MICROSTRUCTURE CHANGES OF CONSTRUCTIONAL STEEL CAUSED AFTER THERMAL CUTTING WITH PLASMA ARC

Michal Hatala,
Faculty of Manufacturing Technologies of the Technical University of Košice,
Štúrova 31, 080 01 Prešov, Slovak Republic

Abstract: Paper deals with problems of thermal cutting with plasma arc. Plasma cutting currently presents progressive and accurate technology of cutting the materials in engineering industry. High accuracy and cut quality is reached on cut surfaces and edges. The heat used for cutting of material affects its microstructure changes.

Key words: Plasma cutting, microstructure, cut quality

1. INTRODUCTION

Thermal plasma is a highly heated gas or gaseous mixture which is conductive and consists mostly of free electrons and ions. The arc strikes between the plasma arc cutting torch's electrode, which is connected as the cathode, and the anode (material).

Plasma Arc Cutting is a process where an open arc can be constricted by passing through a small nozzle, from the electrode to the workpiece. The gas used is typically air and it combines with an electrical current to create a high temperature plasma arc.

Fig. 1. The principle of plasma arc cutting
When placed in contact with an electrically conductive material, the arc passes through the metal, melting a thin area. The force of the arc pushes the molten metal through the workpiece and severs the material. The current flowing in the column of plasma arc can be between 10 and 1000 Amps, the diameter of the jet emerging from the nozzle ranges from several tenths of a milimetre to several milimetres, the temperature inside the jet from 15 000 K to 30 000 K.

The process of the plasma cutting of metal materials is based on a transferred arc, which means that an arc is established between a refractory electrode (- pole) and the piece to be cut (+ pole). This highly rigid and extremely hot stream of plasma fuses the metal over its full thickness and ejects it outside the cut thanks to the plasma’s very high velocity. The choice of gas depends on the thickness of the material that is to be cut and on other criteria such as the quality of cut, productivity and running costs.

The major advantages of plasma cutting lie in the higher cutting performance and the narrower heat-affected zone, along with minimum heat input.

2. PLASMA ARC CUTTING TECHNIQUES

The following plasma arc cutting techniques are used with particular torch constructions and plasma gases.

**Ar/N₂/H₂ technique**

For a long time, a mixture of argon, nitrogen and hydrogen was most frequently used as plasma gas, both for cutting in atmosphere and under water. The wide range of applications which includes nearly all common metal materials over a wide range of sheet thicknesses is an advantage. The fractions of the single gases differ according to the material and the plate thickness.

**Dual-flow technique**

The dual-flow technique was derived from the Ar/N₂/H₂ technique by covering the plasma arc in underwater service with an additional secondary gas (either CO₂ or compressed air). This the cooling effect of the surrounding water, which lessens the power efficiency, is reduced and the water is kept away from the front of cutting kerf.

**Water-injection-plasma-cutting (WIPC) technique**

In recent times the above mentioned variants have been more and more replaced by the WIPC technique. In this case the plasma gas (nitrogen or oxygen) swirls around the directly cooled flat electrode. The complete nozzle consists of two parts: a copper nozzle and a ceramic nozzle below. Between these both a small jet of water is sprinkled onto the plasma arc. These arrangements lead to a better constriction of the arc.

3. EXPERIMENT OF HEAT AFFECTED ZONE (HAZ)

HAZ width is defined as the width of a detectable microstructural change measured perpendicular to the cut edge face. HAZ width is only applicable to alloys that undergo microstructural changes during the heating and cooling cycle of the cutting operation.

**The used material**

As the mild steel is the most commonly used material in metal fabrication, for this investigation was used low carbon steel S 355. Especially for the weldability and thermal properties is this kind of steel attractive for many applications.
The Experiment

All performed cutting experiments were done with a high powered advanced HD 3070 cutting system. Cutting tests have been made at three different thickness (10 mm, 15 mm, 20 mm). Measurements and analysis were made of each cut sample. It was removed a small section from each cut sample. The section was placed in a metallographic mount, polished and etched to reveal details in the microstructure, which allow analysis of HAZ phase content.

Microhardness measurements were made near the cut edge and for the comparison with the base material in the core of the specimen.

Findings

Investigations of microhardness showed that, the maximum value immediately at the cut surface increases appreciably about 255 HV1 in the deposit across a distance of 0,7 mm (thickness 20 mm), about 240 HV1 in the deposit across a distance of 0,5 mm (thickness 15 mm) and about 110 HV1 in the deposit across a distance of 0,4 mm (thickness 10 mm). The microhardness is connected basically to the local changes in mechanical properties of the material.

It can be seen little difference in microhardness, that results in narrow HAZ.

The microstructural damage zone (heat – affected area) is approximately 0,7 deep. The heat affected zone from a plasma cut is narrower and peak hardnesses are higher than that produced for example by flame cutting.

Austenite formation is found to be complex while heated to a temperature 741 °C (in between Ac1 and Ac3 temperatures). The result of this show continued growth of austenite, Passing the eutectoid temperature during cooling requires a radical change. Practically all the homogeneously dissolved carbon now has to go to the inhomogeneously distributed cementite - by diffusion. The austenite is quenched, i.e. rapidly cooled. The carbon stays in place - more or less- and this necessarily prevents pearlite and ferrite formation. Instead, a new lattice type is found, called "martensite". It’s volume is getting down to the core of base material.

HAZ goes through the narrow zone of normalization with fine – grained structure and considerably wider zone of partial pre – crystallization. Damaged created by a plasma torch cut – microstructure was originally a banded pearlite and ferrite, 3% picral etch. Original magnification 50 X.
Fig. 3. The Picture of microstructure and HAZ (zoom 50 x)

HAZ Findings

- All of this HAZ measurements were between 0.4 – 0.7 mm.
- HAZ varies with speed and power. The extent of the HAZ in mild steel is related to process variables, such as cut speed and power, as well as material thickness.

Fig. 4. HAZ after the Plasma cutting for thickness 10,15,20 mm

4. CONCLUSION

The quality of the plasma cut edge is similar to that achieved with the oxy-fuel process. The cut quality may be inferior, however, due to rounding of the top edges and difficulty in obtaining a square cut face of both edges. However, as the plasma process cuts by melting, a characteristic feature is the greater degree of melting towards the top of the metal resulting in top edge rounding, poor edge squareness or a bevel on the cut edge.

5. REFERENCES