OPTIMIZATION OF PROCESS PARAMETERS FOR MIG WELDING ON ASTM A36 MILD STEEL PLATE

[1]P Surendra, [2] B Krishna Murthy, [3] M V Kiran Kumar
[1]Associate Professor, 2Assistant Professor, 3Assistant Professor
[1]Department of Mechanical Engineering,
[1]Sasi Institute of Technology & Engineering, Tadepalligudem, India

Abstract: Metal Inert Gas (MIG) welding is the most widely used welding process in the small scale industries, as well as domestic house hold purpose because of its versatility and flexibility. In manual welding operation, the welder has to have control over the welding parameters which affect the weld penetration, bead geometry and overall weld quality. The welding parameters are welding current, welding voltage, Gas flow rate. ASTM A36 mild steel plates are joined by MIG welding process at different values of input parameters by using L9 orthogonal array in taguchi method. In taguchi method design of experiment technique is used to find out optimal welding parameters. The analysis of signal to noise ratio is done using MINITAB 18 software. An orthogonal array and signal to noise (S/N) ratio are employed to optimize the welding parameters. In this paper it is found that influence of Current, Voltage and Gas flow rate on Tensile strength of welded joint. The tensile strength of metal joints has investigated. Finally suggested the optimal combination of input parameters based on software results.

***Index Terms* - Metal Inert Gas (MIG), MINITAB 18, Taguchi Technique, Welding Current, Welding Voltage, Gas Flow Rate.**

I. INTRODUCTION

Metal Inert Gas (MIG) welding is a joining technique in which an electric arc forms between the wire electrode and the work piece metal, which heats the work piece metal causing them to melt and join. In this welding process, a consumable electrode is used. Metal inert gas (MIG) welding is referred as a Gas Metal Arc Welding (GMAW). The variety of shielding gases used in MIG welding are carbon dioxide, argon and mixture of argon and helium are used. Usually argon, helium, or a suitable mixture of this, is used as an inert gas to protect the weld from atmosphere.

MIG welding parameters are affecting the quality, productivity and cost of welding. The welding parameters are welding current, welding voltage, Gas flow rate, wire feed rate, they influence weld strength, weld geometry of Steel material during welding. GMAW was applied to steels because it is fast welding process compared to other welding processes. In this paper, investigation will be done on the process parameters using MIG welding on ASTM A36 mild steel material to obtain the optimized results by using Taguchimethod.

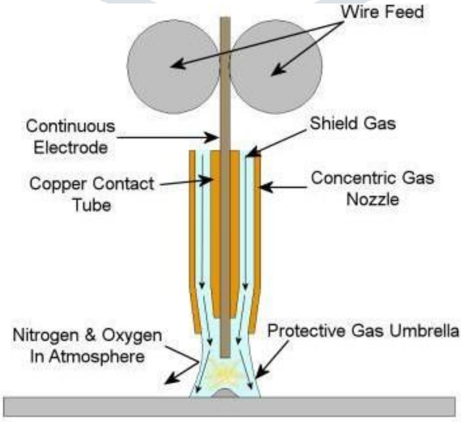

Fig.1 Principleof MIG welding

II. WORKING MATERIAL

ASTM A36 Mild/Low Carbon Steel

ASTM A36 is the most commonly used mild and hot-rolled steel. It has excellent welding properties and is suitable for grinding, punching, tapping, drilling and machining processes. Melting point of ASTM A36 mild steel material is 1510°C (2750°F).

A36 steel has a Poisson's ratio of 0.26, and a shear modulus of 75 GPa (10,900,000 psi). A36 steel in plates, bars, and shapes with a thickness of less than 8 in (203 mm) has minimum yield strength of 36,000 psi (250 MPa) and ultimate tensile strength of 58,000–80,000 psi (400–550 MPa)

Composition of ASTM A36 mild steel material

Table: 1 composition of ASTM A36 mild steel material

S.No.	Element	Composition (%)
1.	Carbon(C)	0.25-0.29
2.	Copper(Cu)	0.2
3.	Iron(Fe)	98
4.	Manganese(Mn)	1.03
5.	Phosphorus(P)	0.04
6.	Silicon(Si)	0.28
7.	Sulphur(S)	0.05

Heat Treatment Process for ASTM A36 Mild Steel

Heat treatment is the heating and cooling of metals to change their physical and mechanical properties, without letting it change its shape.

The purpose of heat treatment is to soften the metal, to change the grain size, to modify the structure of the material and to relieve the stress set up in the material after hot and cold working.
Heat treatment processes are

a)Annealing
b)Normalizing
c)Hardening
d)Carburizing
e)StressRelieving

Properties of ASTM A36 Mild Steel

Physical properties

Table: 2 Physical Properties of ASTM A36 mild steel

Properties	Metric
Density	7.85 g/cm^3

Mechanical Properties

Table: 3 Mechanical Properties of ASTM A36 mild steel

S.No.	Mechanical Properties	Metric
1	Tensile Strength(Ultimate)	400 - 550 MPa
2	Tensilestrength(yield)	250 MPa
3	Modulus of Elasticity	200 GPa
4	Bulk modulus	140 GPa
5	Poisson’s Ratio	0.26
6	Shear modulus	79.3 GPa
7	Elongation at Break (in 200 mm)	20%
8	Elongation at Break (in 50 mm)	23%
9	Hardness (Brinell)	119 - 159
10	Hardness (Rockwell B)	67 - 83

Application of ASTM A36 mild steel

a) It is used in bolted, riveted or welded construction of bridges, buildings and oil rigs.
b) It is used in forming tanks, bins, bearing plates, fixtures, rings, templates, jigs, sprockets, cams, gears, base plates,

forgings, ornamental works, stakes, brackets.
c) It is used in automotive and agricultural equipment, frames, and machinery parts.
d) It is used for various parts obtained by flame cutting such as in parking garages, walkways, boat landing ramps and trenches.
e) ASTM A36 steel plate is one of the most widely used carbon structural steels used in the industry.

III. PROCESS PARAMETERS

Input parameters

1. Weldingcurrent
2. Arcvoltage
3. Polarity
4. Electrode
5. Gas flowrate
6. Length of stickout
7. Shielding gascomposition

Welding current

Welding current depends up on welded metal thickness and metal transfer mode required to the parent metal properties. For metal thickness (T)

T < 7mm=100-200 amps
T 7-8mm=200-450 amps
T >8mm=450-700 amps

Arc voltage

In MIG process we generally use constant voltage is used 200 amp it is kept in between 20- 30V for mild steel work piece.

Polarity

a) In MIG we use DCEP (Direct Current Electrode Positive) or reversepolarity
b) Positive terminal to electrode wire, negativeterminal
c) DC ensure elimination of arc blow to weldfixture
d) Heating effect is produced on electrode wire mainly for welding sheetmetal

Electrode

a) It ranges from 0.7mm to 2.4mm depending upon current metal
b) With higher current diameter should be larger and vice versa
c) Diameter of electrode is dependent on welding current For current ranging from 100- 200amps 0.8-1.2 mm diameter is used
d) Electrode is made of same as parent metal coated with deoxidizing agents such as copper, it also prevents impurities

Gas flow rate

a) The four primary variations of GMAW have differing shielding gas flow requirements for the small weld pools of the short circuiting and pulsed spray modes, about 10 L/min is generally suitable, while for globular transfer, around 15 L/min is preferred
b) Here we use dip mode and require good shielding so rate is kept between 20-30 L/min

Length of stick out

a) Length of stick out is generally kept between 10-12mm
b) For stable arc it should not be large
c) It is controlled by self regulation characteristic of MIG welding

Shielding gas composition

a) Shielding gases are necessary for gas metal arc welding to protect the welding area from atmospheric gases such as nitrogen and oxygen, which can cause fusion defects, porosity, and weld metal embrittlement if they come in contact with the electrode, the arc, or the weldingmetal.

b) The most commonly used gas is argon, it is generally mixed with other gases such as CO2.

c) Pure argon doesn't provide much penetration with ferrousmetals.

IV. DESIGN OF EXPERIMENTS USING TAGUCHI METHODOLOGY

TaguchiMethod

The Taguchi methodology involves reducing the variation in a process through robust design of experiments. The overall objective of the method is to make high quality product at low cost to the manufacturer. The Taguchi methodology was developed by Dr. G. Taguchi. He developed a methodology for designing experiments to investigate how different parameters influence the mean and variance of a process performance characteristic that defines how well the process is functioning.

The experimental design planned by Taguchi involves using orthogonal arrays to organize the parameters affecting the process parameters and the levels at which they should be varied.

Instead of having to test all possible Combinations like the factorial design, the Taguchi methodology tests pairs of combinations. This allows for the collection of the necessary data to decide which factors most affect the product quality with a minimum amount of experimentation, thus saving time and resources. The Taguchi methodology is best used when there are an intermediate number of variables (3 to 50), few interactions between input variables, and when only a few variables contributesignificantly.

Properties of an orthogonal array

The orthogonal array has the following properties, which reduce the number of experiments to be conducted.

1.The vertical column below each independent variables of the table has special combinations of level settings. All the level settings are appeared an equal number of times. For L9 array under variable 4, level 1, level 2 and level 3 appears in three times. This is called the balancing property of orthogonalarrays.

2.All the level values of independent variables are used for conducting the experiments

3.The sequence of level values for conducting the experiments shall not be changed. This means one cannot conduct experiment 1 with variable 1, level 2 setup and experiment 4 with variable 1, level 1setup.

4.The reason for this is that the array of each factor columns is mutually orthogonal to any other column of level values. The inner product of vectors corresponding to weights is zero. If the above 3 levels are normalizedbetween

-1 and 1, then the weighing factors for level 1, level 2 , level 3 are -1 , 0 ,1 respectively. Hence the inner product of weighing factors of independent variable 1 and independent variable 3 would be

$$(-1 \times -1)+(-1 \times 0)+(-1 \times 1)+(0 \times 0)+(0 \times 1)+(0 \times -1)+(1 \times 0)+(1 \times 1)+(1 \times -1)=0$$

Minimum Number of Experiments to be conducted

The design of experiments using the orthogonal array is, in most cases, efficient when compared to many other statistical designs. The minimum number of experiments that are required to conduct the Taguchi method can be calculated based on the degrees of freedom approach. Before selecting an orthogonal array, the minimum number of experiments to be conducted is to be fixed based on the formula as mentioned in the below Equation

$$N = 1 + \mathrm{NV}(L-1)$$

Where

N = Number of experiments to be conducted
NV = Number of factors or variables
L = Number of levels

For example, in case of 8 independent variables with 3 levels (L9 Orthogonal array), the minimum number of experiments required based on the above equation is 9. Because of the balancing property of the orthogonal arrays, the total number of experiments shall be multiple of 2 and 3. Hence the number of experiments for the above case is 27. The following standard orthogonal arrays are commonly used to design experiments:

2-Level Arrays: L4, L8, L12, L16,L32

3-Level Arrays: L9, L18, L27 4-Level Arrays: L16,L32

In this work L_9 is sufficient. It would require a total of 27 experiments to optimize the parameters. Taguchi experimental design of experiments suggests L9 orthogonal array, where 9 experiments are sufficient to optimize the parameters. Based on main factor, the variables are assigned at columns, as stipulated by orthogonal array. The last column can be kept dummy, but no row should be left out. Once the orthogonal array is selected, the experiments are selected as per the level combinations. It is important that all experiments are conducted. The performance parameter (output) is noted for each experimental run for analysis.

V. PRE-EXPERIMENTAL PLANNING

In the present work we choose the factors and levels with their magnitude as shown in below Table 4.1.

Table: 4 Input parameters and their level

Process parameters	Symbol	Units	Level- 1	Level- 2	Level- 3
Current	I	Amp	150	160	170
Voltage	V	Volt	20	24	28
Gas flow rate	GAS	lit/min	20	25	30

Selection of Taguchidesign

Before enter or analyze measurement data in Minitab, first create an experimental design and store it in the worksheet. Depending on the requirements of the experiment choose from a variety of designs.
Minitab helps you select a design by providing a list of all the available designs. Once chosen the design and its features, Minitab automatically creates the design and stores it in the worksheet as shown in Fig. In this process select the taguchi design by choose Stat ➔DOE ➔ Taguchi ➔Create Taguchi Design
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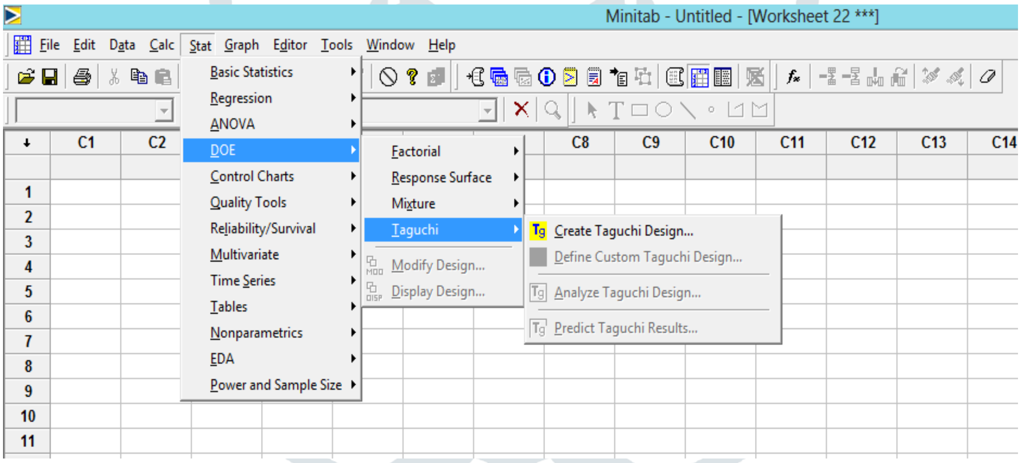

Fig.2 mini tab worksheet-selection of taguchi design

Selection of the factors and levels

Once the number of independent variables or factors and number of levels for each variable is decided. Then select level of design and number of factors as shown in Fig.3

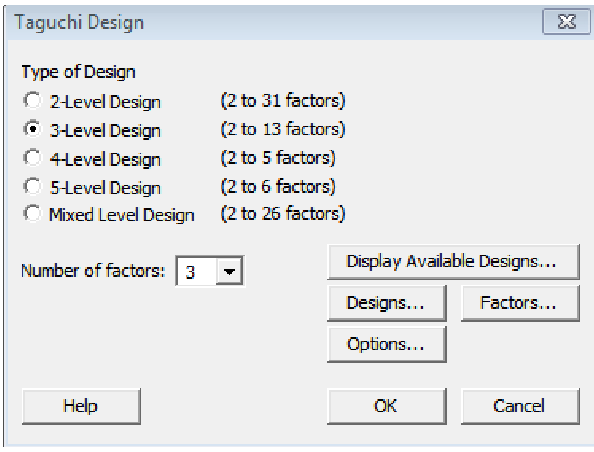

Fig.3 Selection of design level and factors

Selection of an orthogonalarray

Before selecting the orthogonal array, the minimum number of experiments to be conducted shall be fixed based on the total number of degrees of freedom present in the study. The minimum number of experiments that must be run to study the factors shall be more than the total degrees of freedom available. Hence the total degrees of freedom without interaction effect is 1 + as already given by Equation 4.1. For example, in case of 11 independent variables, each having 2 levels, the total degrees of freedom is 12. Hence the selected orthogonal array shall have at least 12 experiments. An L_{12} orthogonal satisfies this requirement.

Once the minimum number of experiments is decided, the further selection of orthogonal array is based on the number of independent variables and number of factor levels for each independent variable is shown below Fig. 4

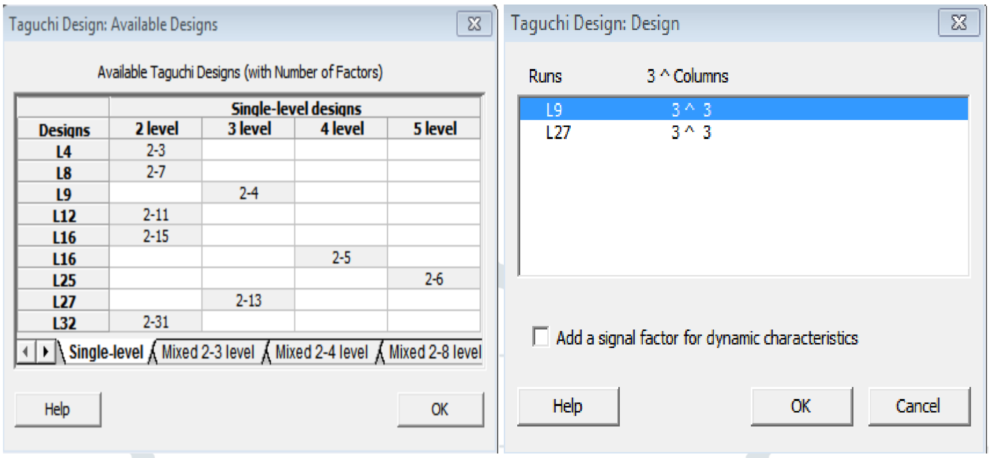

Fig.4 Selection of Orthogonal array (L_9)

Assigning the independent variables to columns

The order in which the independent variables are assigned to the vertical column is very essential.
The following way to assign the factors names and level values
Taguchi Design − Factors (Static Design) Stat > DOE > Taguchi > Create Taguchi Design > Factors Allows to name or rename the factors and assign values for factor settings and assign factors to array columns with the help of table 4. Minitab automatically assigns factors to array columns as shown in Fig.5

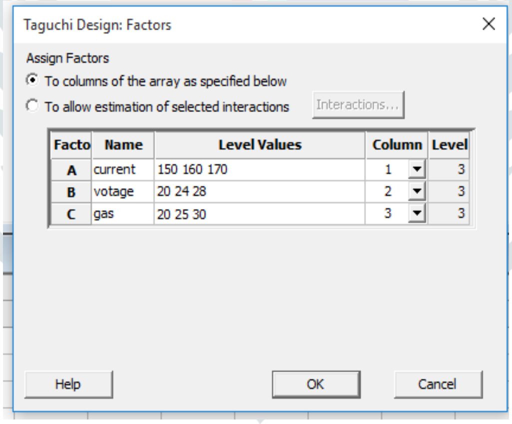

Fig.5 Assigning factors names and values

L9 Orthogonal array

After assigning the factors names and their level values, click ok, then a L_9 orthogonal array is displayed on computer screen as shown in below Fig

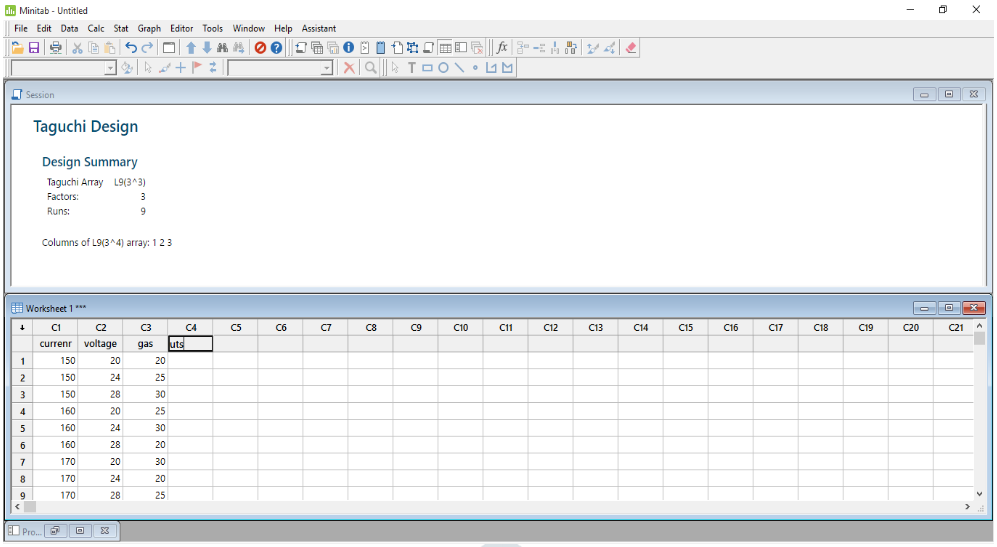

Fig.6 Final Orthogonal array (L_9)

After completion of Decision of Experiment the experimental runs are enlisted in Table 5.

Table: 5 designed machining input parameter as per taguchi method

Input Parameters			
Exp. No	**Current [A]**	**Voltage [V]**	**Gas flow rate [lit/min]**
1	150	20	20
2	150	24	25
3	150	28	30
4	160	20	25
5	160	24	30
6	160	28	20
7	170	20	30
8	170	24	20
9	170	28	25

VI. RESULTS

Firstly the tensile strength and hardness values of MIG welding measured on each specimen. To analyze the results of experiments involving multiple runs, use of the S/N ratio is preferred over standard analysis, because S/N ratio offers objective comparison of two sets of experimental data with respect to variation around the target and the deviation of the average from the targetvalue.
Hence for calculation of tensile strength, consider the S/N ratios of the observed result. The results obtained for Welding on Material ASTM A36 mild steel are given in Table 6 and for the S/N ratios given in Table 7 and Table 8

Table: 6 experimental results for tensile strength

Exp. No.	**Current (amp)**	**Voltage (volt)**	**Gas flow rate (lit/min)**	**Tensile strength (MPa)**
	A	B	C	
1	150	20	20	304.16
2	150	24	25	387.5
3	150	28	30	341.66
4	160	20	25	375
5	160	24	30	366.66
6	160	28	20	333.33
7	170	20	30	400
8	170	24	20	320.83
9	170	28	25	370.8

Table: 7 experimental results S/N ratio for tensile strength

Exp. No	**Tensile Strength (MPa)**	**S/N Ratio**	**Mean**
1	304.16	49.6620	304.16
2	387.5	51.7654	387.50
3	341.66	50.6719	341.66
4	375	51.4806	375.00
5	366.66	51.2853	366.66
6	333.33	50.4575	333.33
7	400	52.0412	400.00
8	320.83	50.1255	320.83
9	370.8	51.3828	370.80

The rank in the Table: 8, indicates that the increasing order of effect on the response variable is as follows current (amp), voltage (volt), and gas flow rate (lit/min). The main effects plot for Means and S/N ratios with respect to the tensile strength and three parameters at the three levels is shown in Fig.7 and Fig 8 as obtained from the MINITAB-18

Response table for S/N ratios of tensile strength for the three parameters at the three levels are calculated from Table 6, 7 & 8

Table: 8 Response table for S/N ratios of Tensile Strength

Level	Current (amp)	Voltage(volt)	Gas flow rate (lit/min)
	A	**B**	**C**
1	50.70	51.06	50.08
2	51.07	51.06	51.54
3	51.18	50.84	51.33
Delta	0.48	0.22	1.46
Rank	**2**	**3**	**1**

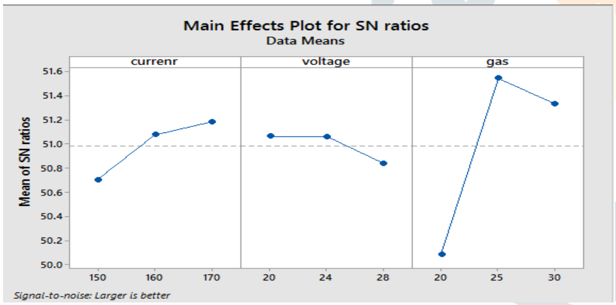

Fig.7 Main Effects Plot for S/N ratio (Tensile Strength**)**

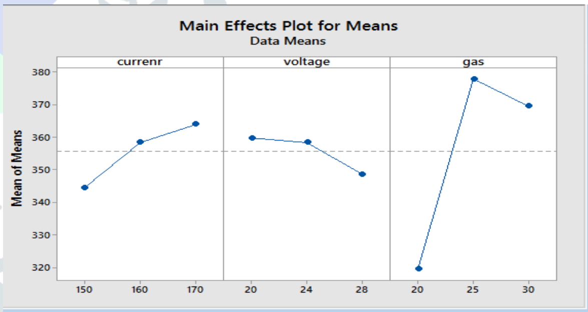

Fig.8 Main Effects Plot for Means (Tensile Strength**)**

Table: 9 Confirmatory Test Results

Optimum parametric condition obtained by Taguchi method		Tensile strength (MPa)
Current(A)	170	429.167
Voltage(V)	20	
Gas flow rate (lit/min)	25	

VII. CONCLUSION

In this work experiments are carried out for tensile strength with respect to variation of current, voltage and gas flow rate. There are 9 experimental readings taken for variation of input parameters based on L9 orthogonal array. MIG welding process is very successful to join ASTM A36 mild steel plates. The optimum value was predicted using MINITAB 18 software. Based on the signal to noise ratio and confirmatory test results, the process parameter values affect the tensile strength.

The optimum parameter values for tensile strength (A3 B1 C2) i.e., current 170amps, voltage 20volts, gas flow rate 25lit/min.

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