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Effects of Plasma Arc cutting Parameters on the Response of cutting hard material

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Abstract
Hard materials that has high abrasion and wear resistance are usually required for special applications where great need is demanded for longer durability, wear resistance and high strength. At the same time, machining such materials by the conventional methods are mostly uneconomical. Non-conventional cutting methods are used to cut such materials. One of such processes is the plasma arc cutting method. In plasma arc cutting, the parameters that are involved in the process mainly are the arc gap thickness, cutting speed and gas pressure.
The aim of this study is to evaluate the effects of the cutting parameters involved in cutting hard steel plates using Plasma arc cutting technology. The effect of these parameters on the quality of cut in terms of kerf width and heat affected zone are studied experimentally.
A CNC plasma arc cutting machine was used in carrying out the experiments. The test pieces used are prepared from Hardox 400 steel plate with a hardness of 400 HBW which is known for its longer durability, lighter structures and considerably high strength. The tests indicated that the optimal quality was obtained at the maximum cutting speed 700 mm/min resulting in minimum Kerf width of 4.658 mm, and the minimum HAZ of 0.886 mm.
Keywords: *Plasma arc cutting, wear resistant material, Kerf width, Heat Affected Zone, Hadox400.*

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I. Introduction

Plasma cutting is considered one of the main non-conventional cutting processes used for cutting electrically conductive hard materials. The process does not provide high quality products, so in order to avoid further processing and to minimize the resulting defects after plasma cutting and to achieve better quality, optimal cutting conditions represented in cutting speed, arc gap thickness and gas pressure should be aimed for. Several researchers worked in this field and in that direction.

Deepak Kumat Nail &Kalipada Maity [1] published an experimental work studying the effect of changing the gas type from Air, Argon, Oxygen and Nitrogen and varying the rate of flow. They kept the cutting speed and standoff distance constant at 300 mm/min and 2 mm respectively. The workpiece used is AR400 of 10 mm thick. They studied the effect of gas flow rate on chamber pressure, arc diameter, temperature, energy and the rate of material removal for the different types of gases. One of their main conclusions is that higher cut quality during plasma arc cutting can achieved with higher gas flow rate.

Pulkit Kumar Agrawal, et al [2] presented a review of experimental works showing the effect of feed rate, cutting current, cutting speed, gas pressure, voltage and torch height on the characteristic of cut while machining for Steel Alloys. Different approaches such as statistical and heuristically methods have been carried out to find optimal condition of input factors on cut attributes of PAC operation. They showed that the majority of research in this field uses Taguchi and RSM in their analysis. The review encourages researchers to carry out further experimental works on other types of materials.

Milan Kumar das et al [3] conducted experiments to cut EN31 steel using plasma arc cutting. They changed the cutting current, gas pressure and standoff distance and used as the input parameters in their work. The resulted (response) parameters measured were the material removal rate and surface roughness of machined surface. From the conducted tests it was concluded that the gas pressure is the parameter which has a significant effect rather than the others.

Subbarao chamarthi et al [4]varied the input parameters represented in voltage, cutting speed and plasma flow rate while cutting specimen prepared from 12 mm thick plate of Hardox 400 using plasma arc cutting through. The defected resulted in the process represented in surface secondary texture waviness is evaluated. They used “ANOVA” and concluded that the defects in the straightness of the surface can be minimized by reducing the cutting speed and that the cutting quality can be improved by changing cutting voltage and plasma flow rate.

Yahahismanselic et al [5] varied, again, the cutting speed, cutting current and voltage to cut S235JR using the CNC plasma cutting machine. They investigated the effect of the input factors on the temperature distribution, thickness of heat affected zone and other responses. They concluded that the quality of the cut depends on the cutting current, cutting speed, arc voltage and material thickness. They quoted that for the thin sheet, the best surface roughness is obtained as the cutting current and voltage are kept low while cutting speed is kept high.

Tetyana Kevka et al [6] took another approach of studying the effect of changing the gas used on the plasma arc cutting while cutting mild steel. The plasma gases used were steam, nitrogen, air, and oxygen. The test pieces were made of 16 mm thick mild steel plate. From the experimental results it was concluded that the steam will generate more energy than other gases for the same current value. The plasma jet generated is much thinner when either of nitrogen and air is used. They, also, concluded that to get the best surface roughness the cutting current and the cutting voltage should be kept low and cutting speed must be high.

From the forgoing, the detailed effect of the cutting speed, air gap and gas pressure was not fully investigated on the special hard, high strength and light weighted Hardox 400 material. This paper tries to fulfil this gap.

II. Experimental Procedure

In carrying out the analysis, specimens of 10 cm x 25 cm with 20 mm thickness made from Hardox 400 having hardness of 400 HBW are prepared. The plan was to cut using Plasma arc cutting machine to cut 5cm on every specimen at its middle. The cuts be through cut so a surface roughness and kerf width measurements could be made.

The factors under examination are: will

- the Cutting Speed which will be varied from 300 – 700mm/min,
- the standoff Distance (arc gap) to be varied from 1 – 5mm, which was measured using standard gauge blocks 1, 2, 3, 4 & 5 mm
- Plasma Gas pressure to be varied from 4 – 6bar
- Nozzle diameter is kept constant at 1.1 mm
- Current used is 120 A is kept constant.

  The response factors are:
- Kerf width which was measured by Mar Vision Workshop Measuring Microscope.
- The photos of the Heat Affected Zone were captured using Carl Zeiss optical macro scope. The specimens were pre-ground manually and etched.

III. Result and Discussion

Kerf Width Measurements

Effect of cutting speed on Kerf width, fig 1

When Cutting Speed increases it greatly influences the top kerf width measurement, As Cutting speed increases the kerf width is getting narrower. It decreased by 1.175 mm as the speed increased from 300 to 700 mm / min. At low speeds, the arc supports more energy than the energy needed to cut the material through and over melts the material thus giving bigger kerf width. At high speed, the concentration of the heat generated by the arc on the workpiece is less than heat concentration on the workpiece at low speeds, so in high speeds kerf width decreases as it supports the workpiece with the energy needed just to cut the material through.

The regression equation between the kerf width (d in mm) and cutting speed (S in mm/min) based on Polynomial of the second degree is:

$$d = -0.0537\ S^2 + 0.0187\ S + 5.862$$

The average value over the experimental range is 5.327 mm. The standard deviation is 0.449

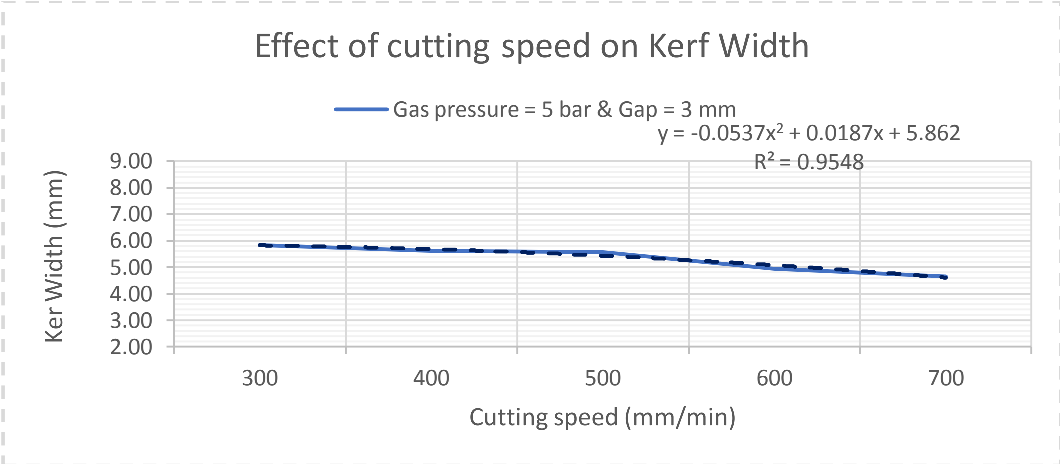
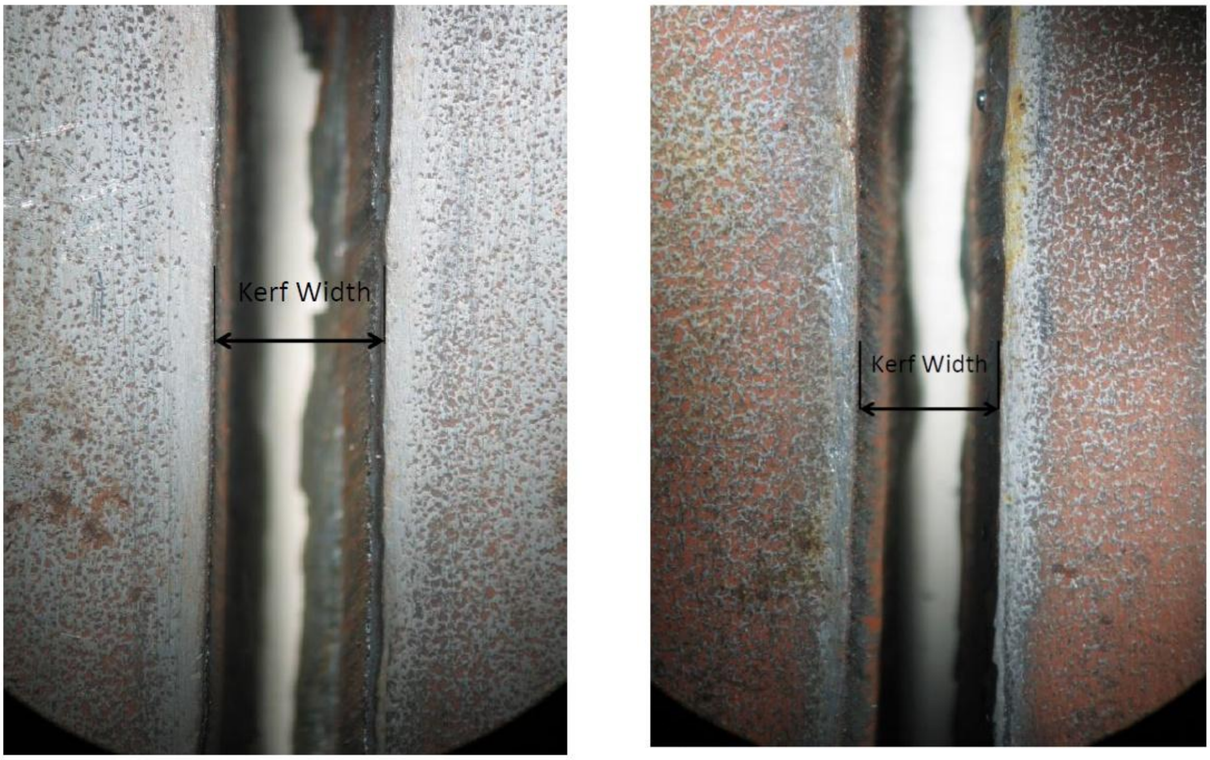


Fig. 1, Effect of cutting speed on Kerf Width

Fig. 2, kerf width at lowest speed 300 mm/min& at highest speed 700 mm/min



Effect of Arc Gap on kerf width, fig 3

A noticeable change to the kerf width is obtained as the arc gap changes. As arc gap decreases the kerf width is narrower. The width decreased by 1.225 mm as the arc gap increased from 1mm to 5 mm. This may be attributed to the fact that the plasma gas beam is not of a cylindrical shape but resembles the shape of a reversed candle flame. Therefore, depending on the relative position of the plasma to the workpiece surface, the top kerf width changes significantly and, as the arc gap decreases the concentration of heat is on the bottom of the workpiece thus less heat on the top of the material which endures narrower kerf width due to the reversed candle flame shape of the arc.

The regression equation between the kerf width (d in mm) and arc gap (g in mm) based on Polynomial of the second degree is:

$$d = 0.0266\, g^2 + 0.1998\, g + 5.023$$

The average value over the experimental range is 5.870 mm. The standard deviation is 0.7772

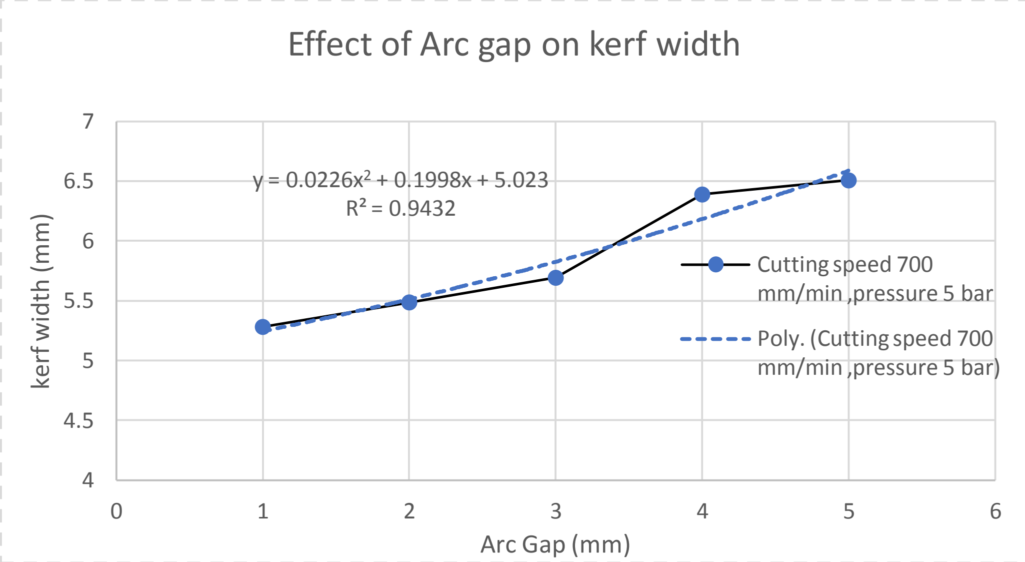


Fig. 3, Effect of Arc gap on kerf width

Effect of gas pressure on Kerf width, fig 4

The effect of the gas pressure on the kerf width is fluctuating shape. This may be caused by contamination of the gas with air. As the air pressure increases the rate of ionization of the gas increases therefore, a higher current should be achieved; but since no current compensation then, the nozzle is just blowing high pressurized air which is not all ionized resulting in unsteady energy to perform the cut.

The regression equation between the kerf width (d in mm) and gas pressure (p in bar) based on Polynomial of the second degree is:

$$d = -0.3143\ p^2 + 3.0089p - 1.4338$$

The average value over the experimental range is 5.596 mm. The standard deviation is 0.335

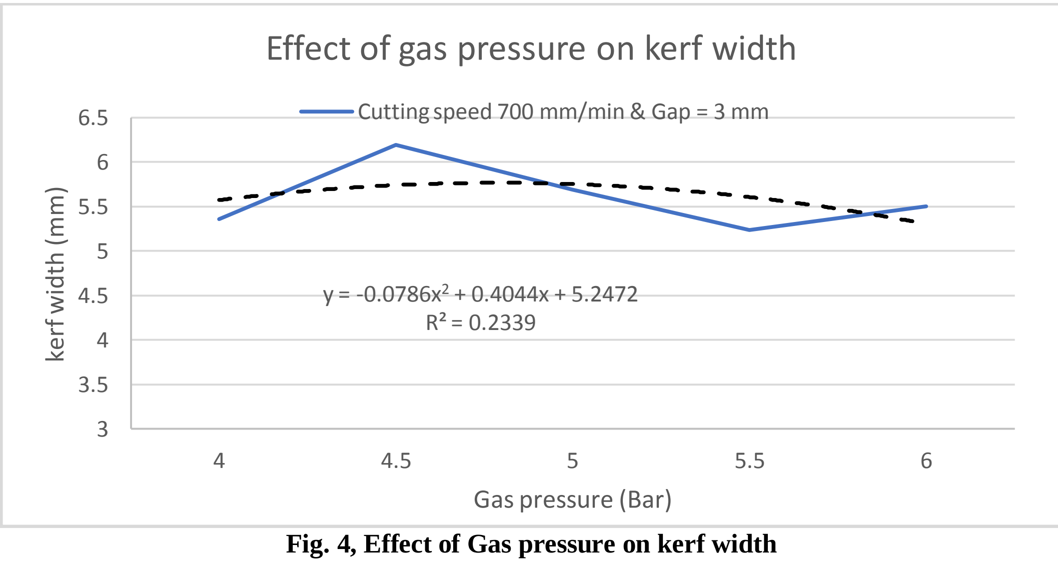


Fig. 4, Effect of Gas pressure on kerf width

Heat affected zone analysis

Effect of Cutting Speed on HAZ, fig 5

As the cutting speed changes, the Heat affected zone significantly changes, as the cutting speed increases the Heat affected zone decreases, comparing the readings of the 300mm/min and the 700mm/min readings it is found that heat affected zone decreased to more than the half of its value. As the cutting speed increases the heat energy absorbed by the workpiece is just sufficient for cutting through the metal no excess heat is absorbed by the metal thus giving us small heat affected zone. On the other hand at low cutting speeds the amount of heat energy absorbed by the workpiece is high thus over heating the material which increases the heat affected zone

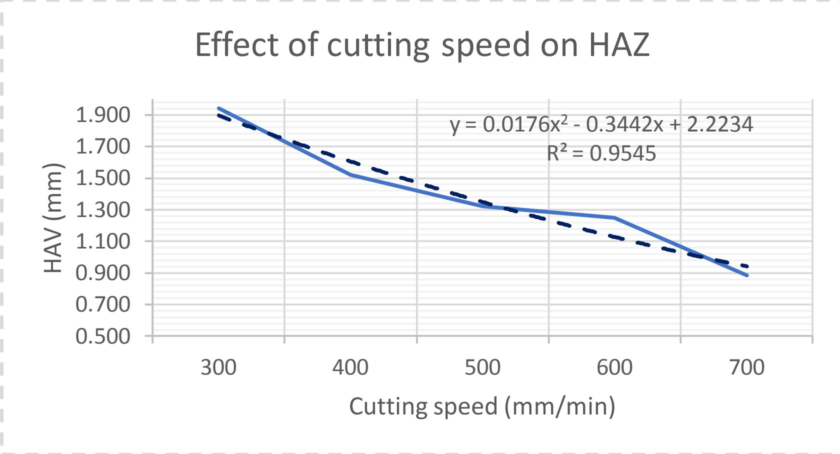


Fig. 5, Effect of cutting speed on HAZ

The regression equation between the cutting speed (S in mm/min) and Heat affected zone (HAZ) (h in mm) based on Polynomial of the second degree is:

$$h = 0.0176\ S^2 + 0.3442\ S + 2.2234$$

The average value over the experimental range is 1.384 mm. The standard deviation is 0.346

Effect of gas Pressure on HAZ

The plasma gas pressure appears to have slight effects on the heat affected zone. At low plasma gas pressure, the flow of gas gives heat energy just sufficient for cutting the material. This results in smaller amount of energy to the cut area, just sufficient for the cut zone. However, as the pressure increases more heat and energy were enough to overheat the zone giving wider heat zone.

The regression equation between the gas pressure (p in bar) and Heat affected zone (HAZ) (h in mm) based on Polynomial of the second degree is:

$$h = -0.075\ p^2 + 0.6414p + 0.5516$$

The average value over the experimental range is 1.650 mm. The standard deviation is 0.3079

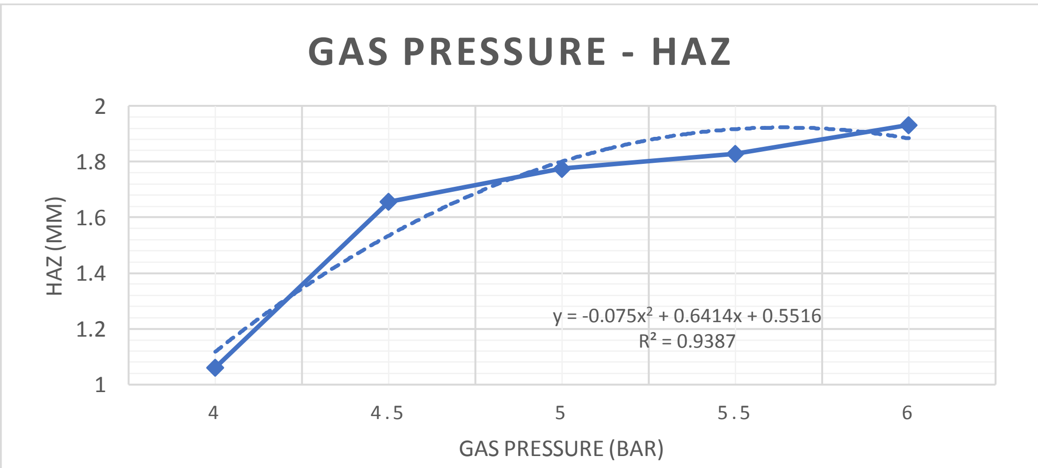


Fig. 6, Effect of gas pressure on HAZ

Effect of Arc Gap on HAZ

As the arc gap changes it affects the heat affected zone. Both are directly related the zone is changed by 1 mm over the 4 mm range of gap. Again, as the arc gap decreases the concentration of heat is on the bottom of the workpiece thus less heat on the top of the material which means less heat energy absorbed by the material which endures narrower heat affected zone due to the reversed candle flame shape of the arc. As the arc gap increases the arc concentrates the heat on the top of the workpiece thus over melting the material which means more heat energy is absorbed by the material which endures wide heat affected zone

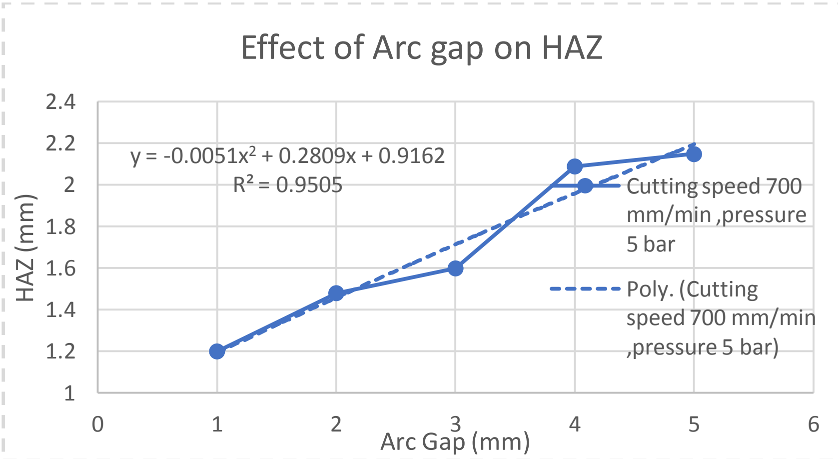


Fig. 7, Effect of arc gap on HAZ

The regression equation between the gap (p in bar) and Heat affected zone (HAZ) (h in mm) based on Polynomial of the second degree is:

$$h = -0.0051g^2 + 0.2809g + 0.9162$$

The average value over the experimental range is 1.7032 mm. The standard deviation is 0.3634

IV. Conclusions

Within the ranges studied in this paper the following conclusion may be applicable:

1. The smallest top kerf width is 4.658 mm was obtained at high cutting speed 700mm/min with moderate plasma gas pressure 300 kPa, arc gap 5mm and relatively high current 120A.
2. The smallest heat affected zone is 0.886mm was obtained at high cutting speed 700mm/min with moderate plasma gas pressure 300 kPa, arc gap 5mm and relatively high current 120A
3. In general it is recommended to use high cutting speed with moderately low gas pressure.
4. as a general assessment it may be concluded that plasma cutting results in kerf width of 5.6 mm and heat affected zone of 1.6 mm.

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