A Six sigma frame work for reduction of GTAW weld defect "Tungsten Inclusion" in a Nuclear piping Facility

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Abstract —
This paper demonstrates the implementation of Six Sigma in a nuclear piping facility of a Nuclear Research organization in India to reduce the GTAW defect of "Tungsten Inclusion" in SS pipe weld joints and thereby enhance nuclear safety and also reduce project overrun and rework cost. This study verifies the applicability of DMAIC methodology in implementing Six Sigma in GTAW process, a non-repetitive activity. The findings of the research suggests devotion of serious consideration to welders' skill, experience in GTAW and formal technical qualification in order to reduce 'Tungsten Inclusion' defect in GTAW process. Till date no comprehensive research has been undertaken to implement Six Sigma in GTAW process. The challenging issue of choosing the correct approach and tools and the nonexistence of research in this field motivated the study.

Key words: Six Sigma, DMAIC, DPMO, GTAW, Weld Defects, Tungsten Inclusion. IGCAR, Nuclear piping facility**I.**

INTRODUCTION

A. Six Sigma

Six Sigma is a business improvement approach that seeks to find and eliminate causes of mistakes or defects in business processes by focusing on process outputs that are of critical importance to customers (1). Six Sigma is a well structured data driven methodology for eliminating defects, waste, quality control problems of all kinds in manufacturing, management, service delivery etc. (2). Six Sigma is a "Business process that allows companies to drastically improve their bottom line by designing and monitoring everyday business activities in ways that minimize waste and resources while increasing customer satisfaction"; (3).

Six Sigma originated at Motorola in the early 80s and has since been applied successfully in numerous organizations having repetitive manufacturing processes. However, very little research has been done in implementing Six Sigma comprehensively in welding process.

Six Sigma uses DMAIC methodology for improving existing processes and DMADV approach for designing new processes/products. This research uses DMAIC methodology for implementing Six Sigma in the GTAW process to reduce "Tungsten Inclusion" defects.

Five phases of DMAIC methodology:

- ***D****efine* the problem, the process, the CTQ factor (Y) and Xs influencing the CTQ and the specific project goals.
- ***M****easure* current defect level and collect data on the possible Xs.
- ***A****nalyze* the data to investigate and verify cause-and-effect relationships between the Xs and the Y.
- ***I****mprove* the process by identifying and implementing solutions for the defects.
- ***C****ontrol* the improved process to prevent it from falling back to previous status.

B. IGCAR

Indira Gandhi Centre for Atomic Research [IGCAR], the second largest establishment of the **Department of Atomic Energy** next to Bhabha Atomic Research Centre, was set up at **Kalpakkam**, 80 KMs south of Chennai [MADRAS], in 1971 with the main objective of conducting broad based multidisciplinary program of scientific research and advanced Engineering, directed towards the development of sodium cooled Fast Breeder Reactor [FBR] technology, in India.

This research was carried out at one of their demonstration nuclear plant involving 62 kilometers of stainless steel (ASTM A312 TP 304L) web of nuclear piping welded by GTAW (Gas Tungsten Arc Welding) which will carry highly corrosive nuclear fluid. This paper is the third in the series of studies carried out focusing on Tungsten Inclusion as the earlier two studies were targeting on LF and OXI defects.

i. GTAW

Gas tungsten arc welding (**GTAW**), also known as **tungsten inert gas** (**TIG**) **welding**, is a welding process which uses a constant current power, tungsten electrode to produce arc for the weld and a filler metal. Fig.1 gives the process setting of GTAW. (4)

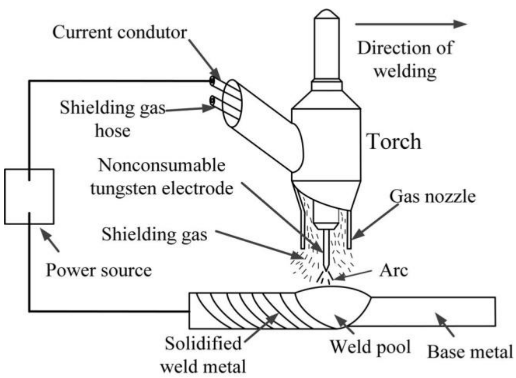

Fig.1 GTAW process setting

GTAW produces exceptionally good quality welds and is to weld thin sections of stainless steel and non-ferrous metals. The process grants the operator greater control over the weld than competing processes such as shielded metal arc welding (SMAW) and gas metal arc welding (GMAW), allowing for stronger, higher quality welds. However, GTAW is very complex slower process calling for greater dexterity and skill on the part of the welder. GTAW finds application in producing high quality joints in the nuclear, aircraft and food industries. In the nuclear piping facility under study, the dense web of pipes spanning over an altitude of 13 meters and the resulting congestion and abnormal positioning of the welder make the GTAW welding even more complex and demand ambidexterity on the part of the welder.

ii. Tungsten Inclusion

Tungsten Inclusion is a defect occurring in GTAW where pieces or particles of tungsten electrode get deposited in the weld reducing the strength of the weld. This mainly happens because of dipping of the electrode in the weld puddle and this contamination will have deleterious effects on the weld properties.

II. APPLICATION OF SIX SIGMA

A. DEFINE

The boundaries of the process were defined and the process of fabricating the ss piping facility was studied and a process flow chart was made (Fig.2)

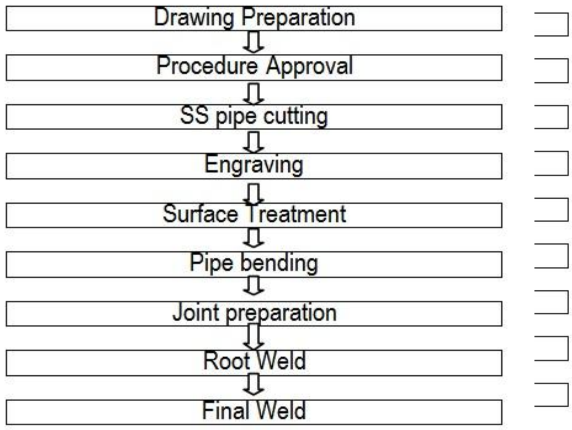

Fig.2 Process flow chart of piping fabrication

Discussions were held with the client / sub-contractor and the Quality assurance Division in order to understand the CTQ (Critical To Quality) characteristics of the process. Absence of discontinuity and non-thinning of material in the piping was identified as the CTQ as the corrosive nuclear fluid can escape and cause disaster. Criticality of this CTQ is enhanced by the fact that after commissioning of the plant no repair work can be attempted. As defective weld joints of the ss pipe can cause discontinuity, defect free GTAW welds were identified as the CTQ of the piping plant.

I. MEASURE

Data on the defects encountered during the fabrication of the piping facility was collected from 10316 sample weld joints and the base line sigma level was established. DPMO (Defects Per Million Opportunities) was calculated using the following formula.

$$DPMO = \frac{\text{Number of defects}}{\text{No. of welds X No. of categories of defects}} X\ 1,000,000 \qquad (1)$$

As there were 9 possible GTAW defect categories (Table 1) and as there were 439 defects that have been encountered in the sample welds chosen for the study, the DPMO was calculated to be 4728 and the corresponding Sigma Level was read from the table and established as 4.1 sigma which offers ample scope for improvement.

Table 1: GTAW Weld defect Categories

S.	Weld defects	Abbrvn.	Number
1	Lack of Fusion	LF	132
2	Tungsten Inclusion	TI	61
3	Under Cut	UC	46
4	Lack of Penetration	LP	43
5	Excess Penetration	EP	22
6	Distortion	DIS	2
7	Oxidation	OXI	93
8	Porosity	POR	35
9	Concavity	CON	4

In order to identify vital few defects from the trivial many, defect categories were prioritized using a Pareto chart based on the sample data (Fig.3).

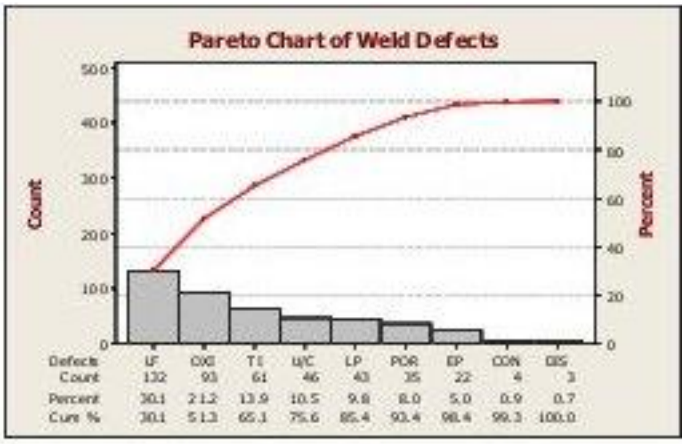

Fig.3.Pareto chart of GTAW defects

As it could be seen from the Pareto chart, it is the "Tungsten Inclusion" that has the highest occurrence accounting for 14% of the total defects, leaving out LF and OXI which have already been dealt with in the first two studies and have been covered in separate research papers.All possible causes for "TI" were identified through a Brain Storming session and the same are depicted in the "Cause and Effect diagram" (Fig.4)

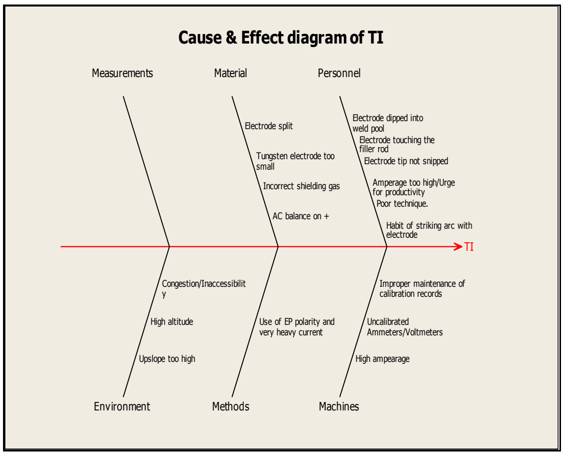

Fig.4 Cause and effect Diagram of TI

II. *Root Cause Analysis*

Root cause analysis was done to identify the significant few causes from among the exhaustive list of causes depicted in the Cause & Effect diagram. The causes were evaluated by their probability of occurrence in the fabrication environment at IGCAR, given the effective and exacting Quality Assurance Plans backed by well defined and tested procedures for every activity and stringent stage inspections during fabrication. Probability of occurrence of the different causes were estimated through an opinion survey among the experts of GTAW at IGCAR on a rating scale of 1-10, where 10 was "most likely root cause", 5 represented "may have an influence but not likely to be root cause" and 1 was "least likely". Based on the probability rating, it was decided to consider the following causes having a score of "7 and above" as significant root causes.

a) Congestion & inaccessibility
b) Welders' Experience in GTAW
c) Welders' Qualification
d) Migration from SMAW
e) Working at high altitude

There are totally 35000 weld joints in the demonstration plant. It was decided to collect data from the Weld Inspection reports and the radiography reports of weld joints on all the above variables from a sample of 10316 weld joints using systematic sampling method in order to give due representation to all the 4 altitude ranges. Data on welders' experience, qualification and migration status were collected from welders' database.

III. ANALYSE

Collected data on the above variables have been analyzed with appropriate statistical tests using Minitab. The tables and output of statistical tests are given below.

A. *Migration factor*

Table 2 : Tungsten Inclusion by Migration

Sl.No.	Migration status	No. of TI defects	Total Welds done	%
1	Migrated	29	2436	1.1
2	Direct	32	7880	0.4

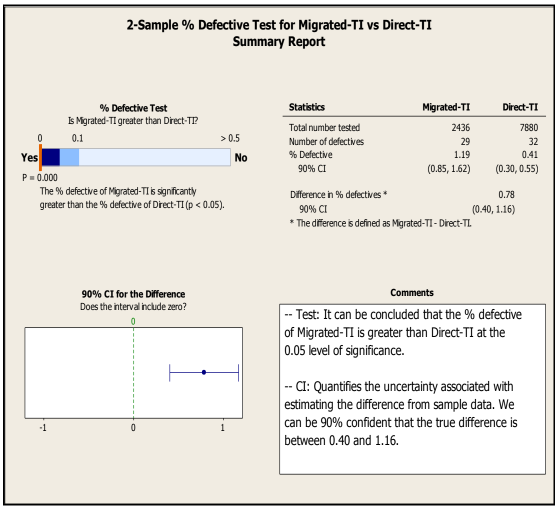

Fig.5 Two Sample % defective test of TI by migration

As the 'P' value is 0.00 which is less than .05 It can be concluded that the % defective of 'Migrated-TI' is greater than 'Direct-TI' at the 0.05 level of significance and there is association between migration status of welders and the quantum of 'TI' defects caused by them.

B. *Altitude*

The nuclear piping facility spans over an altitude of 12.5 meters. In order verify the psychological effect of working at heights, analysis was done to test the influence of altitude on TI defects.

Table 3 : TI defects by Altitude category

Altitude category in meters	Number of TI defects	TI %	Weld Joints (No.)
0 -2.5	6	0.5	1156
2.5 -4.5	27	0.6	4680
4.5 -7.5	14	0.5	2604
7.5 – 10.5	14	0.7	1876
Total	61	0.6	10316

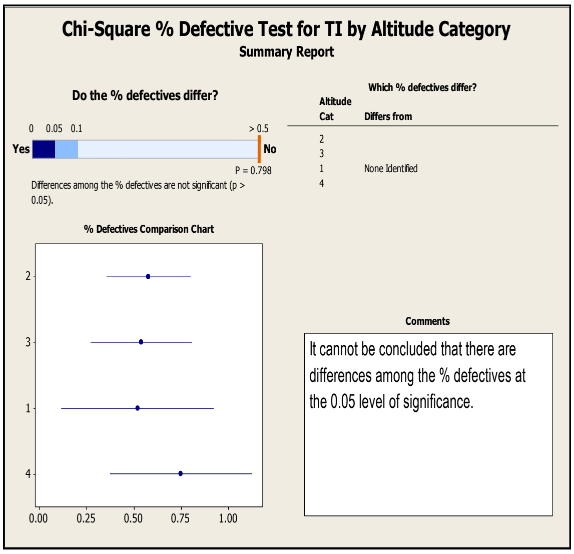

Fig. 6 Chi-Square % defective test

As the 'P' value is greater than .05 it can be concluded that there is no association between altitude and quantum of TI defects.

C. *Experience of welders in GTAW*

Table 4: TI defects by experience of welders

Sl. No.	Experience	Number of TI defects	No. of Weld Joints	%
1	>10 years	2	316	0.6
2	>8-10 years	10	2789	0.4
3	>6-8 years	17	2895	0.6
4	4-6 years	5	1878	0.3
5	<4 years	29	2438	1.2
	Total	64	10316	0.6

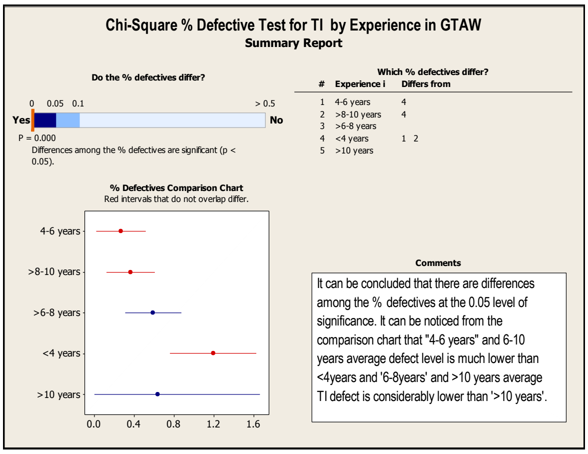

Fig.7 Chi-Square % defective test by experience

As the ‘P’ value is 0.00 it can be concluded that there is an association between Experience of welders and quantum of TI defects.

D. Educational Qualification of welders

Welders with 10th qualification and ITI qualification are performing the GTAW welding at the Nuclear piping facility. Analysis of the TI defects caused by welders with 10th and ITI qualifications revealed a significant association between qualification and quantum of TI defects as seen from the table No.5 and the result of the two proportion test. (Fig.8)

Table 5 : TI defects by Qualification of welders

Sl.No.	Qualifn.	Number of TI defects	Total Weld joints	%
1	10th	31	4711	0.7
2	ITI	33	5585	0.6
	Total	64	10316	1.3

Test and CI for Two Proportions of TI: 10th qualified Vs ITI

Sample	X	N	Sample p
10th	31	4711	0.006580
ITI	33	5585	0.005909

Difference = p (1) - p (2)
Estimate for difference: 0.000671660
95% CI for difference: (-0.00238947, 0.00373279)
Test for difference = 0 (vs not = 0): Z = 0.43 P-Value = 0.667
Fisher's exact test: P-Value = 0.707

Fig.8 Output of Two Proportion test I by Qualification

E. IMPROVE

Statistical analyses reveal that while educational qualifications of the welders and Altitude of the weld joints do not have any influence on TI defects, the migration from SMAW (Shielded Metal Arc Welding) and Experience of welders do have a strong influence on the quantum of TI defects caused. SMAW welders have the habit of striking an arc by scratching the electrode against the metal and this practice is causing breakage of the tungsten tip which gets embedded in the weld.

Welders with less than 4 years experience in GTAW welding have caused almost 2.5 times more TI defects. Hence the researcher has suggested the following improvement strategies to reduce TI defects.

a. Welders having a minimum experience of 4 years should be engaged for GTAW.
b. Welders who come direct to GTAW welding are to be preferred. In case welders who migrate from SMAW with more than 4 years of experience in GTAW have to engaged, proper awareness and training programs have to be conducted in order to wean them away from the habit of striking an arc by scratching the electrode against the base metal.
c. Welders’ performance qualification has to be carried out in a condition which simulates the actual production condition as close as possible and at worst possible elevation to ensure welders’ ability to make sound weld deposit in a highly congested net work of pipes and at higher altitudes.

F. CONTROL

After implementing the above suggestions in the functional plant and realizing the reduction in TI defects level in order to sustain the improvement, the revised welder eligibility criteria in terms of Experience and Migration factor should be incorporated in the contract specifications and the same has to monitored when new welders are inducted in to the team or when new contractors are introduced. TI defect percentage has to be monitored on a monthly basis to ensure and sustain the reduced TI defect level.

IV. CONCLUSION

The outcome of the study confirms the applicability of Six Sigma and its DMAIC methodology in a non-continuous and non-repetitive activity like GTAW process. When the suggested improvement strategies are implemented during the fabrication of the functional plant, it is expected to bring about considerable reduction in TI defects and the consequent improvement in reliability and cost savings in terms of rework and avoidance of project overruns.

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