Design and Thermal Analysis of Plasma Torch Nozzle

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Abstract - *A simple model of plasma nozzle is design and developed and studied under various parameters. Understanding the thermal behavior and calculating the thermal deformation on orifice of nozzle and studying the effect of adding different composition of nozzle materials. In this study, material removal rate and surface roughness is considered to observe effect of using different material in nozzle manufacturing. Analysis of nozzle in ANSYS software is done to support thesis work and found that developed nozzle shows better results than existing one.*

*Key Words***:** *Nozzle, Plasma, ANSYS*

1. INTRODUCTION

The topic for the thesis writing is the Analysis of Process Parameters of Plasma Arc Cutting Using Design of Experiment Techniques. The focus on this project is to obtain an optimum condition (setting) to obtain maximum MRR and minimum the surface roughness (SR) with maximum nozzle life.

Plasma arc cutting (PAC) is a process of metal cutting by a plasma jet. It is becoming increasingly popular because of its high productivity and ability to cut practically all metals. In most cases the current-carrying plasma jet strikes between the cathode located inside the torch and the metal to be cut (the so-called transferred arc configuration). In order for the plasma jet to provide a fast and high quality cut, the jet emanating from the torch should be narrow and hot. Also, it has to exert enough force on the work piece to remove the molten metal from the cut. This is made possible by a special nozzle inside the torch. The nozzle is an electrically neutral duct, through which the plasma is blown out of the torch. The nozzle creates a narrow, highly concentrated plasma flow. The narrowness of the nozzle causes a large voltage drop in the plasma inside the nozzle. Consequently, the resistance heating heats the plasma jet inside the nozzle very intensely. Also, the nozzle provides the high velocity of the arc jet and fast removal of the molten metal during cutting. Together with the electrode, the nozzle is one of the most vulnerable parts of the torch due to its exposure to extremely high heat fluxes. In contemporary systems, heat-flux densities above 103 W cm−2 are the rule rather than the exception. However, even minor melting of the orifice causes the cut's quality to deteriorate and slows down the cutting process. What is worse, in some circumstances, the nozzle develops the so-called double-arcing phenomenon (figure 1), namely two arcs are created: one from the electrode to the nozzle and another from the nozzle to the work piece. The

nozzle becomes an electrical conduit connecting these two arcs. This catastrophically damages the nozzle and, in most cases, destroys the electrode as well. While designing a nozzle, it is necessary to satisfy a number of contradictory conditions. In order to provide a fast, constricted and hot jet, the nozzle should be long and narrow. To increase the force that the plasma exerts upon the work piece, the gas pressure in the plenum chamber (see figure 1) should be high. On the other hand, the longer and the narrower the orifice the higher it is thermally loaded and the higher the risk of double arcing. Also, the higher the chamber pressure the higher the electrode-erosion rate. We see that designing a nozzle necessitates a series of trade-offs. Therefore, it would be desirable to develop a model allowing, if not precise calculations of plasma-flow parameters in the chamber and the nozzle, then at least an initial approximation to an at present mostly empirical endeavor.
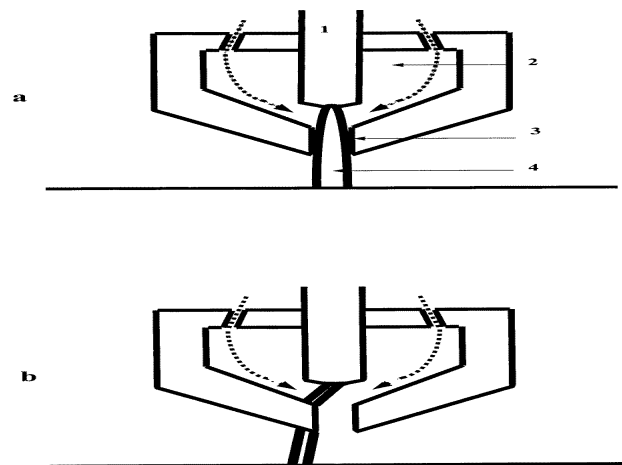
Fig-1 Normal operation (a) and double arcing (b) during plasma arc cutting: 1, electrode; 2, plenum chamber; 3, nozzle orifice; and 4, plasma jet.

1.1 Nozzle materials

Copper–tungsten (**tungsten–copper**, **CuW**, or **WCu**) is a mixture of copper and tungsten. As copper and tungsten are not mutually soluble, the material is composed of distinct particles of one metal dispersed in a matrix of the other one. The microstructure is therefore rather a metal matrix composite instead of a true alloy. The material combines the properties of both metals, resulting in a material that is heat-resistant, ablation-resistant, highly thermally and electrically conductive, and easy to machine. Parts are made from the CuW composite by pressing the tungsten particles into the desired shape, sintering the compacted part, then infiltrating

with molten copper. Sheets, rods, and bars of the composite mixture are available as well.

Commonly used copper tungsten mixtures contains 10–50 wt.% of copper, the remaining portion being mostly tungsten. The typical properties is dependent on its composition. The mixture with less wt.% of copper has higher density, higher hardness, and higher resistivity. The typical density of CuW90, with 10% of copper, is 16.75 g/cm^3 and 11.85 g/cm^3 for CuW50 . CuW90 has higher hardness and resistivity of 260 HB kgf/mm^2 and 6.5 $\mu\Omega.cm$ than CuW50.

Table -1: Sample Table format

Composition	Density	Hardness	Resistivity	IACS	Bending strength
wt. %	$g/cm^3\geq$	HB $Kgf/mm^2\geq$	$\mu\Omega.cm\leq$	$\%\geq$	$Mpa\geq$
W50/Cu50	11.85	115	3.2	54	–
W55/Cu45	12.30	125	3.5	49	–
W60/Cu40	12.75	140	3.7	47	–
W65/Cu35	13.30	155	3.9	44	–
W70/Cu30	13.80	175	4.1	42	790
W75/Cu25	14.50	195	4.5	38	885
W80/Cu20	15.15	220	5.0	34	980
W85/Cu15	15.90	240	5.7	30	1080
W90/Cu10	16.75	260	6.5	27	1160

1.2 Manufactured Nozzle alloy

As from the sources available, manufactured nozzle raw material was selected as w60/Cu40 Having 60% weight of tungsten and 40% weight of copper.

2. DESIGN OF NOZZLE

Design of nozzle is done siemens NX cad software having same dimensions as that of available aftermarket nozzle.

Designed nozzle for material W60Cu40 is manufactured on DAEWOO CNC lathe machine of has accuracy 3 micron**.**

3. EXPERIMENTAL CONSIDERATIONS AND FORMULATIONS

3.1. MATERIAL REMOVAL RATE

The material removal rate, MRR, can be defined as the volume of material removed divided by the machining time. Material Removal Rate (MRR) is defined by:

MRR = WRW/T [g/min]

Where,

WRW: work piece removal weight (g) T: cutting time(s)

WRW is the weight different between before and after work piece cutting. The volume different can be calculated when information regarding material density available. The relation between WRW and WRV is given as follow:

WRV = WRW/ρ

Where,

ρ : Work piece density (g/ mm^3)

The density of the Nickel-Base Alloys is 8 g/cm^3 or 0.008g/mm^3.

3.2. SURFACE ROUGHNESS

Roughness is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough, if they are small the surface is smooth. Roughness is typically considered to be the high frequency, short wavelength component of a measured surface. Surface roughness normally measured.

Roughness plays an important role in determining how a real object will interact with its environment. Rough surfaces usually wear more quickly and have higher friction coefficients than smooth surfaces (see tribology). Roughness is often a good predictor of the performance of a mechanical component, since irregularities in the surface may form nucleation sites for cracks or corrosion.

In this thesis, the average surface roughness is measured and calculated. The average surface roughness is the integral of the absolute value of the roughness profile height over the evaluation length and is denoted by the following equation.

$$R_a = \frac{1}{L}\int_0^L |Y(x)|dx$$

Where L is the length taken for observation, and Y is the ordinate of the profile curve.

3.3 OBSERVING NOZZLE ORIFICE.

Observing the nozzle orifice of ranging between 0.5 to 1.2 mm diameter under microscope and for total deformation due to heat and tallying it with the newly developed.

4. EXPERIMENTAL LAYOUT

Since in my thesis work there are four factors and two levels for each which are shown below:

Table-2 Values of Variables at Different Level

Control Factors	Unit	Level 1	Level 2	DOF
Gas Pressure	bar	5	6	1
Current Flow Rate	ampere	42	45	1
Cutting Speed	mm/min	400	600	1
Arc Gap	mm	2	4	1

After deciding parameters and levels as shown, Data of parameter was collected in such a way that it shouldn't damage or cause any accident to operator and as per literature review. Now perform experiment on **Hyperthermia plasma machine**, output like MRR and surface roughness is being given in tabulated form. After the experimental results have been obtained, analysis of the results was carried out analytically as well as graphically. Graphical analysis of mmr and surface roughness is done by MINITAB, shows interactions of all parameters. Then ANSYS of the experimental data has been done to calculate the total deformation of each nozzle considering each factor in each response.

Then we obtain optimal conditions has been calculated for MRR and surface roughness of specimen. The following table shows readings of MRR and surface roughness at each experiment, it also shows S/N ratio for MRR and surface roughness at each experiments.

5. EXPERIMENTAL RESULTS FOR NOZZLE DEFORMATION AND MMR AND SURFACE ROUGHNESS

Observing aftermarket nozzle and developed w60cu40 nozzle under microscope and by normal eye contact.


Fig- 2 Developed One Nozzle Shows Minimum Deformation in Comparison of Aftermarket Nozzle
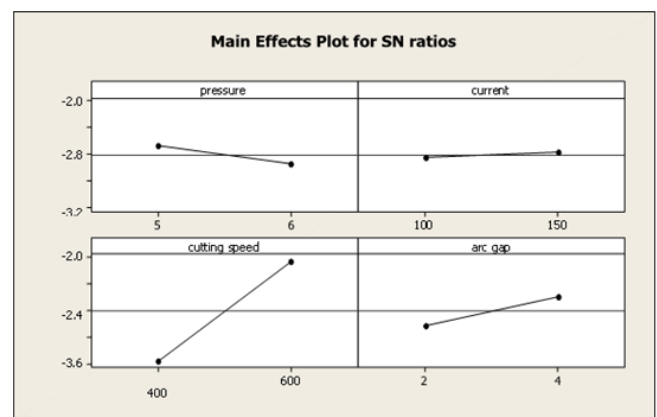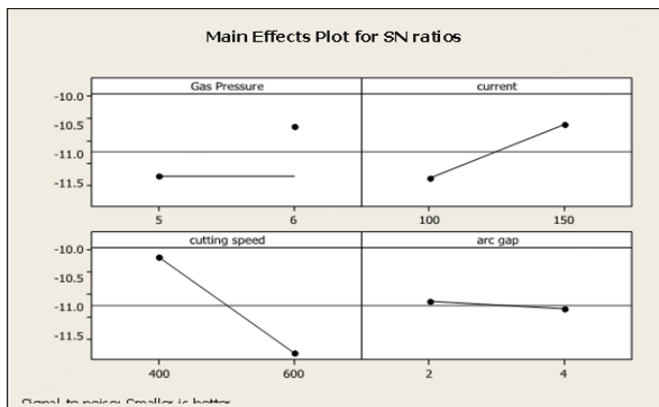

Graph-1 Effects of Various Factors on S/N Ratio of MRR

By using MINITAB software we obtain some interactions if we look at the graph we will observe that with increase in Gas Pressure MRR S/N ratio is decreasing. Material removal rate increases with increase in Current, Cutting Speed and Arc gap.
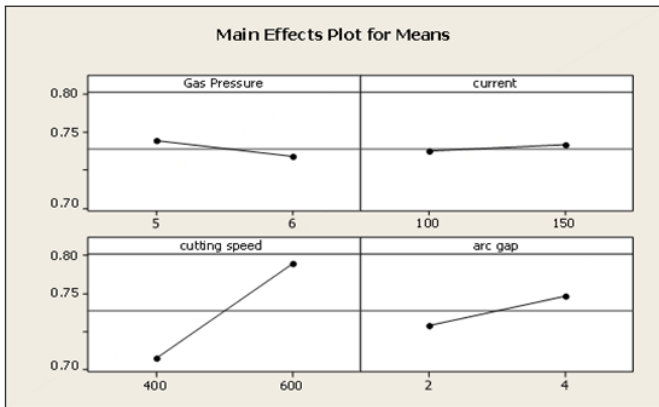
Graph-2 Effects of Various Factors on Mean of MRR

With the above graph of mean of MRR and various factors, we can observe that MRR is decreasing with increase in Gas Pressure and MRR is increasing with increase in Current, Cutting Speed and Arc Gap.

Graph-3 Effects of Various Factors on S/N Ratio of SR

Above graph represent the effect of parameters on Surface Roughness. It can be seen that as value of Gas Pressure and Current increases, S/N ratio of Surface roughness also increases. However S/N ratio of Surface roughness decreases with increase in the Cutting Speed and Arc Gap.

6. THERMAL ANALYSIS IN ANSYS SOFTWARE

Temperature were selected at nozzle tip =13000 Deg C
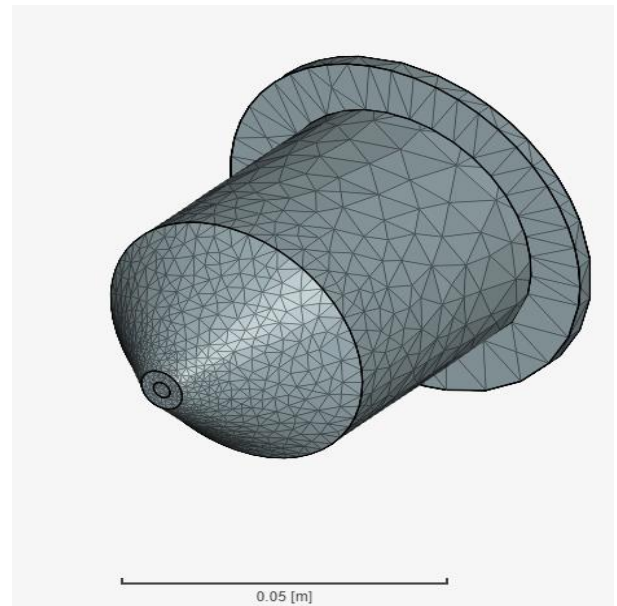Meshing – Fine and smooth

Fig.-3 Meshing – Fine and smooth

- **Considered parameter**

Steady state thermal
Temperature at orifice of nozzle -13000DegC
Normal Conduction
Non-linear heat transfer.
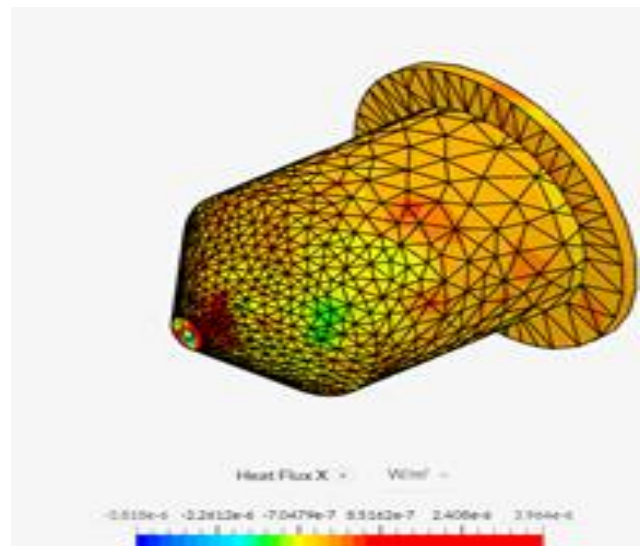Calculated maximum heat flux at tip of nozzle

Fig.-4 Aftermarket Available Nozzle Thermal Analysis Showing Total Heat Flux Material W10cu90
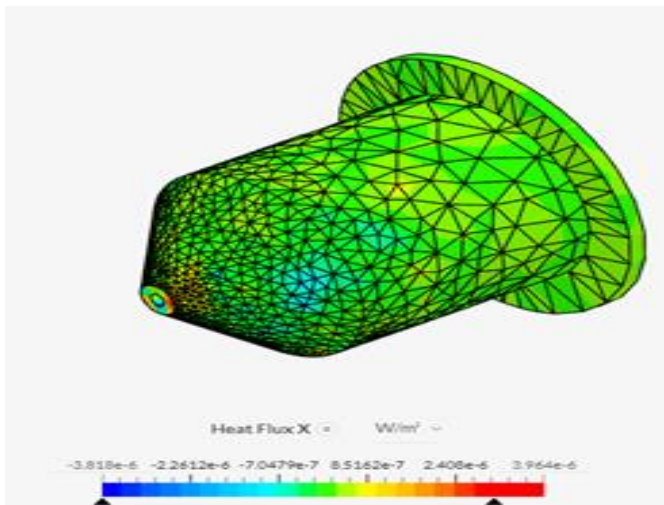
Fig.-5 eveloped Nozzle Thermal Analysis Showing Total Heat Flux Material W60cu40

7. RESULTS

Thermal analysis of plasma nozzle obtained using ANSYS software is done and verified on machine by taking several test for optimizing tool life with best cut results.
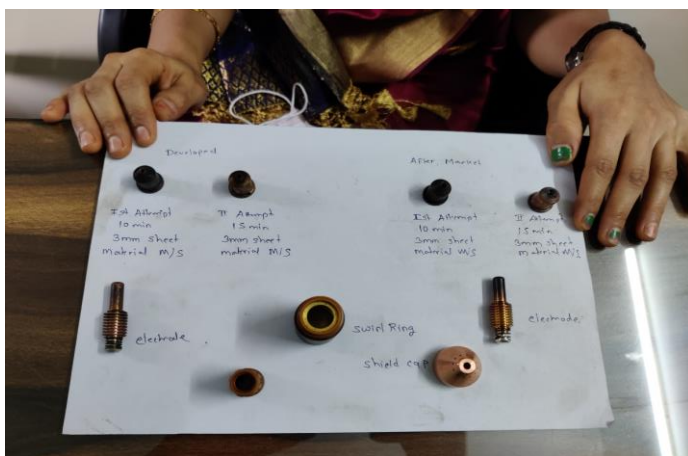

FIGURE 6.1 Operator Verify Results

Orifice of developed nozzle having material composition of w60cu40 was observed and found to be slightly deformed and as that in case of aftermarket nozzle, it was deformed more than developed nozzle while cutting parameters are kept same.

8. CONCLUSION

This thesis has presented for optimization of the nozzle life and machining parameters of Plasma Arc Cutting Machine. As shown in this study, method provides a systematic and efficient methodology for determining optimal parameters with far less work than would be required for most optimization techniques. The confirmation experiments were conducted to verify the optimal parameters. It has been shown that Material Removal Rate (MRR) and Surface Roughness (Ra) can be significantly improved in the Plasma Arc Cutting process using the optimum level of parameters

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