate ventilation and lighting shall be ensured. Special watch shall be kept for safety of personnel in the confined space.

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f) The welding or gas cutting process produces ultraviolet radiation, which can cause a form of sunburn and, in a few cases, trigger the development of skin cancer.
g) Welders are also often exposed to dangerous gases and particulate matter. Shielding gases can displace oxygen and lead to asphyxiation.
h) A fire extinguisher/ Water should be ensured near welding/cutting work areas.
i) Flying sparks and droplets of molten metal can cause severe burns and start a fire if flammable material is nearby. Combustible material should be removed from the work area before welding/cutting activities are begun. Supervision is required if combustibles cannot be removed from the work area.
j) A non-combustible surface should be used to support work.
k) While carrying out welding and cutting work at elevated locations care shall be taken to see that falling of hot sparks, slags, cuttings, etc. do not endanger people and property at lower levels.
l) For stress relieving purposes, use of step-down transformer to have reduced and recommended voltage for such jobs shall be ensured.

2) Arc Welding & Cutting Practices Safety

a) The operator should be properly trained and qualified to use the arc welding.
b) Alternating-current manual arc welders should not exceed 80 volts; automatics should not exceed 100 volts. Direct-current manual or automatic arc welders should not exceed 100 volts.
c) Arc welders should be adequately insulated or should be protected so as not to shock personnel. The machine should also be grounded and the grounding mechanism should be periodically inspected.
d) When electrode holders are not in use, they should be placed so as not to make electrical contact with personnel or conducting objects.
e) Don't use the cables without proper lugs.
f) Don't lay the cable in between the path way or stairs.
g) Never take earthing directly from the equipment having load cell, bearings, gears etc.

Improvement done over the identified sub-causes found from the fishbone analysis from the figures provided below by preventing its repetition through preventive measures. They are: -

Table 13 – Preventive measures taken against spatter

Fishbone Analysis			
Sr	Defect	Causes	Preventive Measures
1	Spatter (Fig 4.31)	Long arc length	Maintained properly by focussing
2		Untrained Operator	Training provided
3		SOP not followed	SOP followed
4		High welding current	Current normalised to 120
5		High welding voltage	Voltage normalised to 415
6		Severe electrode angle	Proper angle maintained
7		Change welding equipment's	Checked old one & found ok
8		No proper setting	Proper setting done

Table 14 – Preventive measures taken against weld burn

Fishbone Analysis			
Sr	Defect	Causes	Preventive Measures
1	Weld Burn (Fig 4.32)	Slow weld travel	Maintained properly
2		Untrained Operator	Training provided
3		Excess burning of electrode	Taken care off
4		High welding current	Current normalised to 120
5		High welding voltage	Voltage normalised to 415
6		Severe electrode angle	Proper angle maintained
7		Poor clamping	Properly done
8		Improper setting	Proper setting done

Table 15 – Preventive measures taken against welding incomplete

Fishbone Analysis			
Sr	Defect	Causes	Preventive Measures
1	Welding Incomplete (Fig 4.33)	Fast weld travel	Maintained properly
2		Less time per cycle	Maintained properly
3		SOP not followed	SOP followed
4		Insufficient electrode length	Maintained properly
5		Fast finish time	Maintained properly
6		Severe electrode angle	Proper angle maintained

Table 16 – Preventive measures taken against welding undercut

Fishbone Analysis			
Sr	Defect	Causes	Preventive Measures
1	Welding Undercut (Fig 4.34)	Long arc length	Maintained properly by focussing
2		Untrained Operator	Training provided
3		SOP not followed	SOP followed
4		High welding current	Current normalised to 120
5		High welding voltage	Voltage normalised to 415
6		Severe electrode angle	Proper angle maintained
7		Rust on surface	Proper surface finishing done
8		Dusty surface	Proper surface finishing done

Table 17 – Preventive measures taken against blowholes

Fishbone Analysis			
Sr	Defect	Causes	Preventive Measures
1	Blowholes (Fig 4.35)	Contaminated electrode	Checked & taken care off
2		Moisture, paint, oil present on surface	Proper surface cleaning done
3		Incorrect surface treatment	Taken care off
4		Improper welding procedure	Maintained properly
5		Too high arc travel	Maintained properly
6		Too high current	Maintained properly

Improvement done over the identified sub-causes found from the cause and effect analysis from the figure 13 by preventing its repetition through preventive measures. They are: -

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Table 18 – Preventive measures taken against C&E measures

C&E Analysis				
Sr	**Effect**	**Cause**	**Sub-Cause**	**Preventive Measures**
1	*Welding Defects*	Personals	Welders Skills	Trained operator with welding skill is undertaken into work.
2			Welders Qualification	ITI qualified & skilled operator is taken into work execution.
3			Welder Training	Proper training is provided timely as per the schedule.
4		Materials	Welding Electrodes	E6013 fresh electrode is utilised everytime.
5			Welding Filler Materials	Properly utilised.
6			Welding Fluxes & Shielding Gas	Good flux quality electrode is utilised in welding work.
7			Base materials specification	Best feasible option of electrode wrt requirement is used in the process.
8			Filler materials specification	Filler material of electrode wrt work requriement is taken for welding work.
9		Measurements	Visual Inspection	Physical inspection done for checking about the quality of work to reduce defect rate.
10			Non destructive test (NDT)	Inspection done in non destructive way (DP testing) such that the work quality can be judged.
11			Destructive test (DT)	Inspection done in destructive way (UTM testing) such that to find out the tensile & compressive strength can be judged.
12		Environment	Welding Condition	Extra care is taken care of during the welding work.
13			Welding Environment	Dusty, moist, warm or cold environment has an direct impact over the welding work. So it is taken into extra care during the welding work.
14			Welding Electrodes storage equipment	Electrode quality during welding work gets impacted due to the storage condition of rod like in moist & dusty conditions. So it is taken into extra care during the welding work. Additionally sometimes workpiece gets heated to improve the welding quality.
15			Base metal storage environment	Workpiece weldable quality during work gets impacted due to the storage condition like in moist & dusty conditions. Workpiece surface needs to be cleaned & clear right before the welding of paint, corrosion, uneveness to improve the overall quality.
16		Methods	Welding Processess	Different processess or methods has different outcomes. So we modify the processess respective to it.
17			Drawing & Specifications	Welding should be done as per the specified drawing provided for the work.
18			Weld Matrix & Map	Should be followed to maintain quality work.
19		Machines	Welders Equipment	Should be kept always in check & addressed properly before starting of the work.
20			Welding Tools	Should be kept always in check & addressed properly before starting of the work.

By analysing & fixing the respective above causes from the fishbone and cause and effect analysis we now move forward to use FMEA & calculate the score again to check for the improvement by evaluating RPN score from before.

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Table 19 – FMEA Matrix for Welding Process (After)

Cause Effect Matrix 2						
Category	Sr.	Cause(X)	Severity	Occurrence	Detection	Score
Welding Process	1	Work piece quality	5	2	5	50
	2	Cleanliness	3	2	2	12
	3	Quality of burr/ polish/grinding wheel	6	1	4	24
	4	Gas Cylinder Purity (LPG, Oxygen)	6	2	5	60
	5	Welding rod quality (E6013)	7	2	5	70
	6	White/Banyan cloth for cleaning	3	2	4	24
	7	Torch Angle	4	1	2	8
	8	Torch Condition	4	2	3	24
	9	Shielding & trailing line quality	5	3	3	45
	10	Arc Blow	7	1	6	42
	11	Change in current	9	2	2	36
	12	Change in voltage	9	2	2	36
	13	Manual Adjustment of Torch	4	2	2	16
	14	Feed rate	9	1	4	36
	15	Welder Skill	8	2	4	64
	16	Tack grinding quality	5	1	3	15
	17	Wire Brush Cleaning	3	2	3	18
	18	Change in rod feed	6	2	4	48
	19	Weld penetration depth	4	1	8	32
Sum Total Score =						660

RPN Score 2 = 660 …………(Score 2) (Sum of scores from Table 25 - Before)

As seen from the RPN Score 1 & 2 comparison the quality is seen to be improved after analysis & preventive measure taken against it. The major factors that have seen to be varied here is the occurrence and detection, so as to improve the process. We now move forward to next step of control phase for DMAIC process completion.

I. Control Phase

Here we ensure that the operations endure its working in a healthy manner producing the wanted yield outcomes, & sustain the quality. It is actually maintaining the improvements which is attained by the work assigned crew. It is all about maintaining the positive variations made from the previous improvement stage to ensure long-term quality outcomes. Here finest control means are those that need no close observation or continuous care. Controls are needed to confirm that the improved developments are sustained over the period.

The improved operations is exposed to watch at consistent intervals of period to confirm that the main parameters don't display any intolerable changes. This phase includes implementation and periodic revaluation of changes made in process or process parameters through laborious and severe hit & trail method.

After changing the process parameters, the amount of imperfections was found to be reduced considerably. All above physical observations is taken into account and further taken into our weld inspection report. Here we try to focus on reducing the severity score of checklist by implementing required steps mentioned above.

Now here we are basically trying to further improve and sustain the best results by fixing current 120 A and taking five sample lot to select best out of five result in terms of significant feed rate. By finding it we will sustain the best results in the control phase so as to improve the overall process sigma level as final. Control phase output are shown in fig. 15 and comparative analysis of output is shown in table 20 weld inspection checklist.

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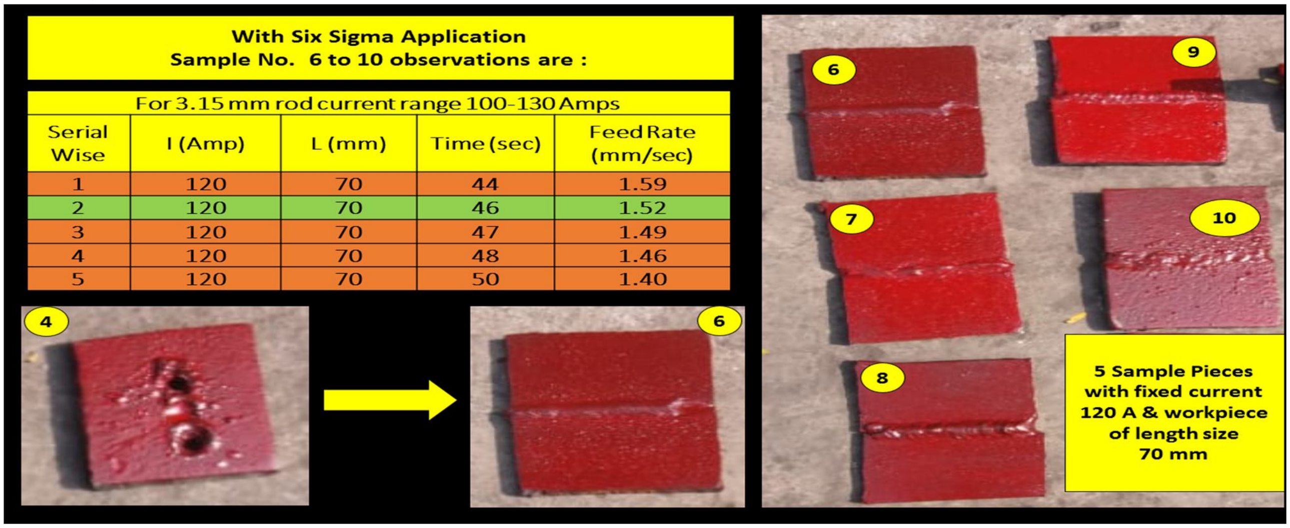

Figure 15 – Control phase five outputs

Table 20 - Before & after Comparison

Weld Inspection Report									
PROJECT:				LOCATION:					DATE:
Quality Inspection of Welded MS Sample Plates				Bhilai, CG					25.12.2019
CODE OR SPECIFICATION:				BASE MAT.					WELDING ROD:
Indian Standard (IS) - 2062/2011 & 814				Mild Steel, IS: 2062/2011, E250, ASTM A 36					MSGP - AWS A/SFA 5.1 = E6013 & IS 814 = ER 4211
WELDING WORK:				Operator SKILL:					
Shielded Metal Arc Welding Operation				Welding & Cutting skill					
Weld Id. & Location	Accept	Reject	Spatter	Weld Burns	Incomplete Welding	Welding Uppercut	Blowholes	Total Sev. Score	Remarks
Before									
Sample piece 1		No	3	0	0	1	1	5	4 out of 5 is rejected due to high severity score of defect rate
Sample piece 2		No	2	0	1	1	1	5	
Sample piece 3		No	3	1	1	1	0	6	
Sample piece 4		No	3	1	1	1	1	7	
Sample piece 5	Yes		2	1	0	1	0	4	
After									
Sample piece 6	Yes		1	0	0	0	0	1	1 out of 5 is rejected due to high severity score of defect rate
Sample piece 7	Yes		1	0	0	1	0	2	
Sample piece 8	Yes		1	0	0	1	0	2	
Sample piece 9	Yes		1	0	0	1	0	2	
Sample piece 10		No	4	0	0	1	0	5	
Additional Notes/Comments:		a. Total Severity Level = Sum total of all five defects b. Here 0 – 4 rating stands for: 0= none, 1= trace, 2= minor, 3= marginal, 4=rejectable							
DPMO 1 =(4/5)*10^6 =8,00,000		0 - None - Deformities = 0							
		1 - Trace - Total Deformities - Range is from 1 to 30							
		2 - Minor - Total Deformities - Range is from 31 to 50							
DPMO 2 =(1/5)*10^6 = 2,00,000		3 - Marginal - Total Deformities - Range is from 51 to 60							
		4- Rejectable - Total Deformities - Range is from 61 to more							
		Note: If Total Severity Score is less than 5 then accept or else reject the weld sample							

We see that there is a drastic improvement in the welding operations by taking the respective current from improvement phase. We see that with 120 A the 1.52 mm/sec sample work piece 6 shows promising output in SMAW welding process. The process sigma level are to be calculated further as per the table 20 findings i.e.; Calculation for the current phase. For it we again refer the welding checklist table 5 along with table 21. Here we have found out one rejection & further we evaluate the improvement after completing control phase: -

Table 21 – Improvement in DPMO & Sigma level

Statistics of The Defect Type - Sample piece 6 - Selected								
Sr.	Component	Defects founds (D)	Sample Size (O)	DPO = D/O	DPMO = DPO X 10^6	Process Sigma Level		Yield %
						Excel Cal.	From Table 4.11	
1	Work piece Sample	1	5	1/5	2,00,000	= - normsinv(0.2)+1.5 = 2.3416212	1. 2,00,000 2. 0.60	80

To calculate the process sigma level more properly we can do it manually in a proper manner:

1) Process Sigma Level can be calculated by two general methods

1st Method :-
Excel Sheet Formula Calculation :
= - normsinv(0.2)+1.5
= 2.3416

2nd Method :-
Table Reference Calculation :
1. For 2,12,000 – 2.30 (Near to 2,00,000)
2. For 1,84,000 – 2.40

2) Process yield % can *b*e calculated for the process as: Yield % = (O-D / O) X 100 = (5-1)/5 X 100 = 4/5 X 100 **= 80%**

3) Process Output: 2nd or 2.342 (To be exact) Process Sigma Level achieved without quality control work or 6 sigma application

1. PROCESS SIGMA LEVEL = 2.342
2. PROCESS YIELD % = 80 %
NOTE: THE VALUES HERE IS ACHIEVED WITH 6 SIGMA APPLICATION)

Output: 2nd or 2.34 (To be exact) Process Sigma Level achieved with quality control work or

J. Resulting Observation

Defect reduction after six sigma implementation is reduced from 4 to 1 defects out of 5 sample size. Process sigma level is upgraded from 0.658 to 2.342 (i.e.; 0th to 2nd sigma level). The process yield improved from 20% to 80% i.e.; about 60% improvement.

V. RESULTS AND DISCUSSION

A. Six Sigma – DMAIC Result, Effectiveness & Conclusion

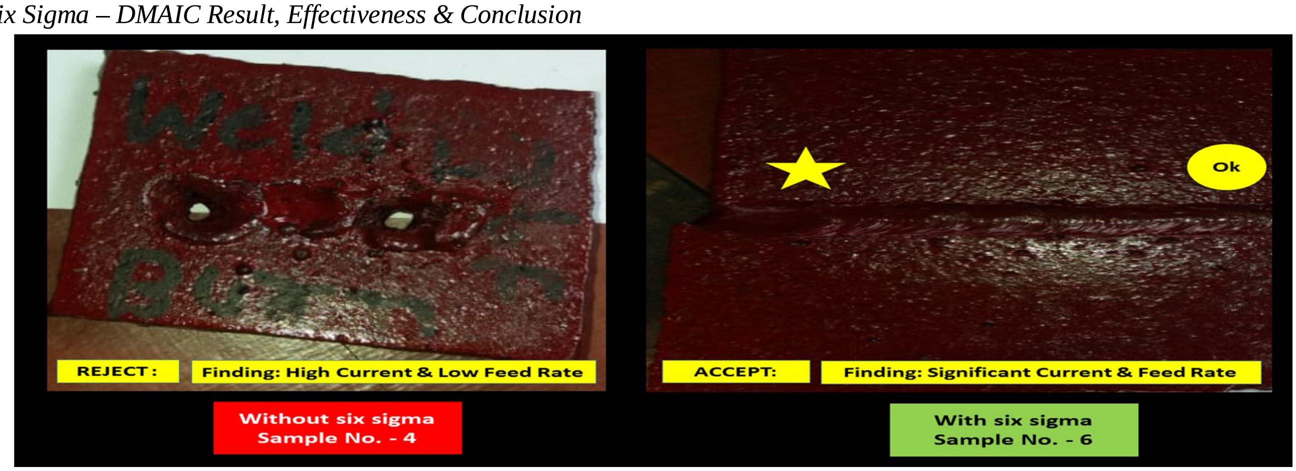

Figure 16 – Side by side comparison of selected sample 4 & 6 by taking table 4.21 parameters into care

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As observed from the above figure 16 it is clear that there is an improvement in the SMAW process which can be understood by checking out the below table 22 to assess the DMAIC work outcome in terms of defect improvement%. The observations are as follows: -

Table 22 – Before & after changes seen & its improvement %

Sr.	Defects	Defects		Improvement	Improvement %
		Before	After		
1	Spatter	56	27	= (56-27)/56 = 0.5178	51.78 %
2	Weld burn	3	0	= (3-0)/3 = 1	100 %
3	Welding incomplete	1	0	= (1-0)/1 = 1	100 %
4	Welding undercut	4	1	= (4-1)/4 = 0.75	75 %
5	Blow holes	7	2	= (7-2)/7 = 0.7143	71.43 %
Average improvement % over 5 defects = (Sum of $I_{1 \text{ to } 5}$ % / 500)					79.62 %

As per calculation seen in table 5.1, we can say that there is an improvement in each by: -

1) Spatter – 51.78%
2) Weld Burn – 100%
3) Welding Incomplete – 100%
4) Welding Undercut – 75%
5) Blowholes – 71.43%

Overall, we can say that there is a drastic improvement over spatter, incomplete welding and burns which has been achieved through a lot of efforts and study taken during the whole operations.

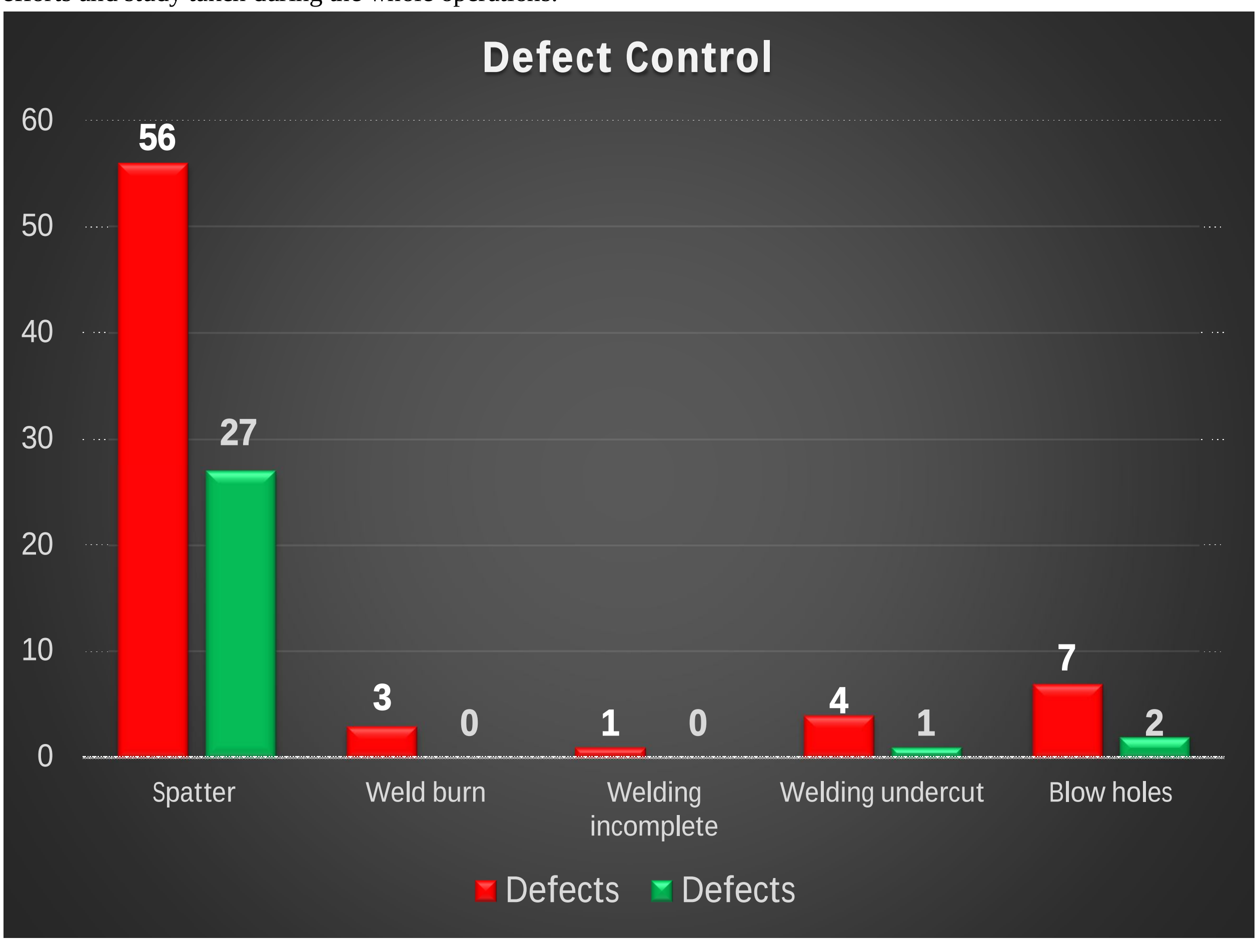

Figure 17 –Improved Results w.r.t defects

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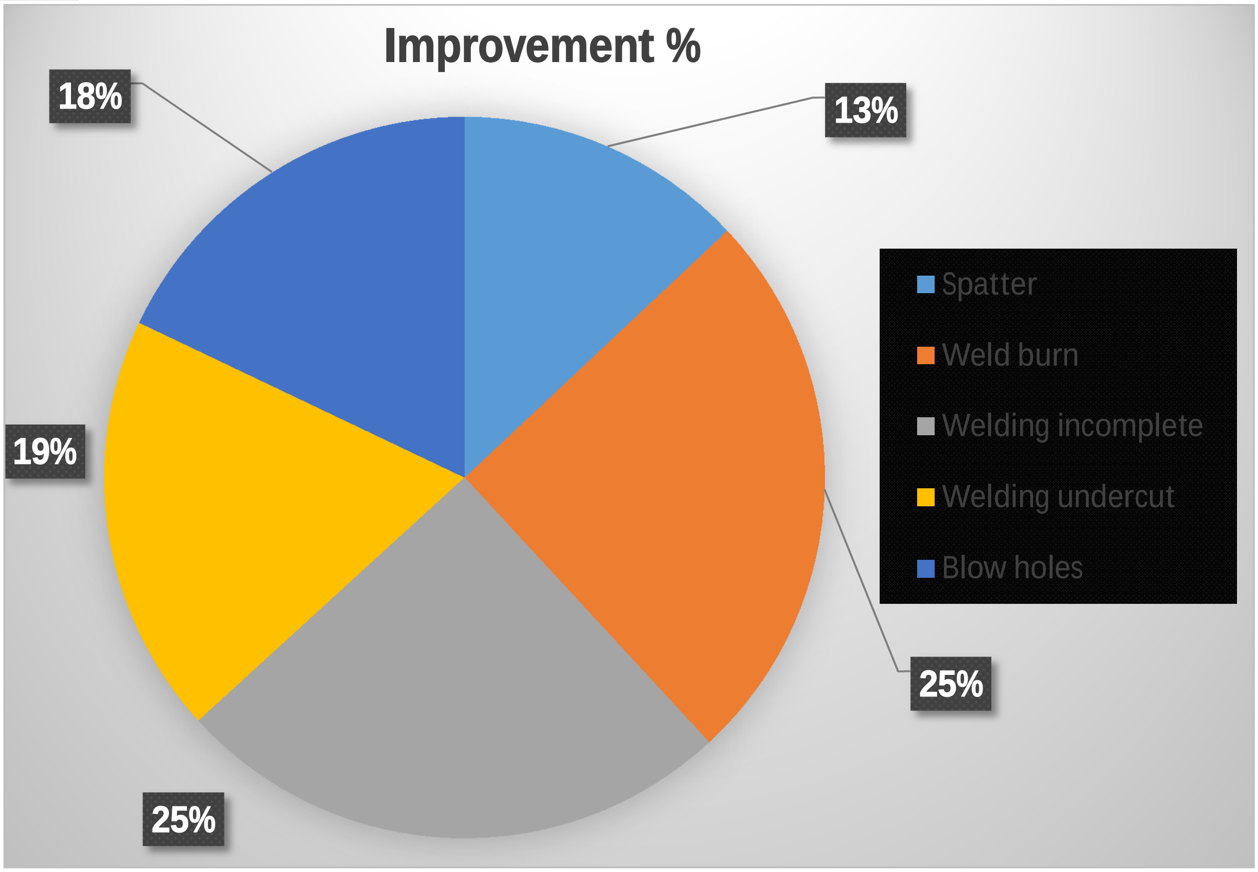

Figure 18 – Improvement% share of 5 defects over the 100% pie chart distribution

Here pie-chart shows % improvement of the five defects over 100% partition. As can be referred from above graphs that there is an improvement and control over the defect rate in the welding operations by following the standards and the positive initiative taken by the supervisor and the welding operator to work in a newer manner i.e.; from traditional method which is their comfort zone to an effective method approach. The DMAIC technique is completed herewith. Now we have to assess the final outcome after its implementation & again evaluate the process sigma level for SMAW operations.

B. *Effectiveness Analysis*

Imperfection rate of spatter & blowholes in SMAW operation is lessened meaningfully over applying the **6σ** DMAIC procedure in the workings of SMAW operations of sample taken.

1) The sigma level is improved from 0.658 to 2.342 i.e. from 0th to 2nd level,
2) The productivity has been increased by improving process yield from 20 to 80%,
3) The RPN score improvement seen from 17.01 to 6.6 accompanied with the cost reduction in operating man-hours & material consumption,
4) The production cycle found to be shortened due to less rejection or DPMO, and
5) The customer's fulfilment & the marketplace standings of the business will likely to improve substantially after implementing these in big scope.

Table 23 – Comparative analysis
(Units here shown are scaled lower to show the values in a single graph)

Six Sigma DMAIC	Process Sigma Level (PSL)	DPMO (In Lakhs)	Sigma Level	RPN Score (In hundreds)	Yield %
Not followed	0.658	8	0th	17.01	20
Followed	2.342	2	2nd	6.6	80

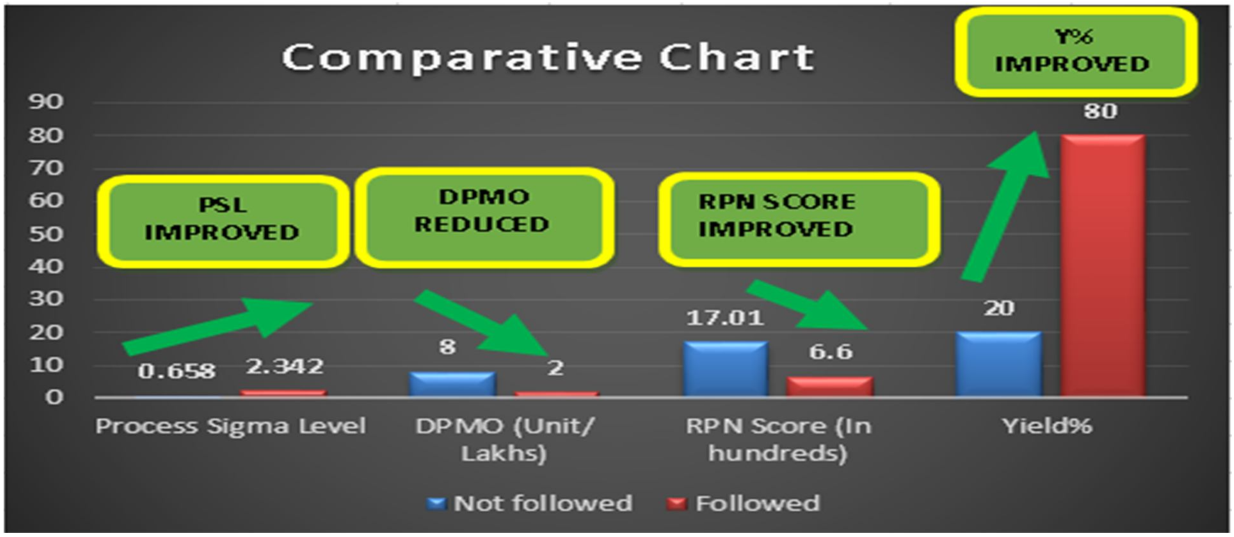

Figure 19 – Comparative chart analysis before and after 6 sigma implementation

6σ is an active means to discover out where the major operation wants array & which are the minor facts of the operation array is. Similarly, **6σ** delivers quantifiable pointers and sufficient information for systematic study.

VI. CONCLUSION

A. Outcome

Actually, in the process of refining the quality of the operations, two major imperfections i.e. spatter & blowholes are analysed and controlled in agreement with the 6σ. A range of tools of 6σ are utilized to resolve the issues seen. Decent amount of changes has been attained with the 6σ, which will offer as a case study or research reference for the others.

Systematic application of 6 Sigma & DMAIC technique within the SMAW process results into several conclusive achievements which can be seen as:

1) Reduced chances of failure rate,
2) Reduction in poor quality costs (PQC),
3) Control & prevent excess workers expenditures,
4) Enhanced client fulfilment level,
5) Reduced rejection rate,
6) Control rejection and thereby scrap rate,
7) Standardise the whole operations, &
8) Enhanced the knowledge level of operator.

B. Scope of Further Work

Additional exploration of study is thinkable in the view of what the individuals & corporate groups have to expense for attaining this excel state in their operations. Here there will be no improvements is feasible without accompanying the enhancement in the work routine. 6σ is a continuous enhancement process including all processes around the job area & adding the chances which are possibly accessible in the workroom.

On the way of advancing in the quality of SMAW process, two welding imperfections are given priority as per Pareto chart principle here i.e.; spatter and blowholes. They are analysed in respect with the 6σ technique. A range of tools of it are utilized here to resolve the issues. Positive results have been attained with the implementation of 6σ, which would offer references for further researchers or scholars in their studies.

There seems a scope to improvement on the present work by considering other type of defects, other techniques, other welding process (like MIG, TIG etc), study on composite materials or other metals, alloys over MS, study of products having complex size and shape, thereby making the research more wider & in-depth. Finally, the concept of six sigma is not restricted to a single process or two as it is a vital tool in overcoming the issue of lower quality output and low yield out of the process. It can lead to higher end result achievement if worked out properly in the area or scope considered for the study respectively.

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[11] Table No. – 5 & 20 - Inspection Checklists :- https://www.inspection-for-industry.com/welding-inspection.html

APPENDICES

1. Appendix A: Six Sigma Conversion Table required for calculating yield, DPMO & Sigma level

Six Sigma Conversion Table

Yield	DPMO	Sigma	Yield	DPMO	Sigma	Yield	DPMO	Sigma
6.6%	**934,000**	**0**	**69.2%**	**308,000**	**2**	**99.4%**	**6,210**	**4**
8.0%	920,000	0.1	72.6%	274,000	2.1	99.5%	4,660	4.1
10.0%	900,000	0.2	75.8%	242,000	2.2	99.7%	3,460	4.2
12.0%	880,000	0.3	78.8%	212,000	2.3	99.75%	2,550	4.3
14.0%	860,000	0.4	81.6%	184,000	2.4	99.81%	1,860	4.4
16.0%	840,000	0.5	84.2%	158,000	2.5	99.87%	1,350	4.5
19.0%	810,000	0.6	86.5%	135,000	2.6	99.90%	960	4.6
22.0%	780,000	0.7	88.5%	115,000	2.7	99.93%	680	4.7
25.0%	750,000	0.8	90.3%	96,800	2.8	99.95%	480	4.8
28.0%	720,000	0.9	91.9%	80,800	2.9	99.97%	330	4.9
31.0%	**690,000**	**1**	**93.3%**	**66,800**	**3**	**99.977%**	**230**	**5**
35.0%	650,000	1.1	94.5%	54,800	3.1	99.985%	150	5.1
39.0%	610,000	1.2	95.5%	44,600	3.2	99.990%	100	5.2
43.0%	570,000	1.3	96.4%	35,900	3.3	99.993%	70	5.3
46.0%	540,000	1.4	97.1%	28,700	3.4	99.996%	40	5.4
50.0%	500,000	1.5	97.7%	22,700	3.5	99.997%	30	5.5
54.0%	460,000	1.6	98.2%	17,800	3.6	99.9980%	20	5.6
58.0%	420,000	1.7	98.6%	13,900	3.7	99.9990%	10	5.7
61.8%	382,000	1.8	98.9%	10,700	3.8	99.9992%	8	5.8
65.6%	344,000	1.9	99.2%	8,190	3.9	99.9995%	5	5.9
						99.99966%	**3.4**	**6**

2. Appendix B: Pg- 9/22/23/15 of SAIL Brochure for MS Plates referred for basic specification

Applications

Specification	Application
IS: 2062/2011 ASTM-A-36	General structurals

Chemical Composition

Specification	Grade	C %	Mn %	P % max	S % max	Si %	CE
ASTM-A-36	–	0.25 max	0.80-1.20	0.04	0.05	0.15-0.40	

Mechanical Properties

Specification	Grade	Yield Strength, MPa, Min	Ultimate Tensile Strength, MPa, Min	Elongation % min GL5.65 $\sqrt{S_o}$	Internal diameter of bend
ASTM-A-36		250	400-550	200 mm GL -18 50 mm GL-21	

Chemical Composition IS: 2062/2011

Grade	Quality	Ladle Aalysis, wt % Max					Carbon Equi-valent, Max	Mode of Deoxidation
		C	Mn	S	P	Si		
E 250	A	0.23	1.50	0.045	0.045	0.40	0.42	Semi Killed/Killed
	BR, BO	0.22	1.50	0.045	0.045	0.40	0.41	Semi Killed/Killed
	C	0.20	1.50	0.040	0.040	0.40	0.39	Killed

3. Appendix C: Pg- 14 of Ador Welding Rod Brochure referred for E6013 Welding Rods specification

ador WELDING

E BOND

MILD STEEL GENERAL PURPOSE (MSGP)

General Purpose Electrode for Welding Mild Steel and Low Carbon Steels

CLASSIFICATION : AWS A/SFA 5.1	IS 814	APPROVALS :
E 6013	ER 4121	BIS

KEY FEATURES :

- Superior welding characteristics
- All position electrode
- Operates at low OCV
- Ideal for mild steel and low carbon Mn steel with UTS of 430-540 MPa

WELDING POSITION : AC (50 OCV min.)/ DCEN

TYPICAL APPLICATIONS :

- Sheet metal work
- Storage tanks
- Vehicles, Railway wagons
- Shipbuilding, Pipes
- Steel furniture
- General structural application
- Welding IS 2062 and equivalent grades upto 20 mm thick

CHEMICAL COMPOSITION OF UNDILUTED WELD METAL, Wt %:

	C	Mn	Si	S	P
Typical	0.08	0.35	0.25	0.02	0.02
Specification	0.10 max	0.2-0.5	0.30 max	0.03 max	0.03 max.

MECHANICAL PROPERTIES OF ALL WELD METAL :

	Condition	UTS, MPa	YS at 0.2% offset, MPa	EL%	CVN Impact at 27°C, J
Typical	As Welded	490	435	24	58
Specification		430-540	370-480	22-26	40-70

PARAMETERS - PACKING DATA :

Ø x L, mm	Amperage, A	Approx. Pcs/Carton	Carton/Box	Approx. wt. of 1000 pcs, Kg
2.5 x 350	60-90	150	6	17
3.15 x 350	100-130	85	6	29
3.15 x 450	100-130	85	6	36
4.0 x 450	140-180	55	6	56
5.0 x 450	180-240	36	6	87

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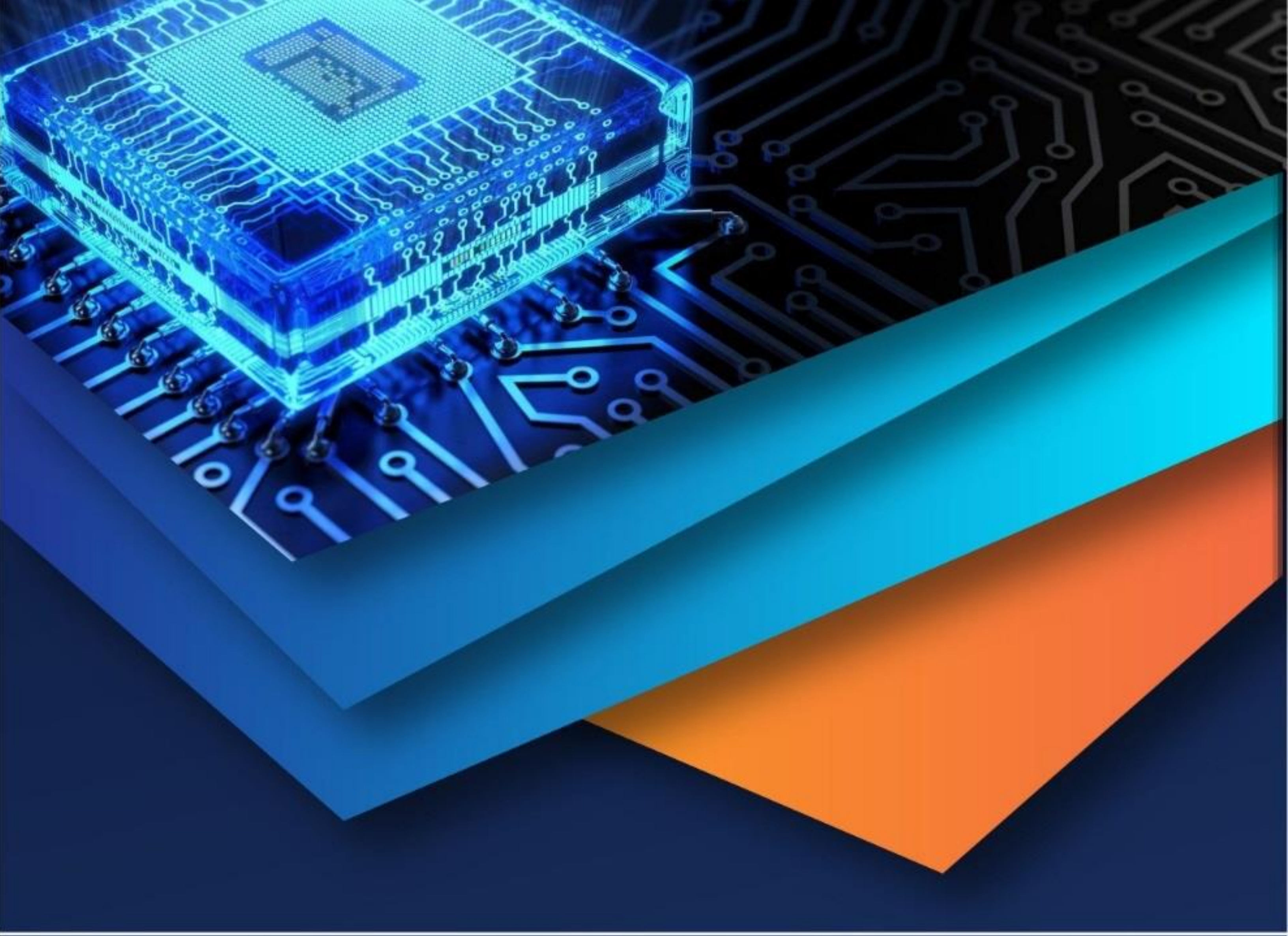

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