Optimizing plasma arc cutting parameters for minimal dross production in Hypertherm Duramax® consumables

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Introduction

Plasma arc cutting (PAC) is a novel manufacturing process in which a high amperage electrical current passed through an electrode rapidly generates ionized gas (plasma). Gas is pressurized through a constricted nozzle propelling the plasma, which melts and blasts away localized areas of metal. The nozzle and electrode are referred to as a consumable cartridge (Figure 1).

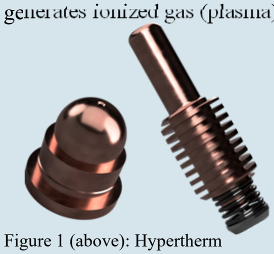


Figure 1 (above): Hypertherm Duramax consumable nozzle (left) and electrode (right).

PAC is limited by precision and a need for additional finishing steps such as the removal of dross—molten metal ejected by the kerf (Nemchinsky, 1997)—which sticks to the part. PAC reliability is affected by variables such as humidity, temperature, and atmospheric pressure. The goal of this project was to design experimental methods—implementable in a commercial fabrication shop—to develop a predictive model to find parameters for minimal dross and maximum yield, in any environment.

Materials and Methods

A 3 × 3 full factorial experimental design was used with three input variables: Cut height (CH)—the distance between the torch and work surface—Cut speed (CS)—the rate that the torch travels along the cut paths—and cutting current (CC)—the power of the electrical current—measured in inches, inches per minute, and amps, respectively.

Each variable was tested at three levels, with one at manufacturers recommended settings—CS = 220, CH = 0.06, CC = 45—and two additional levels each ± 5% manufacturers settings variable.

Level	CS (inches / minute)	CH (inches)	CC (amps)
−1	209	0.057	43
0	220	0.006	45
1	231	0.063	47

Table 1 (left): The three variables tested and their corresponding levels.

A bracket was used as the sample to help compensate for the metal cost. Samples were cut in batches of five from a 7.5″ × 10″ 14-gauge A36 steel blank (Figure 2). Three pieces of software were used: AutoCAD to make vector drawings, SheetCam to process the vector drawings into g-code, and MyPlasm CNC to interface directly with the plasma table and perform the cutting operations.

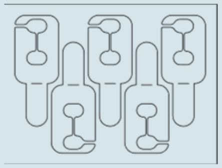


Figure 2 (above): The nested samples and blank.

A blank was center punched 0.53″ from the top and left sides to aid in aligning samples within the blank.

Materials and Methods (continued)

Figure 3 (above): An arcing PAC torch, during production of the blanks.

A jig was constructed using two scrap pieces of quarter inch mild steel which were welded together at a 90° angle. The jig was placed so that its interior corner was 59″ and 7.5″ from the top and left edges of the plasma table respectively. The alignment blank was placed within the jig and the torch was placed over the center punch. In MyPlasm CNC the torch location was zeroed as the top left corner of the cut file, centering the samples inside of the blank. The alignment blank was replaced with another which had been prelabeled with its corresponding numerical ID and the cut operation was performed. After cutting each blank was dropped from chest height before successful samples were dried and placed in a prelabeled plastic bag. Samples were then weighed using an analytical balance before dross was removed using a braided wire wheel then once again weighed using the analytical balance to determine the mass of the slag.

Results

A general factorial regression was conducted with respect to the three input parameters and two response variables yield and dross mass. The low coefficient of determination means that the reliability—if any—of both models are insufficient to make valid predictions (Table 2). The 0.00% predictive R^2 value implies that the model is overfit for its data set and that further testing is required.

Model Summary

Response	S	R^2	R^2 (adj)	R^2 (pred)
Yield	0.253	79.46%	23.72%	0.00%
Dross Mass	0.113	82.61%	27.53%	0.00%

Table 2 (above): Statistical summary of the factorial model and its coefficient of determination.

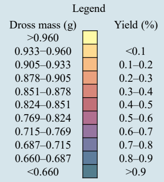
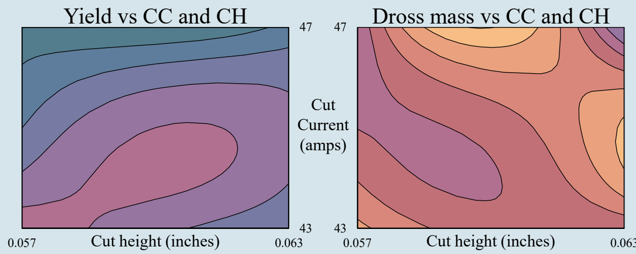
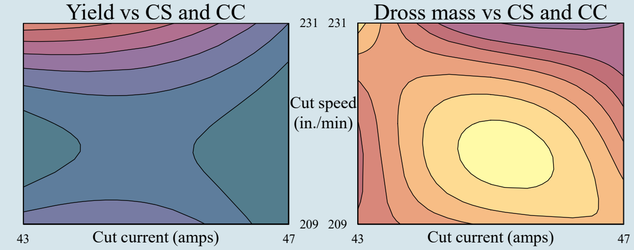


Figure 4 (left): Contour plot legend.

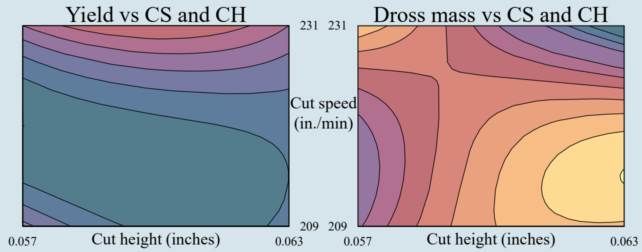


Graphs 1 and 2 (above): Yield and dross mass with respect to cut current and cut height.

Results (continued)



Graphs 3 and 4 (above): Yield and dross mass with respect to cut speed and cut current.



Graphs 5 and 6 (above): Yield and dross mass with respect to cut speed and cut height.

Conclusions

Although the model was unable to determine the absolute best combination of parameters it can still determine combinations for better performance than manufacturers settings. PAC technicians may still improve parameters for their machine's unique environmental variables like humidity and cutting gas as these variables would be controlled between trials.

The methods could be expanded to include response variables such as dimensional accuracy, heat affected zone, and energy cost to reach a more holistic optimization. The methods could be improved with a simpler sample design, additional replicates of trials, and random assignment of blank position on the plasma table. By conducting the tests in the same position, the dross buildup on the plasma table increased the height of the blank by over 0.25″ over the 27 successive trials. Lastly, if the model can be perfected, it can be used to validate manufacturer's claims of performance vs. other products.

References

Nemchinsky, V. A. (1997). Dross formation and heat transfer during plasma arc cutting. *Journal of Physics D: Applied Physics, 30*(18), 2566–2572. https://doi.org/10.1088/0022-3727/30/18/011