DEFECT ANALYSIS AND MECHANICAL CHARACTERIZATION OF TIG WELDED EN31 ALLOY STEEL JOINTS

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Abstract: Chrome alloy is a high carbon steel which is manufactured using chromium and molybdenum elements. The molybdenum element enhances strength and higher working temperatures while the chromium provides outstanding corrosion resistance and oxidation. This alloy steels have found applications in oil, gas, energy and automotive industries.
In this present work, EN31 Chrome alloy steel joints were prepared by varying process parameters such as current, voltage, weld speed in TIG welding process. Tensile testing, impact testing and Rockwell hardness testing were chosen for destructive testing, where in radiography testing was chosen for non-destructive testing. Optimization techniques like Taguchi and Taguchi Grey Relational Analysis are also applied to know the process parameters influence on the mechanical properties of the weld part in order to achieve improved mechanical properties. The ANOVA also carried out to know the percentage contribution of process parameters.
The influence of the process parameters and presence of defects will be examined visually and also through radiography tests. It can be concluded from this work that different types of defects such as lack of penetration, root undercut were originated in three weld joints. The quality of the weld was evaluated in terms of Tensile Strength, Hardness and Impact Strength of the weld specimens

***Index Terms* – Defect Analysis, Mechanical Characterization, TIG Welded EN31 Alloy Steel.**

I. INTRODUCTION

Until the end of the 19th century the only welding process was forge welding which black smith had used for centuries to join iron and steel by heating and hammering. Arc welding and oxy-fuel welding were among the first processes to develop late in the century, and electric resistance welding followed soon after welding technology advanced quickly during the earlier 20th century as world war 1 and world war 2 drove demand for reliable and inexpensive joining methods. Following the wars, several modern techniques were developed, including manual methods like SMAW, now one of the most popular welding methods, as well as semi-automatic and automatic processes such as GMAW, SAW, FCAW and ESW. Alloy steel is steel that is alloyed with a variety of elements in total amounts between 1.0% and 50% by weight to improve its mechanical properties. Alloy steels are broken down into two groups: low alloy steels and high alloy steels. The difference between the two is somewhat arbitrary: Smith and Hahemi define the difference at 4.0%, while Degarmo, et al., define it at 8.0%. Most commonly, the phrase "alloy steel" refers to low-alloy steels.

Chromium-molybdenum alloy steel (or chrome moly), is an alloy used for high pressure and temperature use. It is used in oil and gas, energy, construction and the automotive industries because of its corrosion resistance and high-temperature and tensile strength. The added reliability provided by chrome moly means that it is the material of choice for a number of applications, and this article outlines a few of these applications and also the material's properties. Chromium molybdenum steel – frequently shortened to chrome moly – is a kind of low alloy steel used in a number of applications and industries. As the name suggests, the two key alloying elements are molybdenum (Mo) and chromium (Cr). These alloys are normally sorted into one main group, with names such as chrome, Chromalloy, moly and Cr Mo often used. Industries where the alloy is common include construction, energy, oil and gas, and automotive.

II.TIG WELDING

Tungsten Inert Gas (TIG) or Gas Tungsten Arc (GTA) welding is the arc welding process in which arc is generated between non consumable tungsten electrode and work piece. The tungsten electrode and the weld pool are shielded by an inert gas normally argon and helium. Figures show the principle of tungsten inert gas welding process.

The Tungsten arc process is being employed widely for the precision joining of critical components which require controlled heat input. The small intense heat source provided by the tungsten arc is ideally suited to the controlled melting of the material. Since the electrode is not consumed during the process, as with the MIG or MMA welding processes, welding without filler material can be done without the need for continual compromise between the heat input from the arc and the melting of the filler metal. As the filler metal, when required, can be added directly to the weld pool from a separate wire feed system or manually, all aspects of the process can be precisely and independently controlled i.e. the degree of melting of the parent metal is determined by the welding current with respect to the welding speed, whilst the degree of weld bead reinforcement is determined by the rate at which the filler wire is added to the weld pool.

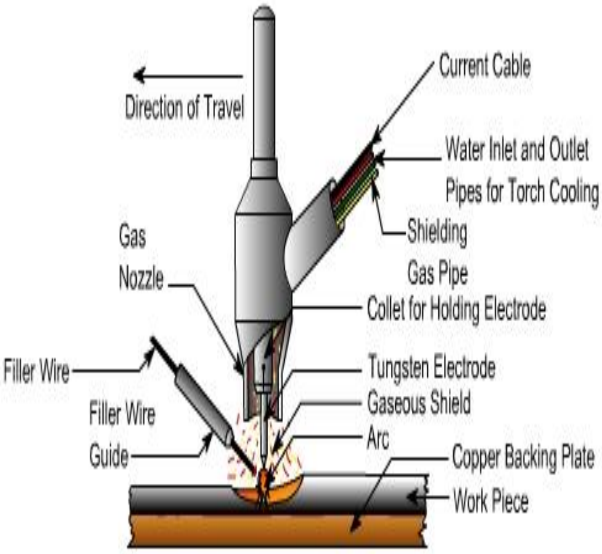


Fig.2.1. Principle of TIG Welding

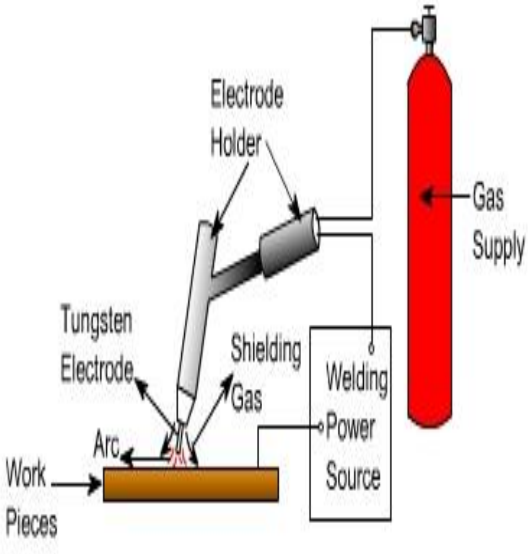


Fig2.2. Schematic Diagram of TIG Welding System

2.1 Chemical Composition of TIG Electrodes:

AWS Classification	Tungsten, min. percent	Thoria, percent	Zirconia, percent	Total other elements, max. percent
EWP	99.5	-	-	0.5
EWTh-1	98.5	0.8 to 1.2	-	0.5
EWTh-2	97.5	1.7 to 2.2	-	0.5
EWZr	99.2	-	0.15 to 0.40	0.5

Table 2.1. Chemical Composition of TIG Electrodes

Tungsten electrodes are commonly available from 0.5 mm to 6.4 mm diameter and 150 - 200 mm length. The current carrying capacity of each size of electrode depends on whether it is connected to negative or positive terminal of DC power source. AC is used only in case of welding of aluminum and magnesium and their alloys.

Below Table gives typical current ranges for TIG electrodes when electrode is connected to negative terminal (DCEN) or to positive terminal (DCEP).

Electrode Dia. (mm)	**DCEN**	**DCEP**
	Pure and Thoriated Tungsten	**Pure and Thoriated Tungsten**
0.5	5-20	-
1.0	15-80	-
1.6	70-150	10-20
2.4	150-250	15-30
3.2	250-400	25-40
4.0	400-500	40-55
4.8	500-750	55-80
6.4	750-1000	80-125

Table 2.2 **Typical Current Ranges for TIG Electrodes**

TIG welding can be used in all positions. It is normally used for root pass during welding of thick pipes but is widely being used for welding of thin walled pipes and tubes. This process can be easily mechanized i.e. movement of torch and feeding of filler wire, so it can be used for precision welding in nuclear, aircraft, chemical, petroleum, automobile and space craft industries. Aircraft frames and its skin, rocket body and engine casing are few examples where TIG welding is very popular.

III. EXPERIMENTATION:

3.1 SELECTION OF MATERIAL

Base material: Material selected for this work is chromium alloy steel (EN31 alloy steel).Chrome alloy steel is an excellent high carbon steel which is manufactured using chromium and molybdenum elements. The molybdenum element enhances strength and higher working temperatures while the chromium provides outstanding corrosion resistance and oxidation.

Applications of chrome alloy steel: The applications for Alloy EN31 are: oil, gas, energy, construction and automotive industries because of its corrosion resistance and high temperature and tensile strength. Chemical composition of EN31 Alloy Steel: The chemical composition of base metal was obtained using vacuum spectrometer. Sparks were ignited at various locations of base metal sample and their spectrum was analyzed for the estimation of alloying elements. The chemical composition of the base metal in weight percent.

ELEMENTS	PERCENTAGE
Carbon	0.20% Max
Manganese	0.40-.070%
Silicon	0.75% Max
Phosphorus	0.04% Max
Sulphur	0.045% Max
Chromium	4.00-6.50%
Nickel	0.50% Max
Molybdenum	0.45-0.65%
Tungsten	0.10% Max

Table 3.1 Chemical composition of EN31 Alloy

PROPERTIES	VALUE
Density(1000kg/m3)	7.85
Elastic modulus(GPa)	190-210
Poisson's ratio	0.27-0.3
Thermal conductivity(W/m-k)	26-48.6
Specific heat(J/Kg-K)	452-1499
Electrical resistivity(10-9W-m)	210-1251
Tensile strength(MPa)	758-1882
Yield strength(MPa)	366-1793
Percentage elongation (%)	4-31
Hardness (Brinell 3000kg)	149-627
Thermal Expansion(10-6/k)	9.0-15

Table.3.2 Mechanical Properties of EN31 Alloy

Fig 3.1: Chrome Alloy Steel specimens

The dimensions of chrome alloy steel plate is length 200mm, width 80mm, thickness 15mm. The following are the critical process parameters which are used in TIG welding process.

S.NO	Current (A)	Voltage (V)	Welding Speed (mm/sec)
1.	135	18	3.2
2.	135	22	3.5
3.	135	26	3.8
4.	145	18	3.5
5.	145	22	3.8
6.	145	26	3.2
7	155	18	3.8
8	155	22	3.2
9	155	26	3.5

Table 3.3: Welding process parameters:

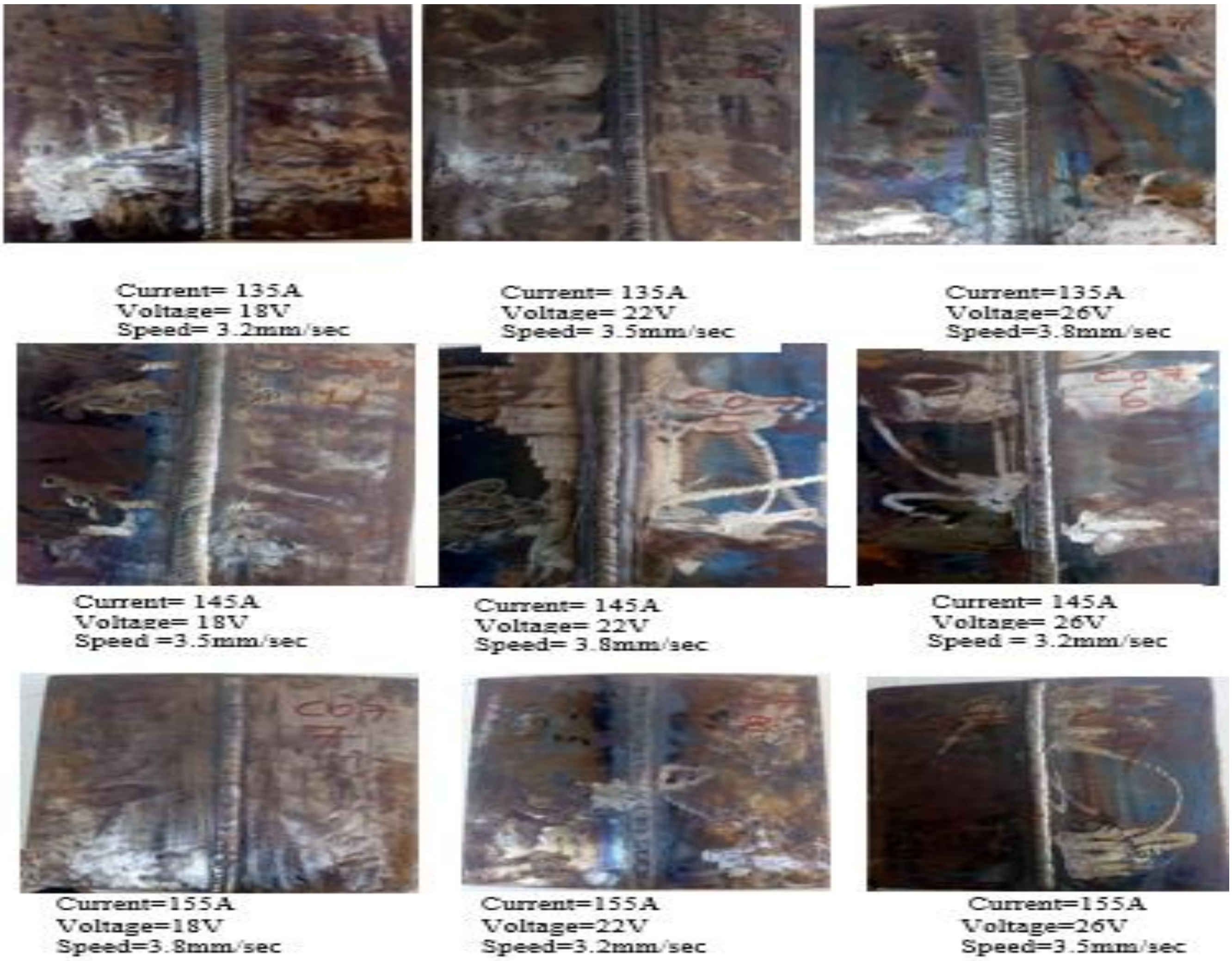


Fig 3.2: TIG Welded Chrome Alloy Steel joints by varying parameters

3.2 Radio Graphic Testing Specifications:

Particulars	Description
Isotope	Iridium-192
Half life	74 days
Maximum capacity	50 curie
Source to object distance (SOD)	7inches
Object to film distance (OFD)	1mm
Shielding materials	Lead
Camera operation	Manual
Maximum operating distance	8 mm from the camera
Front guide tubes (2 Nos)	2.5mm
Overall dimension	375*250*275 mm
Weight	37 kg
Developer	Hydroquinone
Fixer	Ammonium Thio-Sulphite

IV. **TESTING OF SPECIMENS**

The sample specimen is gripped between the two test fixtures and tensile load is applied through load frames when cross heads move upwards, the elongation is calculated in the extensometers, when the load on the specimen reaches beyond the fracture limit the specimen breaks and the values are charted.

A. Specimen-1

This test specimen-1 was prepared by TIG welding with parameters current-135A, voltage-18V and welding speed-3.2mm/sec. The following are the observations during the test.

Input parameters:
Specimen type : **flat plate**
Specimen width: **20mm**
Specimen thickness: **15mm**
Original gauge length: **0mm**
Final gauge length: **0mm**
Output results:
Ultimate tensile strength: **54.614 N/mm^2**
Ultimate load: **17.120 KN**

B. Specimen-2

This test specimen-2 was prepared by TIG welding with parameters current-135A, voltage-22V and welding speed-3.5mm/sec. The following are the observations during the test.

Input parameters:
Specimen type : flat plate
Specimen width: 20mm
Specimen thickness: 15mm
Original gauge length: 0mm
Final gauge length: 0mm

Output result:
Ultimate tensile strength: 35.322 N/mm^2
Ultimate load: 11.160 KN

C. Specimen- 3

This test specimen-3 was prepared by TIG welding with parameters current-135A, voltage-26V and welding speed-3.8mm/sec. The following are the observations during the test.

Input parameters:
Specimen type : flat plate
Specimen width: 20mm
Specimen thickness: 15mm
Original gauge length: 0mm
Final gauge length: 0mm

Output result:
Ultimate tensile strength: 28.864 N/mm^2
Ultimate load: 9.120 KN

D. Specimen-4

This test specimen-4 was prepared by TIG welding with parameters current-145A, voltage-18V and welding speed-3.5mm/sec. The following are the observations during the test.

Input parameters:
Specimen type : flat plate
Specimen width: 20mm
Specimen thickness: 15mm
Original gauge length: 0mm
Final gauge length: 0mm

Output result:
Ultimate tensile strength: 21.714 N/mm^2
Ultimate load: 6.840 KN

E. Specimen-5

This test specimen-5 was prepared by TIG welding with parameters current-145A, voltage-22V and welding speed-3.8mm/sec. The following are the observations during the test.

Input parameters:
Specimen type : flat plate
Specimen width: 20mm

Specimen thickness: 15mm
Original gauge length: 0mm
Final gauge length: 0mm

Output result:
Ultimate tensile strength: 30.890 N/mm^2
Ultimate load: 9.760 KN

F. Specimen-6

This test specimen-6 was prepared by TIG welding with parameters current-145A, voltage-26V and welding speed-3.2mm/sec. The following are the observations during the test.
Input parameters:
Specimen type : flat plate
Specimen width: 20mm
Specimen thickness: 15mm
Original gauge length: 0mm
Final gauge length: 0mm

Output result:
Ultimate tensile strength: 38.279 N/mm^2
Ultimate load: 12.040 KN

G. Specimen-7

This test specimen-7 was prepared by TIG welding with parameters current-155A, voltage-18V and welding speed-3.8mm/sec. The following are the observations during the test.

Input parameters:
Specimen type : flat plate
Specimen width: 20mm
Specimen thickness: 15mm
Original gauge length: 0mm
Final gauge length: 0mm

Output result:
Ultimate tensile strength: 24.968 N/mm^2
Ultimate load: 7.880 KN

H. Specimen-8

This test specimen-8 was prepared by TIG welding with parameters current- 155A, voltage-22V and welding speed-3.2mm/sec. The following are the observations during the test.

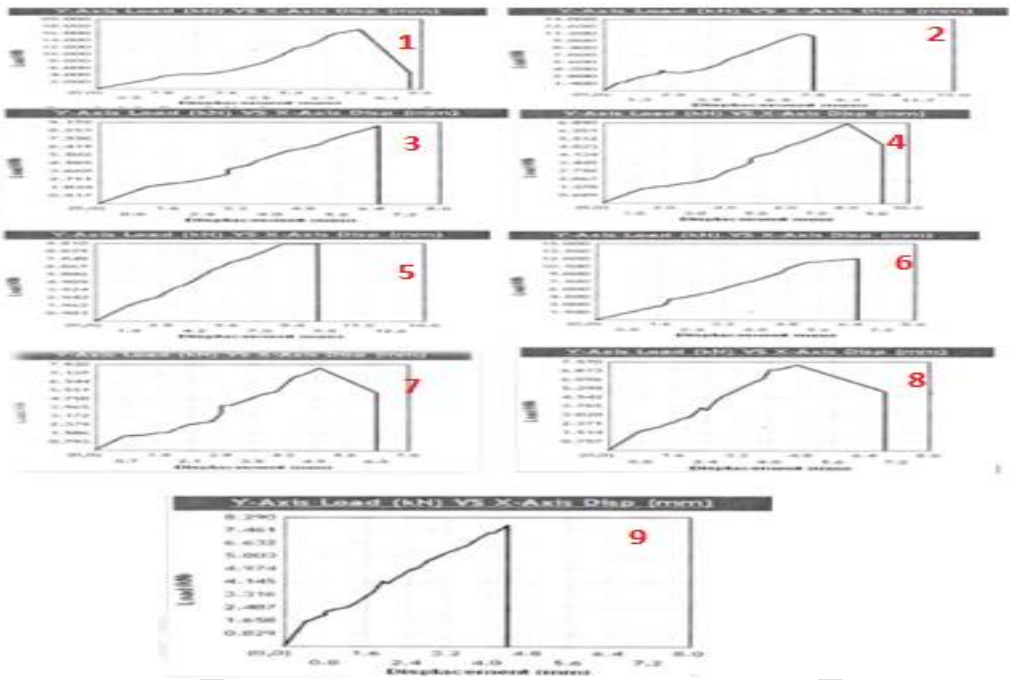
Input parameters:
Specimen type : flat plate
Specimen width: 20mm
Specimen thickness: 15mm
Original gauge length: 0mm
Final gauge length: 0mm

Output result:
Ultimate tensile strength: 23.758 N/mm^2
Ultimate load: 7.520 KN

I. Specimen-9

This test specimen-9 was prepared by TIG welding with parameters current-155A, voltage-26V and welding speed-3.5mm/sec. The following are the observations during the test.
Input parameters:
Specimen type : flat plate
Specimen width: 20mm
Specimen thickness: 15mm
Original gauge length: 0mm
Final gauge length: 0mm

Output result:
Ultimate tensile strength: 26.043 N/mm^2
Ultimate load: 8.240 KN



Graph 4.1 Load displacement curves for specimens 1-9

4.1 Observations during tensile testing:

S.NO	Sample Name	Ultimate Tensile Strength (N/mm^2)
1.	Specimen-1	54.614
2.	Specimen-2	35.322
3.	Specimen-3	28.864
4.	Specimen-4	21.714
5.	Specimen-5	30.890
6.	Specimen-6	38.279
7.	Specimen-7	24.968
8.	Specimen-8	23.758
9.	Specimen-9	26.043

V. CHARPY IMPACT STRENGTH TEST

Charpy impact testing is an ASTM E18 standard method of determining the impact resistance of materials. A pivoting arm is raised to a specific height (constant potential energy) and then released. The arm swings down hitting a notched sample, breaking the specimen. The energy absorbed by the sample is calculated from the height the arm swings to after hitting the sample. A notched sample is generally used to determine impact energy and notch sensitivity.

The test is similar to the izod impact test but uses a different arrangement of the specimen under test.

Fig 5.1: Schematic sketch of Charpy impact test specimens

S No	Sample Name	Observed Values(JOULES)
1.	Specimen-1	12
2.	Specimen-2	10
3.	Specimen-3	10
4.	Specimen-4	12
5.	Specimen-5	8
6.	Specimen-6	10
7.	Specimen-7	16
8.	Specimen-8	16
9.	Specimen-9	14

Table 5.1: Observations during impact testing

VI. VICKERS HARDNESS TEST

The **Vickers hardness test** was developed in 1921 by Robert L. Smith and George E. Sand land at Vickers Ltd as an alternative to the Brinell method to measure the hardness of materials. The Vickers test is often easier to use than other hardness tests since the required calculations are independent of the size of the indenter, and the indenter can be used for all materials irrespective of hardness. The basic principle, as with all common measures of hardness, is to observe a material's ability to resist plastic deformation from a standard source. The Vickers test can be used for all metals and has one of the widest scales among hardness tests. The unit of hardness given by the test is known as the **Vickers Pyramid Number** (**HV**) or **Diamond Pyramid Hardness** (**DPH**). The hardness number can be converted into units of Pascal's, but should not be confused with pressure, which uses the same units.

The hardness number is determined by the load over the surface area of the indentation and not the area normal to the force, and is therefore not pressure.

For thin samples indentation depth can be an issue due to substrate effects. As a rule of thumb the sample thickness should be kept greater than 2.5 times the indent diameter. Alternatively indent depth can be calculated according to:

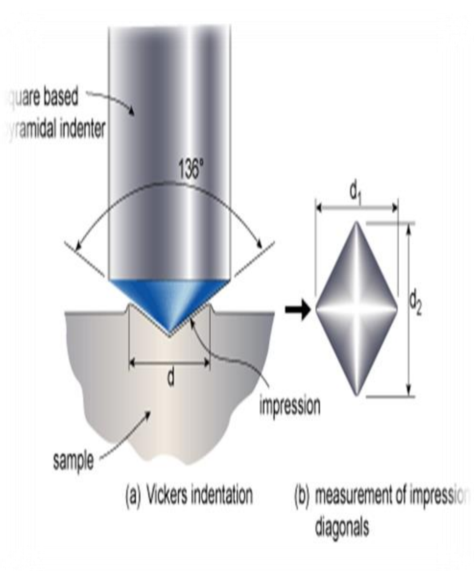


Fig 6.1: Vickers Hardness Test Indention.

S.NO	SAMPLE NAME	OBSERVED VALUES, HV_{10}			
		At Base metal	At Heat affected zone	At Weld bead	Avg
1.	Specimen-1	281	282	284	282.33
2.	Specimen-2	270	271	272	271.00
3.	Specimen-3	222	222	221	221.67
4.	Specimen-4	228	227	227	227.33
5.	Specimen-5	322	322	324	322.67
6.	Specimen-6	205	206	207	206.00
7.	Specimen-7	260	261	261	260.67
8.	Specimen-8	242	241	241	241.33
9.	Specimen-9	238	236	239	237.67

Table 6.1: Observations during vickers hardness testing.

VII. OPTIMIZATION OF PROCESS PARAMETERS:

7.1 Single Variable Optimization (Taguchi Method)

Taguchi's method is systematic and experimentally designed to find the main process parameters and will locate a good combination of process parameters to improve the output quality by using the experiments of Orthogonal Array. In this method each experimental value is converted to Signal to Noise ratio and is defined as the deviation between the experimental value and ideal value.

7.1.1 Process parameters optimization by Taguchi Design of Experimentation

Process parameters are optimized using Taguchi Design by Using the MINITAB 18. In this Means and S/N ratios for all response parameters were calculated. Then response table for each response parameter was created to find out the optimum level of experiment for each parameter i.e., Tensile Strength, Hardness, Impact Strength.

7.1.2 Procedure to calculate Mean and S/N ratio in MNITAB 18

After creating Orthogonal Array L_9 for the selected levels of process parameters, the next step is to enter the values of response variables i.e., Tensile Strength, Hardness, Impact Strength which were calculated after the experimentation.

Then go to STAT-DOE-TAGUCHI-DEFINE CUSTOM TAGUCHI DESIGN. In this enter the factors (process parameters that effect output responses).

Then again go to STAT-DOE-TAGUCHI-ANALYZE TAGUCHI DESIGN. In this enter response data (response variable for which we want S/N ratios) and in storage select S/N ratios. In options give the S/N criteria whether Larger is better, Smaller is better or Nominal is better.

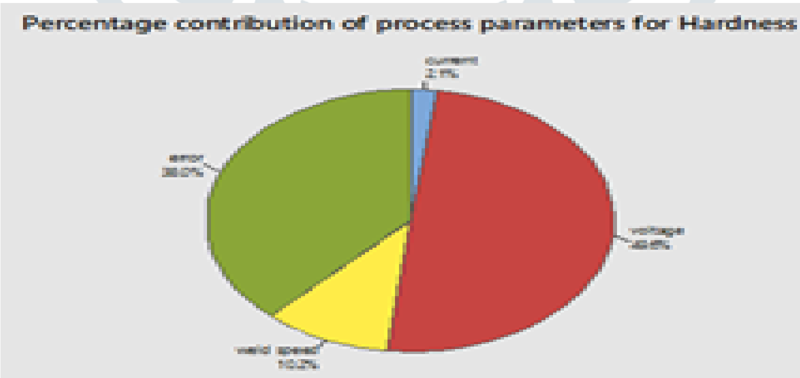
Then we can see the generation of S/N ratios for all 9 experimental runs as in Table No: 7.1

S.No	Current (A)	Voltage (V)	Weld speed (mm/sec)	Ultimate Tensile Strength (N/mm²)	S/N Ratio of UTS	Hardness (HV_{10})	S/N Ratio of H	Impact Strength (J)	S/N Ratio of IS
1	135	18	3.2	54.614	34.7461	282.33	49.0151	12	21.5836
2	135	22	3.5	35.322	30.9609	271.00	48.6594	10	20.0000
3	135	26	3.8	28.864	29.2071	221.67	46.9141	10	20.0000
4	145	18	3.5	21.714	26.7348	227.33	47.1331	12	21.5836
5	145	22	3.8	30.890	29.7964	322.67	50.1752	8	18.0618
6	145	26	3.2	38.279	31.6592	206.00	46.2773	10	20.0000
7	155	18	3.8	24.968	27.9477	260.67	48.3218	16	24.0824
8	155	22	3.2	23.758	27.5162	241.33	47.6522	16	24.0824
9	155	26	3.5	26.043	28.3138	237.67	47.5195	14	22.9226

7.1.3 Taguchi Analysis: Tensile Strength, Hardness and Impact Strength VS Current, Voltage, Weld speed

Table No: 7.2 Response Table for Ultimate Tensile Strength (N/mm^2) (S/N ratios and Means) [Larger is better criteria]

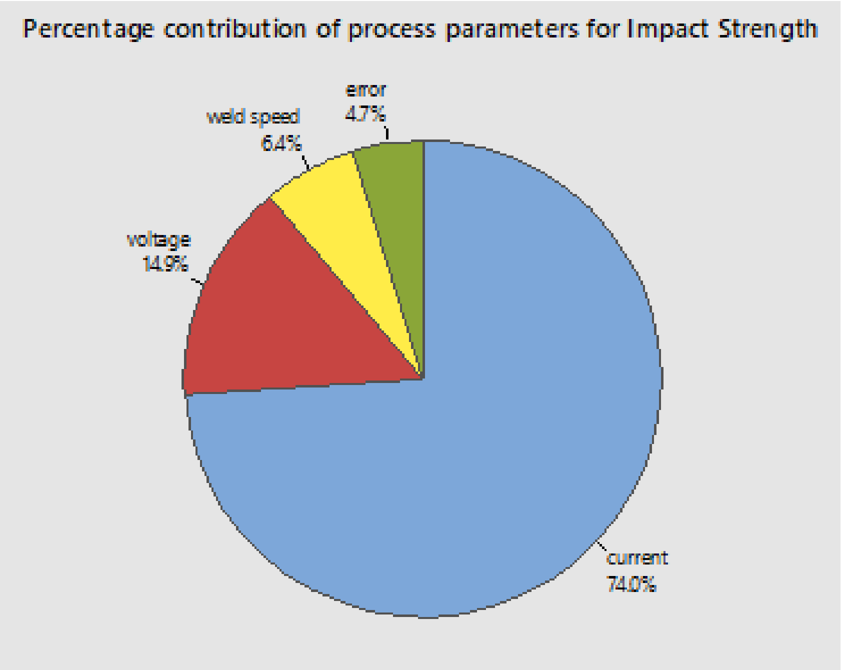
	S/N Ratios			Means		
Level	Current (A)	Voltage (V)	Weld speed (mm/sec)	Current (A)	Voltage (V)	Weld speed (mm/sec)
1	**31.64**	**29.81**	**31.31**	39.60	33.77	38.88
2	29.40	29.42	28.67	30.29	29.99	27.69
3	27.93	29.73	28.98	24.92	31.06	28.24
Delta	3.71	0.39	2.64	14.68	3.78	11.19
Rank	1	3	2	1	3	2



Graph 7.2 Percentage Contribution of process Parameters for Hardness

7.2 ANOVA for Impact Strength

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Current	2	24.999	73.98%	24.999	12.4997	15.63	0.060
Voltage	2	5.044	14.93%	5.044	2.5220	3.15	0.241
Weld speed	2	2.147	6.36%	2.147	1.0737	1.34	0.427
Error	2	1.600	4.73%	1.600	0.8000		
Total	8	33.791	100.00%				



Graph 7.3 Percentage Contribution of process parameters for Impact Strength

Exp. No	NORMALIZED SEQUENCES			DEVIATION SEQUENCES		
	UTS	H	IS	UTS	H	IS
1	1.000	0.654	0.500	0.000	0.346	0.500
2	0.414	0.557	0.250	0.586	0.443	0.750
3	0.217	0.134	0.250	0.783	0.866	0.750
4	0.000	0.183	0.500	1.000	0.817	0.500
5	0.279	1.000	0.000	0.721	0.000	1.000
6	0.503	0.000	0.250	0.497	1.000	0.750
7	0.099	0.469	0.250	0.901	0.531	0.750
8	0.062	0.303	1.000	0.938	0.697	0.000
9	0.132	0.275	0.750	0.868	0.725	0.250

Table No: 7.4 Results for Comparability & Deviation Sequences

Exp. No.	CURRENT	VOLTAGE	WELD SPEED	Grey Relational Coefficient			Grey relational grade	Order
				UTS	H	IS		
1	135	18	3.2	1.000	0.591	0.333	0.642	1
2	135	22	3.5	0.460	0.530	0.400	0.464	5
3	135	26	3.8	0.390	0.366	0.400	0.385	9
4	145	18	35	0.333	0.380	0.500	0.404	8
5	145	22	3.8	0.409	1.000	0.400	0.603	2
6	145	26	3.2	0.502	0.333	0.400	0.412	7
7	155	18	3.8	0.357	0.485	0.400	0.414	6
8	155	22	3.2	0.348	0.418	1.000	0.588	3
9	155	26	3.5	0.365	0.408	0.667	0.480	4

Table No: 7.5 Results for Grey Relation Coefficient and Grey relation grades

VIII. RESULTS AND DISCUSSION:

The Radiography testing were conduct with utmost care and safety and all the precautions were taken so that were obtained results would not deviate from the desired ones. The radiography testing results were obtained on a radiograph, which is shown in the films below. The defects that are observed on the radiography test are root undercut and lack of penetration.

- The first film was taken by conducting radiography testing on specimen-1, there were no defects found in the specimen.
- The second film was taken by conducting radiography testing on specimen-2, there were no defects found in the specimen.
- The third film was taken by conducting radiography testing on specimen-3, there were no defects found in the specimen.
- The fourth film was taken by conducting radiography testing on specimen-4, there were defects found in the specimen. i.e., root undercut.
- The fifth film was taken by conducting radiography testing on specimen-5, there were no defects found in the specimen.
- The sixth film was taken by conducting radiography testing on specimen-6, there were defects found in the specimen, i.e., lack of penetration.
- The seventh film was taken by conducting radiography testing on specimen-7, there were no defects found in the specimen
- The eighth film was taken by conducting radiography testing on specimen-8, there were no defects found in the specimen
- The ninth film was taken by conducting radiography testing on specimen-9, there were defects found in the specimen, i.e., incomplete penetration.

Fig. 8.1: gamma radiographic films for specimens 1-9

Results of Radiography testing of specimens is given below:

Sample no.	Current (amperes)	Voltage (volts)	Weld Speed (mm/sec)	Observations of gamma ray radiography test	Remarks
1	135	18	3.2	No significant defect	Acceptable
2	135	22	3.5	No significant defect	Acceptable
3	135	26	3.8	No significant defect	Acceptable
4	145	18	3.5	Root Undercut	Rejected
5	145	22	3.8	No significant defect	Accepted
6	145	26	3.2	Lack of penetration	Rejected
7	155	18	3.8	No significant defect	Acceptable
8	155	22	3.2	No significant defect	Acceptable
9	155	26	3.5	Incomplete penetration	Rejected

Table 8.1 Radiography testing results of specimens

8.1 RESULTS OF DESTRUCTIVE TESTING:

Mechanical testing is carried out on all test specimens to investigate the effect of mechanical properties on chrome alloy steel. The results of mechanical properties like tensile strength, hardness and impact strength are tabulated below.

			(JOULES)
Specimen-1	54.614	282.33	12
Specimen-2	35.322	271.00	10
Specimen-3	28.864	221.67	10
Specimen-4	21.714	227.33	12
Specimen-5	30.890	322.67	8
Specimen-6	38.279	206.00	10
Specimen-7	24.968	260.67	16
Specimen-8	23.758	241.33	16
Specimen-9	26.043	238.67	14

Table 8.2 Destructive testing results

8.3 ANOVA Analysis:

The ANOVA analysis is conducted to know the percentage contribution of the process parameters on Tensile Strength, Hardness and Impact Strength. ANOVA analysis results shows that the, for Tensile Strength percentage contribution of current is 42.21%, Voltage is 0.50%, Welding speed is 25.07%. This shows that the influence of Current is more compare to the Voltage and Welding speed on Tensile Strength.

While for Hardness percentage contribution of Current is 2.13%, Voltage is 49.65%, Welding speed is 10.23%. This shows that the influence of Voltage is more compare to the current and welding speed on Hardness.

For Impact Strength, the percentage contribution of Current is 73.98%, Voltage is 14.93%, and Welding speed is 6.36%. This shows that the influence of Current is more compare to Voltage and Welding speed on Impact Strength.

IX.CONCLUSION

The following conclusions are drawn from the experimental investigation carried out on EN31 Alloy steel to find out the defects on TIG welded joints by performing destructive and non-destructive testing. It can be concluded from this work that different types of defects such as Lack of penetration, root undercut were originated in the welded joints.

Radiography testing has higher penetrating power than ultrasonic testing and can detect the flaws deep in the test object. It is quite sensitive to small flaws and allows the precise determination of the location and size of the flaws. It can also be concluded that radiography testing method is good for testing of welding defects.

The best results in whole process is obtained for the specimen 1(corresponding to current – 135A, voltage – 18V and speed – 2.2mm/sec), for this specimen the ultimate tensile strength = 54.614 N/mm^2, the Charpy impact strength = 10 J, the hardness (HV_{10}) = 221.67

The worst result in whole process is obtained for the specimen – 4(current – 145A, voltage – 22V and speed – 2.4mm/sec) for this specimen the ultimate tensile strength = 21.714 N/mm^{2,} the Charpy impact strength = 8 J, the hardness (HV_{10}) = 227.33

The optimal results in whole process is obtained for the specimen – 5(corresponding to current – 155A, voltage – 18V and speed – 2.2mm/sec) for this specimen the ultimate tensile strength = 30.890 N/mm^{2,} the Charpy impact strength =10 J, the hardness (HV_{10}) = 322.67.

Taguchi Analysis:
Tensile Strength Current =135A, Voltage = 18V, Weld speed = 3.2mm/sec
Hardness- current =135A, Voltage=22V, Weld speed= 3.5mm/sec
Impact Strength-Current=155A, Voltage=24V, Weld speed= 3.2mm/sec
Taguchi Grey Relational Analysis:
Current=155A, Voltage= 22V, Weld speed= 3.2mm/sec

ANOVA analysis:
From ANOVA it can be concluded that Current is the most influential parameter on Tensile Strength and Impact strength, Voltage is the influential parameters for Hardness.
By considering all these observations Radiography test gives the best results when we are going to find the defects between the joints and the best optimal parameters to weld EN31 alloy steel by TIG welding are current 155A, voltage 22V , Weld speed 3.2mm/sec.

X. References:

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