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An optimization and experimental analysis of plasma arc cutting of Hardox-400 using Taguchi based desirability analysis

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Abstract

The plasma cutting process is widely used in manufacturing or fabrication units for cutting the metal plates. The optimum selection of process parameters is essential for smoother and faster cutting. In this research work, experimental investigation of plasma arc cutting has been carried out. The workpiece material was taken as Hardox 400 which is very high resistance steel. This material has good bendability, high toughness and better weldability. Hardox 400 variously used in manufacturing of Dump truck, Front loaders, Barges and Buckets. Argon is used as the inert gas and oxygen gas was taken for shielding. During the cutting process, the parameters for the operation are varied cutting current, supply gas pressure, cutting speed and Standoff distance. The material removal rate, surface roughness chamfer and kerf are considered as the output responses. The individual effect of cutting parameters related to the output responses also described. Taguchi based desirability analysis (TDA) was observed to find the optimal cutting conditions for improving the quality characteristics of the plasma arc cutting process. The goal of the experiment was to maximize the MRR and minimize the other output responses. The confirmation test was obtained according to the optimal setting of process parameter in achieving the improved efficiency of plasma arc cutting machine. The result of this analysis will offer a better database for the industries. The outcomes of the investigations clearly show that the specific range of input process parameter achieved the improved machinability.

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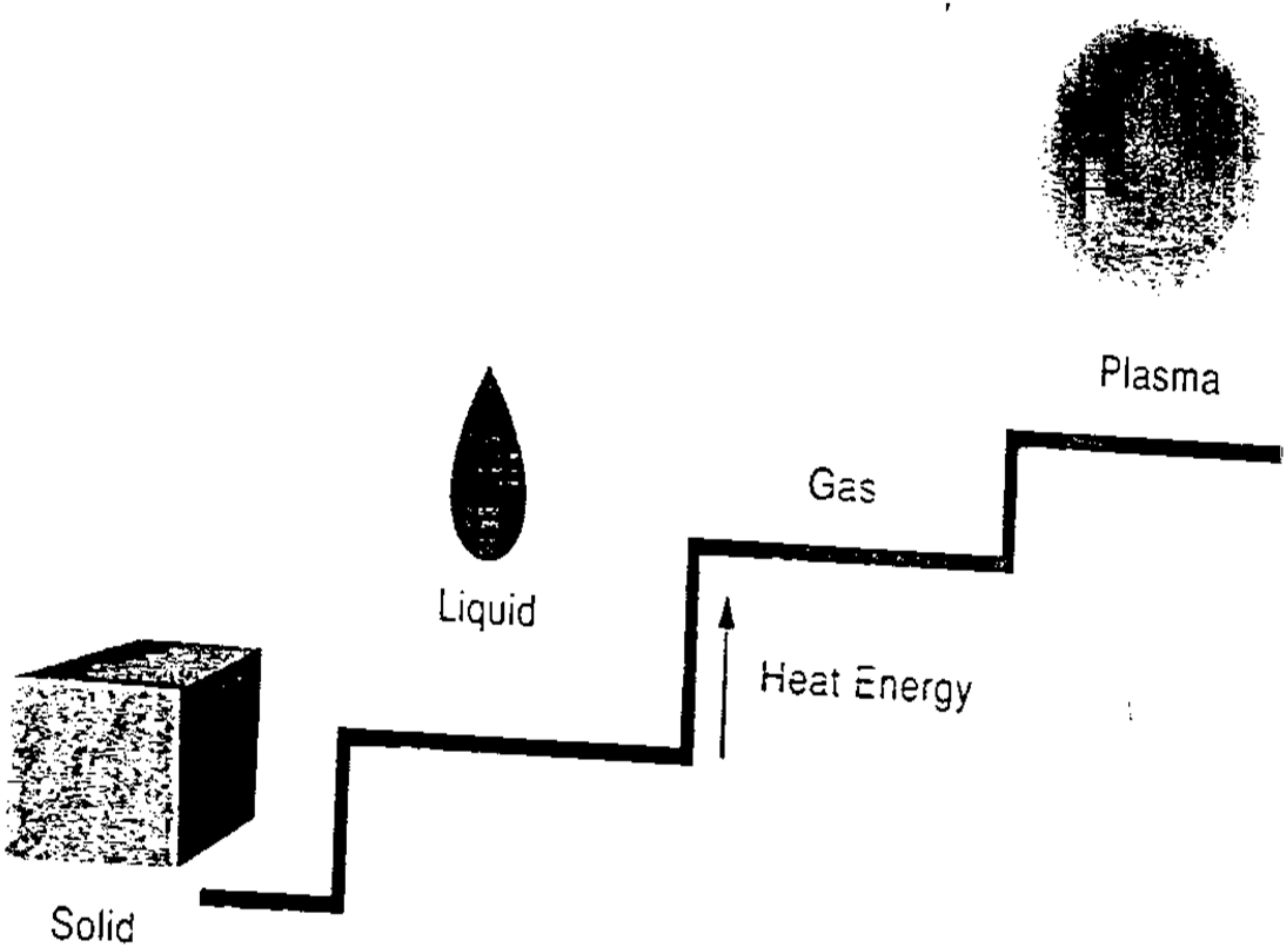
Introduction

- Plasma is the fourth state of the matter.
- Normally there are three states of matter i.e. solid, liquid and gas. For the most commonly known substance, water, these states are ice, water and steam.
- If heat energy is added, the ice will change from a solid to a liquid, and if more heat is added, it will change to a gas (steam).
- When substantial heat is added to a gas, it will change from gas to plasma, the fourth state of matter

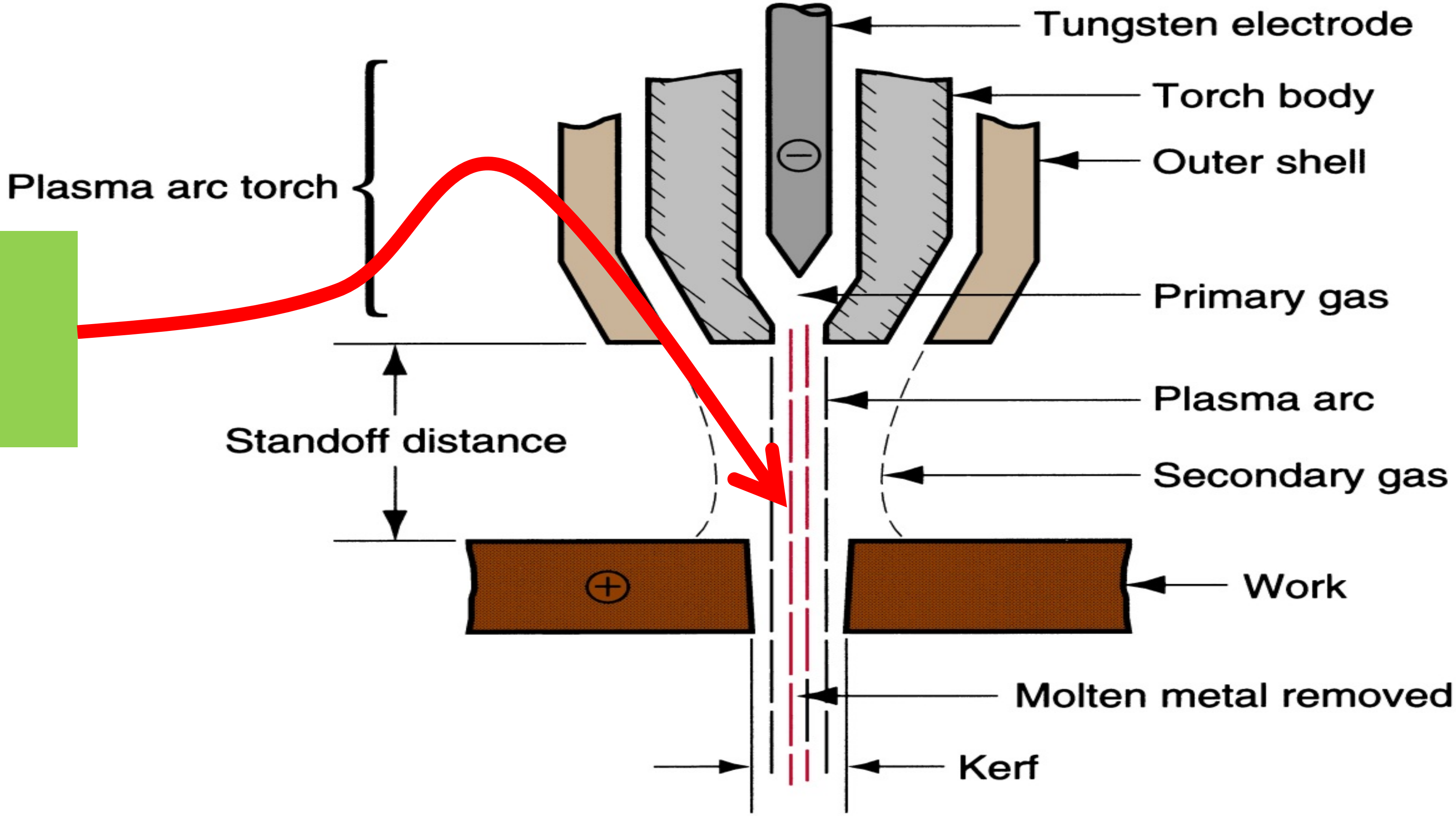


Plasma
Gas
Liquid
Heat Energy
Solid

Plasma Arc Cutting (PAC)

- Uses plasma stream operating at very high temperatures to cut metal by melting

The punch is a plasma arc



Investigations on plasma cutting process on various materials have identified the dominant process parameters as follows:

- Voltage
- Cutting current
- Cutting height or standoff (i.e. the distance maintained between torch and work piece after piercing and while cutting)
- Nature, pressure and flow of the plasma gas
- Feed rate

Metals to be cut

- Any material that is conductive can be cut using the PAC process.
- In a few applications nonconductive materials can be coated with conductive material so that they can be cut.
- Most popular materials cut
  - Carbon steel
  - Stainless steel
  - Aluminum

  Other metals commonly cut
  - Hardox
  - Copper
  - Nickel-alloys
  - High-strength, low alloy steels

Objectives

The main objectives of this research work are as follows:

- To carry out the experimental investigation of plasma arc cutting of Hardox-400.
- To study the effect of plasma arc cutting with different types of process parameter.
- To find out the optimal cutting condition of plasma arc cutting process using Taguchi based desirability analysis.
- To compare the optimal and initial setting of the plasma arc cutting machine.

BURNY 1250

Hardox-400

Chemical composition of Hardox-400:

Material	Elements									
	C	P	Mn	S	Si	Ni	Cr	Mo	B	Fe
HARDOX 400	0.15	0.025	1.6	0.01	0.7	0.25	0.5	0.25	0.004	Balance

Application of Hardox-400

- Bucket
- front loaders
- dump trucks
- barges

The proposed input setup for the experiment is as under:

Symbol	Input parameters	Units	Level 1	Level 2	Level 3
A	Arc current	A	70	90	110
B	Gas pressure	Bar	3	5	7
C	Cutting speed	mm/min	1200	1400	1600
D	Stand-off-distance	mm	3	4	5

Fixed parameters

- Plate thickness- 10 mm
- Cutting gas (Plasma)- Argon
- Shielding gas- Oxygen
- Supply pressure of shielding gas- 30 Mpa
- Working voltage- 400V

Taguchi based desirability methodology

1. Compute the signal-to-noise using the desired equation.

- Smaller is better $$S/N Ratio = -10\log_{10}\left(\frac{1}{r}\right)\sum_{i=1}^{r}(y_{ij})^2$$
- Larger is better $$S/N Ratio = -10\log_{10}\left(\frac{1}{r}\right)\sum_{i=1}^{r}\frac{1}{y_{ij}^2}$$

2. Compute the individual desirability value using the formulae.

For Smaller-the-better

$D_{ij} = 1$, if $y_{ij} \leq y_{min}$

$$D_{ij} = \left(\frac{y_{ij} - y_{min}}{y_{min} - y_{max}}\right), \text{ if } y_{min} \leq y_{ij} \leq y_{max}$$

$D_{ij} = 0$, if $y_{ij} \geq y_{min}$

For Larger-the-better

$D_{ij} = 0$, if $y_{ij} \leq y_{min}$

$$D_{ij} = \left(\frac{y_{ij} - y_{min}}{y_{max} - y_{min}}\right), \text{ if } y_{min} \leq y_{ij} \leq y_{max}$$

$D_{ij} = 1$, if $y_{ij} \geq y_{min}$

Taguchi based desirability methodology cont.

3. Calculate composite desirability value using equation.

$$DI = \frac{1}{n}\left(\sum_{i=1}^{n} D_{ij}\right)$$

4. Find out the optimal setting of the process parameter based on the desirability index.

5. Execute the analysis of variance (ANOVA) with the Desirability index. ANOVA shows the contribution of the various process parameters.

6. Conduct the confirmatory test with the result which is carried out from the Taguchi's desirability approach.

L_9 Orthogonal array

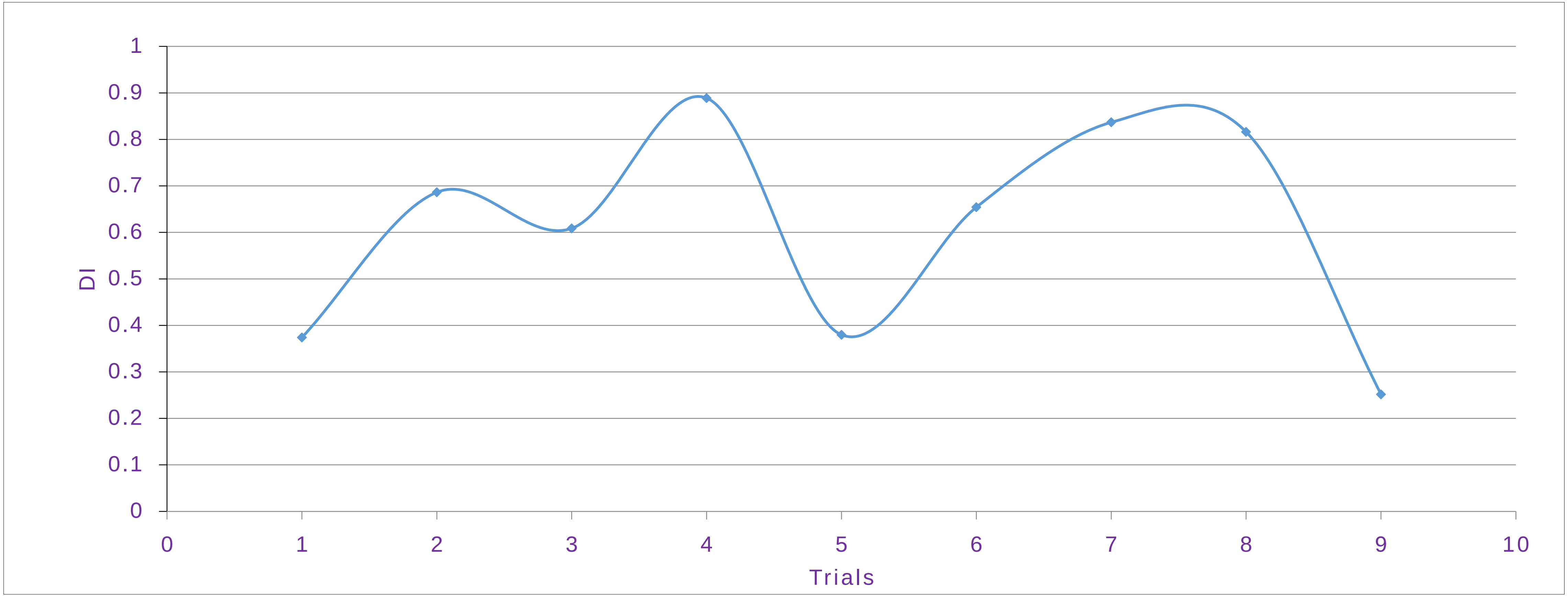
Run order	A	B	C	D	A	B	C	D
	Coded				Uncoded			
1	1	2	2	2	70	5	1400	4
2	1	1	1	1	70	3	1200	3
3	2	2	3	1	90	5	1600	3
4	1	3	3	3	70	7	1600	5
5	3	2	1	3	110	5	1200	5
6	3	1	3	2	110	3	1600	4
7	2	1	2	3	90	3	1400	5
8	2	3	1	2	90	7	1200	4
9	3	3	2	1	110	7	1400	3

S/N ratio and DI values

Run order	S/N Ratio				Individual DI				DI
	MRR	SR	Kerf	Chamfer	MRR	SR	Kerf	Chamfer	
1	71.256	-22.860	-8.818	-1.214	-0.255	0.164	0.000	0.958	0.374
2	71.770	-22.144	-5.201	-1.656	0.128	0.483	0.698	0.878	0.686
3	72.073	-22.007	-5.889	-2.542	0.353	0.544	0.565	0.717	0.609
4	71.471	-20.984	-5.008	-1.364	-0.096	1.000	0.735	0.931	0.889
5	72.491	-23.227	-7.005	-2.144	0.664	0.000	0.350	0.789	0.380
6	72.498	-22.671	-4.350	-1.798	0.669	0.248	0.862	0.852	0.654
7	71.495	-21.868	-3.637	-1.511	-0.078	0.606	1.000	0.904	0.837
8	71.772	-21.364	-5.621	-0.984	0.129	0.831	0.617	1.000	0.816
9	72.599	-22.671	-6.193	-6.486	0.745	0.248	0.507	0.000	0.252

Variation of DI values for different trials

The highest value of DI obtained from the graph as the optimum conditions of process parameter.

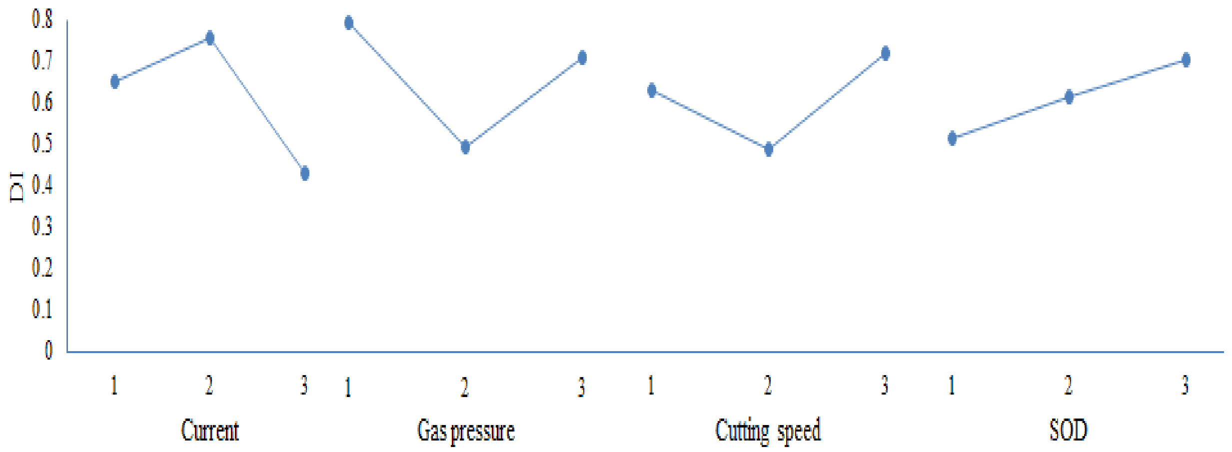


Effects of parameters on DI

The effect of input process parameter for desirability index is shown which reveals that the optimal parametric combinations are lying at $A_2B_1C_3D_3$.

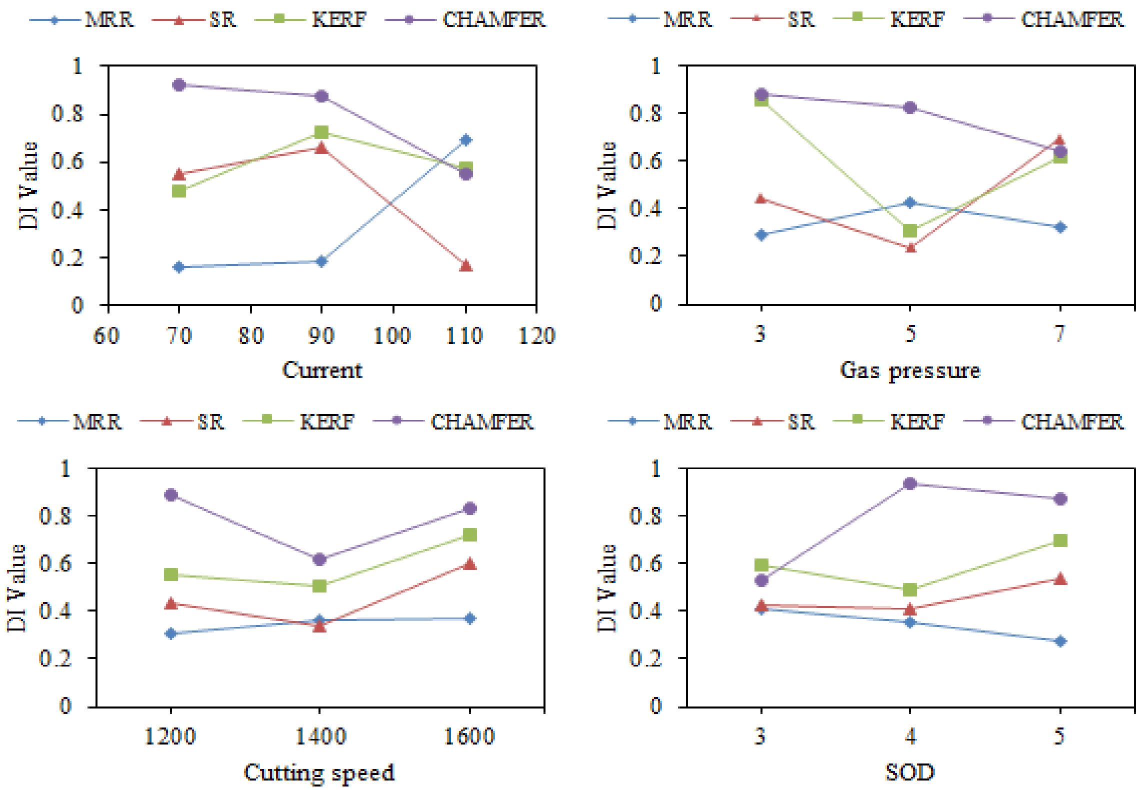
factor	Level 1	Level 2	Level 3	Max-Min
A	0.6497	0.7538	0.4285	0.3253
B	0.7257	0.4541	0.6521	0.2716
C	0.6273	0.4874	0.6147	0.2298
D	0.5155	0.6147	0.1862	0.1862

The graph was drawn between DI values and process



Effects of cutting parameters on the responses

- The effect of different process parameter on the obtained quality characteristics at their various levels is plotted on a graph.
- The graphs were drawn between individual desirability value and different process parameter using their levels.
- It is observed from the graph that the 70A current and 3Mpa gas pressure produces good chamfer during the cutting operation

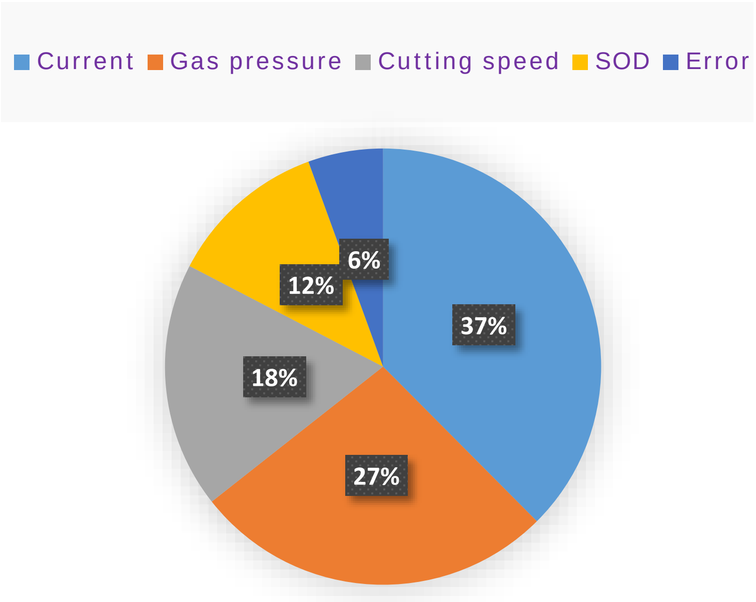


Result of ANOVA

ANOVA was carried out for the contribution of various cutting parameters which is influencing the quality characteristics of output responses, i.e. MRR, surface roughness, kerf and chamfer.

To complement the technique of Taguchi based desirability analysis, ANOVA was performed. From the ANOVA, it is observed that Current is the most influencing parameter and it contributes 37.54%.

Factor	DOF	SS	MS	F	% Contribution
A	2	0.1656	0.8278	4.2068	37.54
B	2	0.1184	0.0592	3.7848	26.84
C	2	0.0805	0.0402	3.2415	18.25
D	2	0.0521	0.0261	2.9756	11.81
Residual	2	0.0245	0.0123		5.56
Total	10	0.4411			



Confirmation test

A confirmation test was very important to validate the outcomes of TDA method.

The input process parameter of The 4th trial of the experiment was chosen as initial setting because the highest value of the desirability index in this trial. The corresponding values of initial setting are, current 70A, gas pressure 7Mpa, cutting speed 1600mm/min and stand-off-distance is 5 mm.

The optimal setting obtained from TDA method was compared with the initial setting. The optimal setting found from TDA methods were, current 90A, gas pressure 3Mpa, cutting speed 1600mm/min and stand-off-distance is 5 mm.

Parameter setting	Desirability index(DI)		Responses		
		MRR	SR	Kerf	Chamfer
Initial setting ($A_1B_3C_3D_3$)	0.889	3745.74	11.2	1.78	1.17
Optimal setting using TDA	0.912	3862.09	10.7	1.66	1.09
Improvement	0.023	116.35	0.5	0.12	0.08
Percent Improvement	2.58%	2.93%	4.46%	6.74%	6.83%

Conclusion

This research paper described the application of Taguchi based desirability analysis for parametric design of plasma arc cutting process. Taguchi's L_9 orthogonal array was used to design the run of the experiment. The following outcomes were disclosed:

- The TDA technique was very convenient for predicting the parametric design of input process parameter.
- This process improves the quality characteristics in term of the best output responses.
- The optimum cutting condition found as current 90A, gas pressure 3Mpa, cutting speed 1600 mm/min and stand-off-distance is 5 mm.
- Cutting current was largest influencing process parameter for this research and it contributes 37%, followed by gas pressure, cutting speed and stand-off-distance.

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Thank You