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APPLICATION OF SIX SIGMA TO REDUCE "EXCESS PENETRATION" DEFECTS IN GTAW PROCESS OF A NUCLEAR PIPING INSTALLATION

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Short Profile

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ABSTRACT:
Six Sigma is a powerful business strategy that employs a disciplined approach to tackle process variability using the application of statistical and non-statistical tools and techniques in a rigorous manner. This paper explains the implementation of Six Sigma for reduction of GTAW defect "Excess Penetration" (EP) in the nuclear piping facility of a nuclear research organization in India. The study aimed at verifying the applicability of Six Sigma in a non-mass manufacturing process like GTAW of ss pipes. This study has deployed DMAIC (Define-Measure-Analyze-Improve-Control) methodology for finding a solution to the high rate of "Excess Penetration" weld defects in GTAW of ss pipes. The study identifies variation in "welders' skill and practice" as the root cause for "Excess Penetration" defects.

KEYWORDS
Six Sigma, DMAIC, DPMO, GTAW, Weld Defects, Extra Penetration .

1.INTRODUCTION:

A. Six Sigma

Six-Sigma is a management philosophy focused on eliminating mistakes, waste and rework. Six-Sigma is a statistical measurement of only 3.4 defects per million. (1). The main focus of Six Sigma is to reduce potential variability from processes and products by using a continuous improvement methodology, which follows the phases: De?ne, Measure, Analyze, Improve and Control (2). This approach is known as DMAIC methodology and is employed in reducing process variation, in an existing process, which will result in no more than 3.4 defects per million opportunities (DPMO). For designing new processes Six Sigma uses DMADV (Define, Measure, Analyze, Develop and Verify) approach.

Since Six Sigma was first developed at Motorola, refined at AlliedSignal and transformed into legend at GE under Jack Welch, it has found application in almost all business sectors involving mass manufacturing activities.(3) However, very little research has been done in implementing Six Sigma in a non-continuous and non-mass activity like welding process.

This study is an initiative to implement the Six Sigma DMAIC approach in a nuclear plant for reducing ‘Extra Penetration’ defects in the GTAW (Gas tungsten Arc welding) process of ss piping facility. Nuclear Plant has been chosen for implementation of six sigma on account of the new challenges faced by the nuclear industry in India and elsewhere in the world.

A1. Five phases of DMAIC methodology:

DEFINE the requirements and expectations of the customer and define the project boundaries
MEASURE the process by mapping the business flow, collect data and establish Base line Sigma level
ANALYSE the root causes of defects and Prioritize opportunities for future improvement
IMPROVE the process to eliminate variations by developing and implementing creative solutions
CONTROL the improvements to keep the process on the new course

B. The Nuclear Research Organisation

This study was carried out at one of the demonstration nuclear plant of a Nuclear Research Organization, 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 sixth in the series of studies carried out focusing on “Extra Penetration” defects.

B.1 GTAW

Gas Tungsten Arc Welding (GTAW), also known as Tungsten Inert Gas (TIG) welding, is an arc welding process that uses a non-consumable tungsten electrode to produce the weld. The weld area is protected from atmospheric contamination by an inert shielding gas (argon or helium) by purging, and a filler metal is normally used. A constant-current welding power supply produces electrical energy.(4)

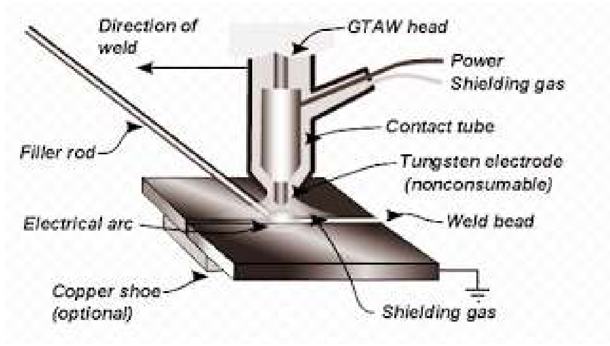

Fig.1 GTAW process setting

GTAW produces exceptionally clean, high quality welds and is most commonly used to weld thin sections of stainless steel and non-ferrous metals such as aluminum, magnesium, and copper alloys. 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 comparatively more complex and difficult to master as it calls for greater skill on the part of the welder, and furthermore, it is significantly slower than most other welding techniques. . It is widely used for high quality joints in the nuclear, chemical, aircraft and food industries. In the nuclear piping facility under study, because of the dense web of pipes spanning over an altitude of 10.5 meters and the resulting congestion and abnormal positioning of the welder, it calls for ambidexterity on the part of the welder.

B.2Excess Penetration

Excess penetration (EP) is a condition where the weld metal penetrates more than the thickness of the pipe and projects into the pipe internal passage. It creates a burning through effect and removes pipe wall material and may result in thinning of pipe wall or a discontinuity. Excess penetration arises from too high a heat input and / or too slow transverse of the welding torch. Excess penetration - burning through - is more of a problem with thin walled pipes as a higher level of skill is needed to balance heat input and torch traverse when welding thin metal.

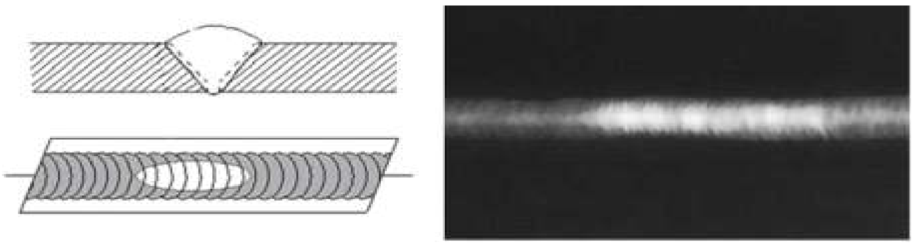

Fig.2 Excess Penetration - Sketch & Radiography

II. IMPLEMENTATION OF SIX SIGMA

A. DEFINE

Under the define phase, the process of fabrication of the piping installation was studied in order to establish the boundaries of the process and a high level process map was made as depicted in Fig.3.

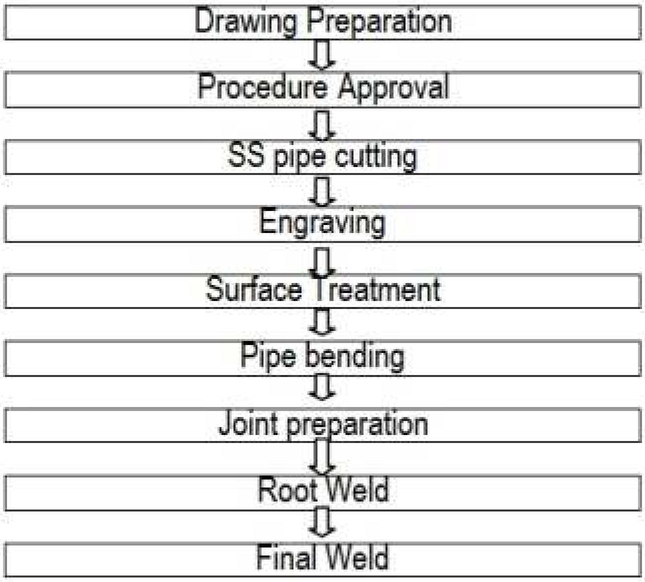

Fig.3 High level process map of piping fabrication

Having understood and identified the boundaries of the process, discussions were held with the client / sub-contractor and the Quality Assurance Division in order to identify the CTQ (Critical To Quality) factor of the process. Absence of discontinuity emerged as the CTQ of the nuclear piping facility as the corrosive nuclear fluid which flows through them can cause further erosion of material leading to leakage of nuclear fluid. The absence of discontinuity becomes all the more critical as no repair or maintenance work can be attempted inside the concrete cells housing the fuel piping structure after commissioning of the plant. Discontinuities can occur only on account of defective weld joints which are done in this process by GTAW, “Defect free GTAW weld joints” were identified as the CTQ of the nuclear piping fabrication.

B. MEASURE

Measure phase started with collection of data on current GTAW defects and their frequency of occurrence in order to arrive at the “Base line performance” of the process. GTAW weld quality is assessed through Non-Destructive Testing methods such, as visual Examination, radiography, liquid Penetration examination, pneumatic testing. Data on defects were collected from the Welding Inspection Reports (WIR) and Radiography reports of a sample of 10316 weld joints from among the total weld joints of 35000 involved in the Demonstration plant.. There are nine possible defect categories that occur in GTAW pipe welding. Terminology, abbreviation and frequency of occurrence of these defects are given in Table-1. Base line sigma level was established by calculating DPMO (Defects per Million Opportunities) and by reading the corresponding sigma level from the sigma level table. DPMO was calculated using the formula (1).

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

As there were 9 possible GTAW defect categories (Table 1) and as there were 439 defects that have been encountered in the chosen sample weld joints of 10316, the DPMO was calculated to be 4728 and the corresponding Sigma Level was read from the table and the Base Line Sigma Level was established as 4.1 sigma which offers ample scope for improvement. This process sigma could be improved by eliminating / reducing all the possible defect categories.

Table 1: GTAW Weld defect Categories

Sl.No	Weld defects	Abbreviation	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 defect categories from the trivial many, defect categories were prioritized using a Pareto chart based on the sample data (Fig.4).

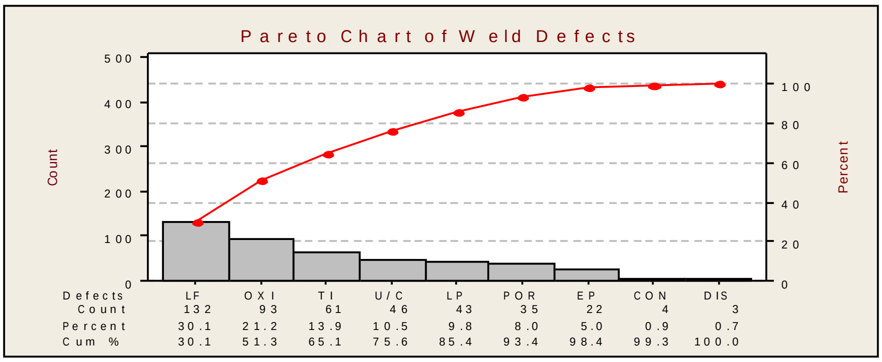

Fig.4.Pareto chart of GTAW defects

As it could be seen from the Pareto chart, it is the “Extra Penetration” that has the highest occurrence, leaving out ‘LF’, “OXI, “TI’, ‘UC’ and ‘POR’ which have been dealt with in separate research papers, accounting for around 10% of the total defects. Hence, it was resolved to focus on “EP” for improvement through further data collection and analysis.

After narrowing down on EP, all possible potential causes of EP were identified through a brain storming session with all the process owners and the QAD officers and the same are depicted in the “Cause and Effect diagram” (Fig.5) also known as ‘Fish Bone diagram.

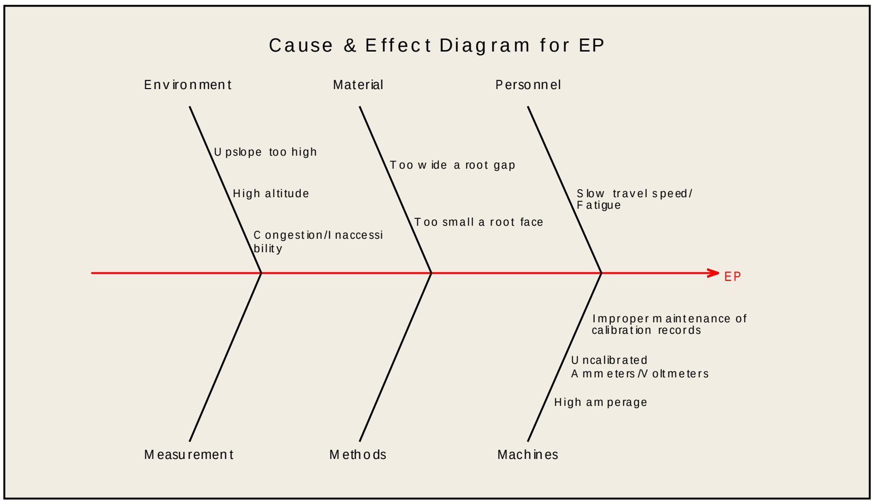

Fig.5 Cause and effect Diagram of EP

B.1 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 GTAW parameters and every other connected activity and the stringent incoming and 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", 5 represented "may have an influence but not likely to be root cause" and 1 was "least likely root cause". Using the probability rating, it was decided to consider the following causes having a score of "7 and above" as possible root causes of EP.

a)Congestion & inaccessibility
b)Welders' Experience in GTAW
c)Welders' Qualification
d)Migration from SMAW
e)Working at high altitude
f)NB of pipe
g)Welding position

There are totally 35000 weld joints in the demonstration plant. Data on GTAW weld defects were collected 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.

C. ANALYSE

Under this phase, data was gathered on all the above variables from records and the same were analysed using Chi-square and 'two proportion test' to confirm the statistical significance of association between these variables and the EP defects. These data have also been presented graphically for visual confirmation. Data tables, Outputs of statistical tests and the charts are provided for all the seven root causes shortlisted.

C1.Altitude of weld joints

The nuclear piping facility spans over an altitude of 13 meters. In order to verify the psychological effect of working at heights, analysis was done to test the influence of altitude on EP defects.

Table 2 : Extra Penetration by Altitude

Sl. No	Altitude in Meters	EP (Nos.)	Total weld Joints	EP (%)
1	-2.5 < 0	1	1156	0.1
2	0 < 4.5	10	4680	0.2
3	4.5 < 7.5	6	2604	0.2
4	7.5 to 10.5	5	1876	0.3
	Total	22	10316	0.2

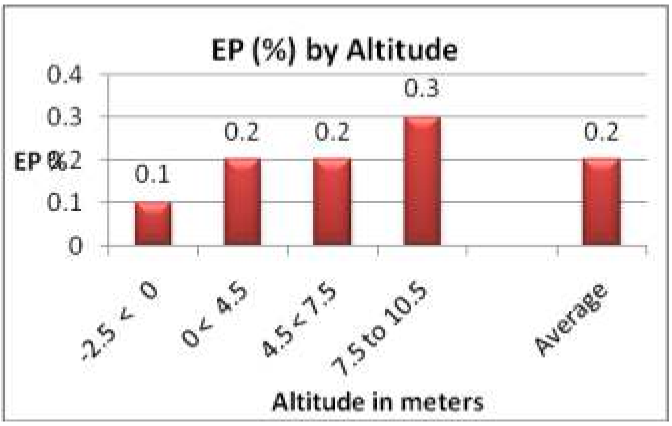

Fig.6 Bar Chart of EP defects by Altitude

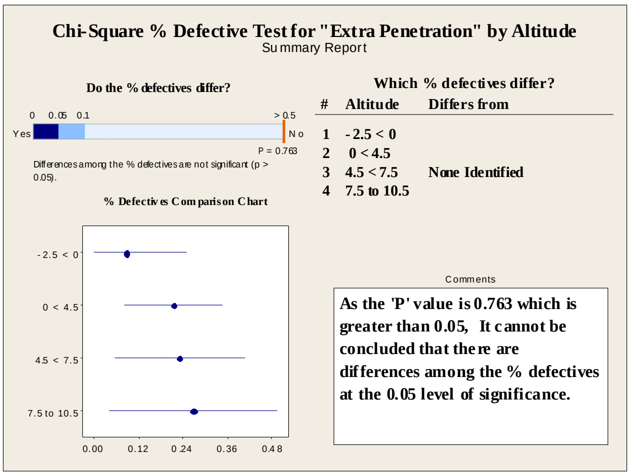

Fig.7 Chi-Square test for EP by Altitude

As the 'P' value is 0.763 which is greater than .05, it cannot be concluded that the differences among the % of EP defectives of weld joints between different altitudes are statistically significant.

C2.Pipe size

Nuclear piping structure involves many NB sizes of ss pipes. But 6NB, 15 NB, 20 NB and 25 NB pipes are predominant. The difference in EP defect rates between different NB of pipes was tested using

Chi-Square test.

Table 3: EP defects by pipe size

Sl.No.	PIPE NB	EP (Nos.)	Total weld Joints	EP (%)
1	8	11	5172	0.2
2	15	10	4759	0.2
3	20	1	143	0.7
4	25	0	208	0
5	40	0	7	0
6	50	0	25	0
7	150	0	2	0
	Total	22	10316	0.2

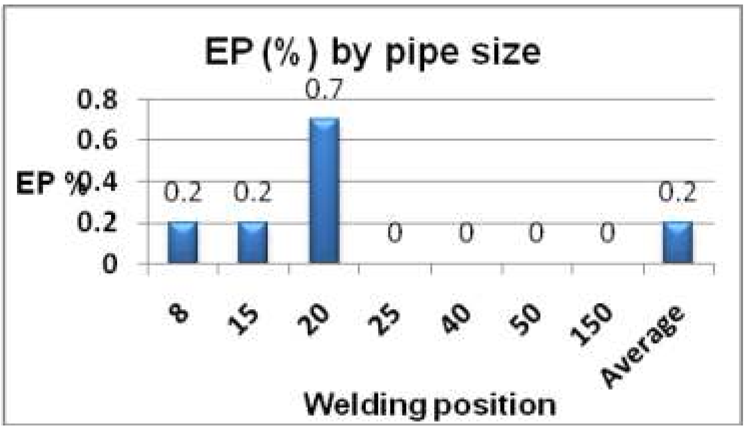

Fig.8 Bar chart of EP defects % by pipe size

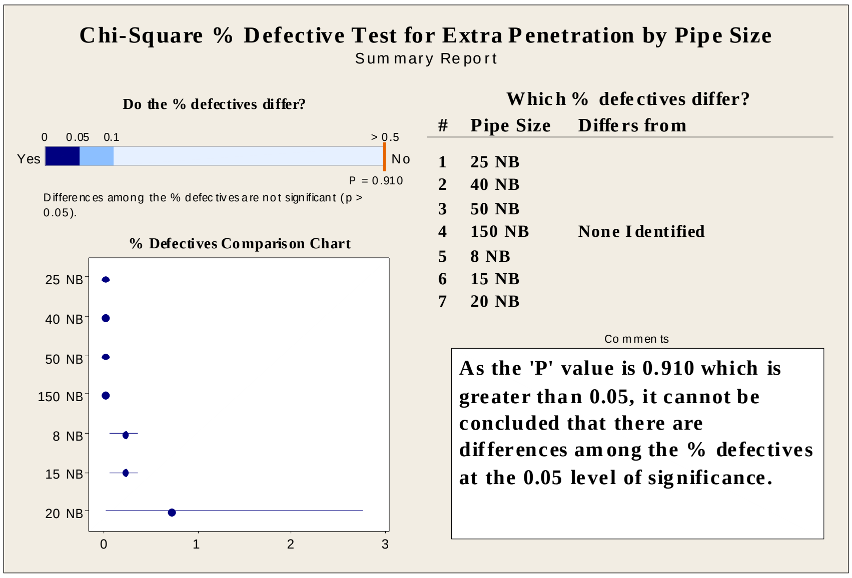

Fig. 9 Chi-Square test for EP by Pipe Size

As the ‘P’ value is 0.910, it cannot be concluded that there is association between pipe size and quantum of EP defects.

C3.Welding position

Pipe welding involves 5 different positions of welding namely 1G, 2G, 3G, 5G and 6G. Some of the welding positions call for high level of dexterity and skill on the part of the welders and hence the possible causal relationship with the quantum of EP defects was tested using Chi-Square test.

Table 4 : EP defects by welding position

Sl.No.	Welding Position	EP (Nos.)	Total weld Joints	EP (%)
1	1G	0	31	0
2	2G	11	7087	0.2
3	3G	0	3	0
4	5G	9	2633	0.3
5	6G	2	562	0.4
	Total	22	10316	0.2

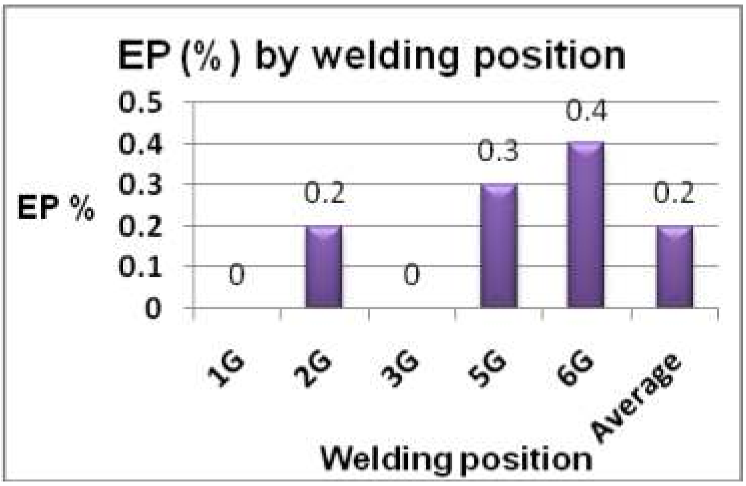

Fig.10 Bar chart of EP % by welding position

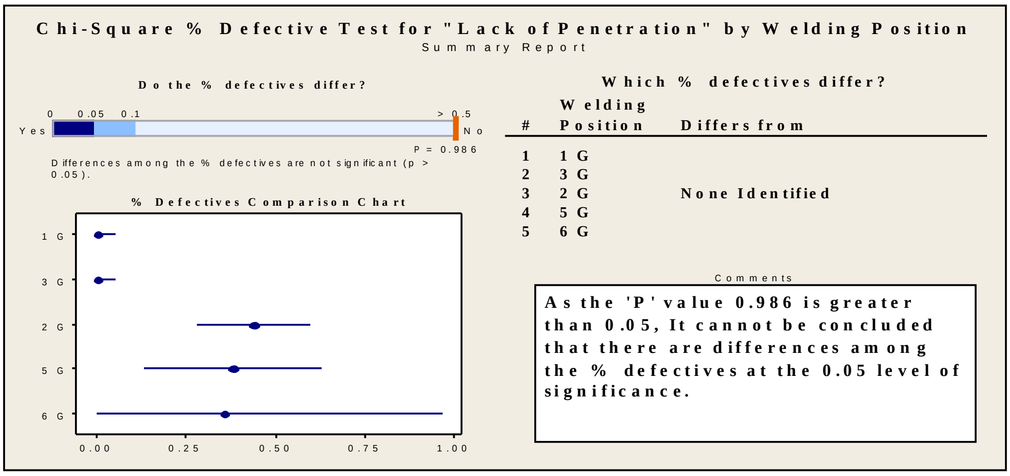

Fig.11 Chi-Square test for EP by welding position

As the ‘P’ value is 0.986 which is greater than .05 it cannot be concluded that there is an association between welding position and quantum of EP defects.

C4.Educational Qualification of welders

Welders with 10th qualification and ITI qualification are performing the GTAW welding at the nuclear piping facility. Analysis of the EP defects caused by welders with 10th and ITI qualifications revealed a significant association between qualification and quantum of EP defects as seen from the table No.5 and the result of the two proportion test. (Fig.13) where the ‘P’ value is 0.024 which is less than 0.05.

Table 5: EP defects % by Qualification of welders

Sl. No.	Qualification	LP (Nos.)	Total Weld Joints	LP (%)
1	10th Avg	24	4634	0.5
2	ITI Avg	19	5682	0.3
	Total	43	10316	0.4

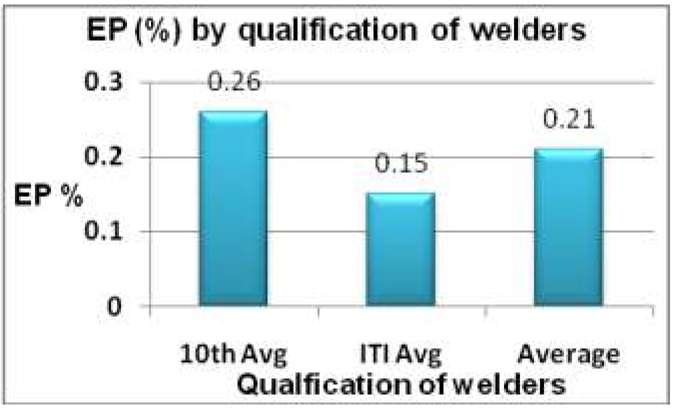

Fig.12 Bar chart of EP % by welders' qualification

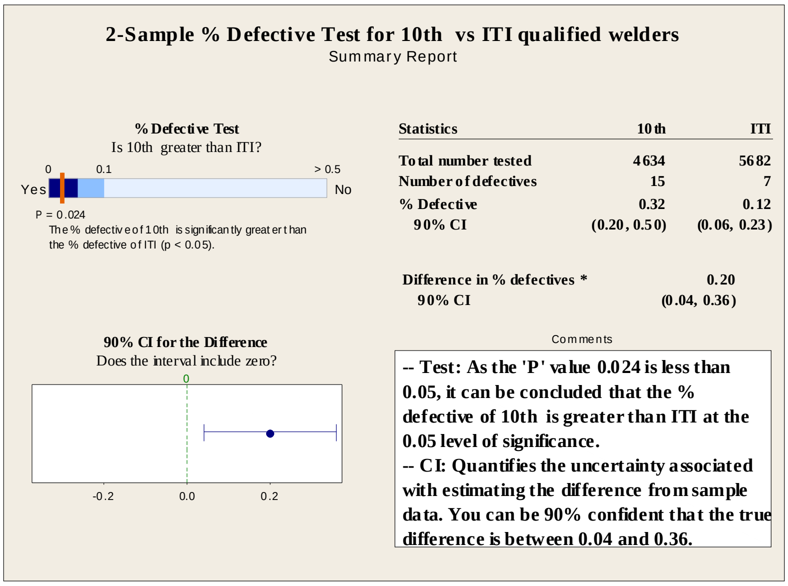

Fig.13 Two sample proportion test of EP by Qualification

C5. Experience of welders in GTAW

Experience improves the GTAW welding skill of the welders. In GTAW it is more so as the weld quality largely depends on the 'welder technique' such as correct angle or manipulation of the electrode/welding gun, travel speed when standard welding parameters, Joint preparation procedures and standard fabrication practices are ensured.

Table 6 and Fig.14 give the analysis of EP% by experience category of the welders. It could be seen that welders with less than 4 years experience in GTAW have caused over 2 to 3 times the EP defects caused by welders with longer years of experience. It is more evident in the bar chart of EP defects by Experience category of welders. (Fig.14).

Table 6 : EP defects % by experience of welders

Sl. No.	Experience	EP (Nos.)	Total weld Joints	EP (%)
1	>10years	1	316	0.32
2	>8-10	3	2789	0.11
3	>6-8	3	2895	0.1
4	4 to 6	1	1878	0.05
5	< 4 years	14	2438	0.57
	Total	22	10316	0.21

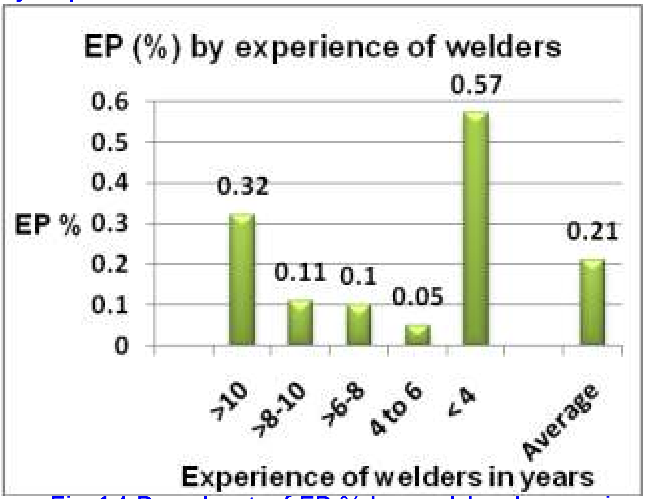

Fig.14 Bar chart of EP % by welders’ experience

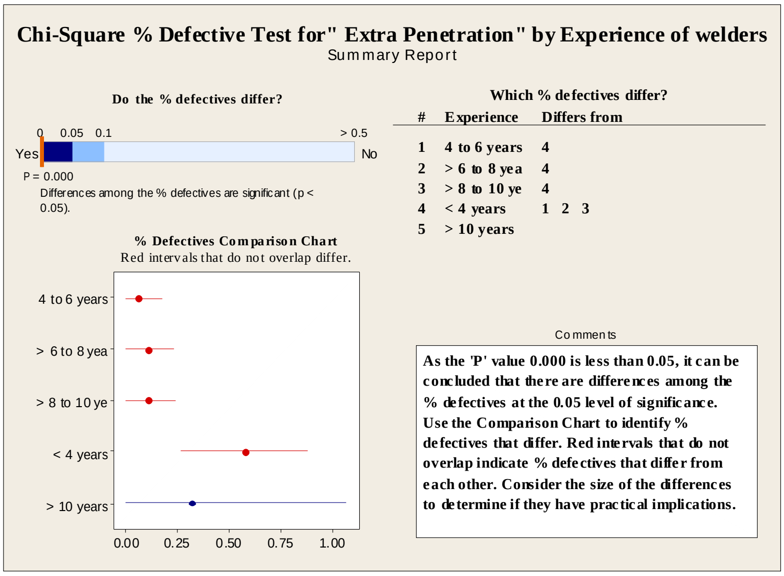

Fig.15 Chi-Square test for EP by experience

Chi-Square test also confirms that difference in % of EP defects between welders with less than 4 years and welders with 4-6 and 6-8 is statistically significant.

Table 6: EP defects % by Migration status

Sl. No.	Migration Status	EP (Nos.)	Total weld Joints	EP (%)
1	Migrated	14	2436	0.57
2	Direct	8	7880	0.1
	Average	22	10316	0.21

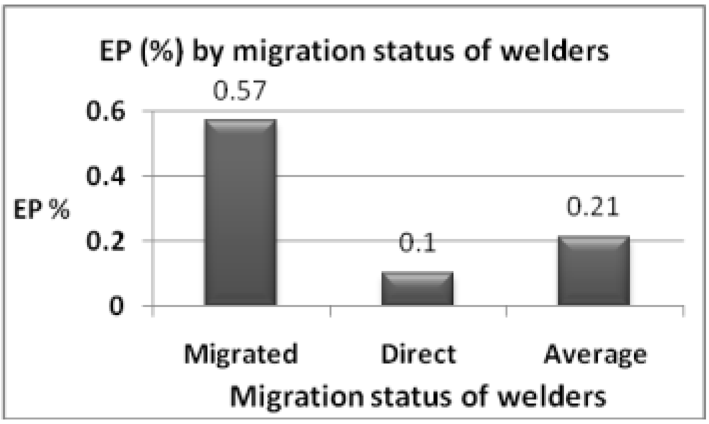

Fig.16 Bar chart of EP % by migration status

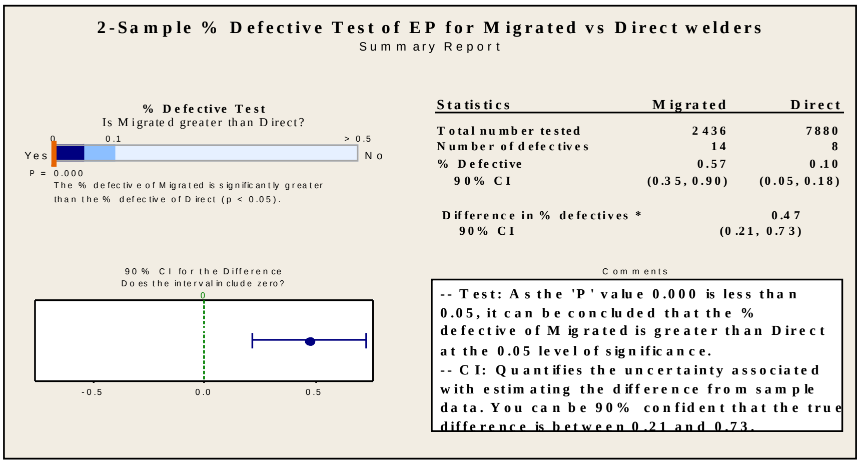

Fig.17 Two sample proportion test of EP by Migration status

From Table 6 and Fig.16 one can see that welders who have migrated from SMAW have caused 5 times the EP defects caused by those who have come direct to GTAW. Two proportion test (Fig. 17)also confirms with a ‘P’ value of 0.000 that the % of EP caused by Migrated welders are greater than the defects caused by Direct welders.

From the analyses the following factors emerge as the root causes for EP defect in GTAW as there is a strong association between them and the quantum of EP defects.

a)Congestion and inaccessibility of weld joints and the consequent abnormal positioning of the welder
b)Variability in welders’ skill as manifested in their educational qualification, experience in GTAW and their migration status.

D. IMPROVE

Improve phase of Six Sigma aims at finding solutions for the root causes identified in the Analyze phase. The following solutions have been offered to the nuclear research organization for reducing the EP defects in their GTAW process and improving the sigma level from 4.1 sigma.

a)Welders with a minimum experience of 4 years in GTAW should be engaged.
b)GTAW welders with Technical qualification such as ITI have to be engaged and those with non-technical qualification are to be avoided.
c)Welders’ performance qualification has to be carried out in a condition which simulated production condition with heavy congested net work of SS pipes at worst possible elevation to test welders’ ability to make sound weld deposit in realistic site conditions.

E. CONTROL

Real difficulty in Six Sigma application is the sustenance of the improved performance. After implementing the above suggestions and realizing the reduction in EP defects level, in order to sustain the improvement, it has been suggested to standardize the welder engagement procedure by incorporating the revised welder eligibility criteria in terms of Experience, Qualification and Migration status in the contract specifications / and to monitor the same when new welders are inducted in to the team or when new contractors are introduced.

EP defect percentage has to be monitored on a monthly basis using ‘C charts’ to ensure and sustain the reduced EP defect level.

III.CONCLUSION

This paper has presented the phase-by-phase implementation of the DMAIC methodology in GTAW at the SS piping facility of a nuclear research organization for their demonstration plant for reducing ‘Extra of Penetration’ (EP) defects. The outcome of the study confirms the suitability of Six Sigma and its DMAIC methodology in a non-continuous and non-repetitive activity like GTAW process. By implementing the suggested improvement strategies while fabricating the functional plant, the organization can benefit from considerable reduction in EP defects and the resulting improvement in safety & reliability and savings through reduction of rework and avoidance of project overruns.

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