Some studies of the Plasma Cutting of Aluminium Plates

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AND

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1. Introduction :

Plasma arc cutting of metals is of recent origin and is widely employed in the cutting of stainless steels, special steels, non-ferrous metals and their alloys, thick sections of steel and even C.I. In oxygen cutting, the metal burns reacting with oxygen. Therefore, the speed of cutting of carbon steels for which it is widely used is limited by the speed of the chemical reaction of oxygen with iron and the speed with which the molten metal is blown away from the reaction zone. In the case of plasma cutting, the metal evaporates due to the high temperature of plasma arc forming a "keyhole" and as the plasma arc advances forward the "keyhole" moves with the arc resulting in a cut. Speed of plasma cutting is higher than oxygen cutting as the energy density in plasma flame is several orders of magnitude higher than in oxygen flame. In plasma cutting, the deformation and the width of the cut is reduced and the quality of the cut is improved due to its high speed of cutting.

Even though considerable work has been done in oxygen cutting, very little information is available on plasma cutting. Most of the literature deal with the general process of plasma cutting and its economic aspects (1, 2, 3). Spies (3) and Czech and Lassocinski (4) have compared the heat affected zones between plasma and oxygen cutting. Czech and Lassocianski have concluded that the gas mixture used in plasma torch has no influence on the quality of plasma cut. In comparison with oxygen, cutting heat affected zone in plasma cutting is about 50% smaller and hardness lower. Vasil'ev and Kokhlikyan (5, 6) have examined the changes occuring in the metal adjacent to the cut suface in low alloy steel and stainless steel plates cut by plasma. They have also suggested the equations for calculating the depth of the heat affected zone. It was also noted that a convenient general indication of the changes of the metal during cutting is the extent of HAZ, in conjunction with external freedom from defects. Recently Goldberg (7) has studied the influence of thermal cutting and its quality on the fatigue strength of steel.

Thermal cutting gives rise to two effects in the region of the cut. Firstly it alters the microstructure and chemical composition of the material in the region of the cut. Secondly it introduces distortion and residual stress. These changes occur due to the rapid heating and cooling when cutting takes place. The microstructural changes and the presence of residual stresses have considerable effects in the subsequent operations like cold working of metals or fabrication process or even transportation. Under unfavourable conditions, these changes may give rise to the development of cracks. Hence it is necessary to grind or mill the thermally cut surface before it is used for further

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work. The following factors which contribute to the above harmful effects have been investigated.

(i) Temperature distribution in the region of cut.

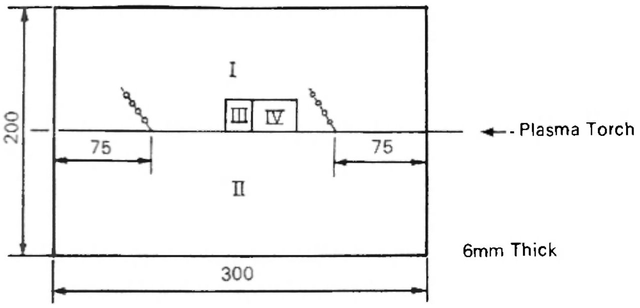
(ii) Residual stresses.

(iii) Microhardness and structural changes in HAZ.

Commercial quality aluminium plates were used for the present investigations.

2. Experimental Procedure :

Commercially pure aluminium plates of size 300×200×6 mm thick machined to size were stress relieved since these plates were used for studying the temperature distribution as well as the residual stresses developed during cutting. One mm holes were drilled at specified intervals as shown in fig. 1 and Chromel-Alumel thermocouples insulated with glass wool were peened to the plates. Before the thermocouples were fixed to the plates, necessary calibration was carried out. The free ends of the thermocouples were connected to a twelve channel type 1508 Visicorder. The motion of the plasma flame was aligned with the centre line of the plate. Two cutting speeds viz. 2000 mm/min and 1000 mm/min were selected. The plates were cut in a plasma cutting machine, type PSG 120, 20 KW (East Germany) which operates on a mixture of Argon and Hydrogen. One half of the plates in which thermocouples were fixed were used for temperature distribution, microstructure and microhardness studies whereas the other half was used for residual stress studies.



I First half used for temperature studies.
II Second half used for residual stress studies.
III Specimen for microstructure studics.
IV Specimen for microhardness studies.

Fig. 1. Detail of the specimen used for investigation.

The theoretical temperature distribution was calculated using the Rykalin's (8) equation which is given below for a linear heat source of length equal to the thickness of the plate moving rapidly over it.

$$T(y_0, t) = \frac{q}{v\ \delta \sqrt{4\pi\ c\ \rho\ t}}\ e^{-\frac{y_0^2}{4\,a\,t} - bt}$$

Where,

$T(y_0, t)$ — temperature at any given distance, y_0 from the centre of the source at time, t.

v — speed of cutting, cm/sec

q — heat input cal/sec

q — η E Iwhere, E is arc voltage
I is the current
and η is the efficiency of the process.

δ — thickness of the plate being cut, cm

π — thermal conductivity, $\frac{cal}{cm\ sec^\circ C}$

c — specific heat, $\frac{cal}{gm^\circ C}$

ρ — density, gm/cm³

a — coeff. of thermal diffusion, cm/sec

b — a constant which depends upon the coeff. of heat transfer between the hot plate and the surrounding medium.

In our calculations, b is assumed to be zero.

Bonded wire resistance strain gauges of the type KWR-3 were applied to the face opposite to the edge of cut. The change in the strains were meassured by a strain gauge bridge by gradually removing the material after filing and allowing the specimen to attain the room temperature. All strain measurements were made in unconstrained position of the specimen. The stress state existing before the layer removal was calculated from the strain gauge readings using the method of Leeser and Daane (9). The initial or residual strain in the longitudinal direction at any point "h" is given by,

$$E = 2\,E_g + \tfrac{1}{2}h\,\frac{dE_g}{dh} - 3h\int_h^H \frac{E_g}{h^2}\,dh$$

where,

H — original height.

h — thickness remaining after layer removal.

E_g — change in strain at gauge surface.

E — youngs modulus, 7000 kg/mm²

The stress in the longitudinal direction is given by,

$$\sigma = E\left[2E_g + \tfrac{1}{2}h\,\frac{dE_g}{dh} - 3h\int_h^H \frac{E_g}{h^2}\,dh\right]$$

3. Discussion of Results :

3.1 *Temperature distribution :* Fig. 2 and 3 show the temperature distribution curves in aluminium plates at the cutting speeds of 1000 mm/min and 2000 mm/min during plasma cutting. It could be observed that the theoretical and experimental results agree closely. There is a steep rise and steep fall in temperature in the vicinity of the cutting zone. It is seen from the graph that it takes only 10 seconds for the temperature to reach around 100°C whereas it takes more than 20 seconds to attain this temperature during oxygen cutting of steel plates.

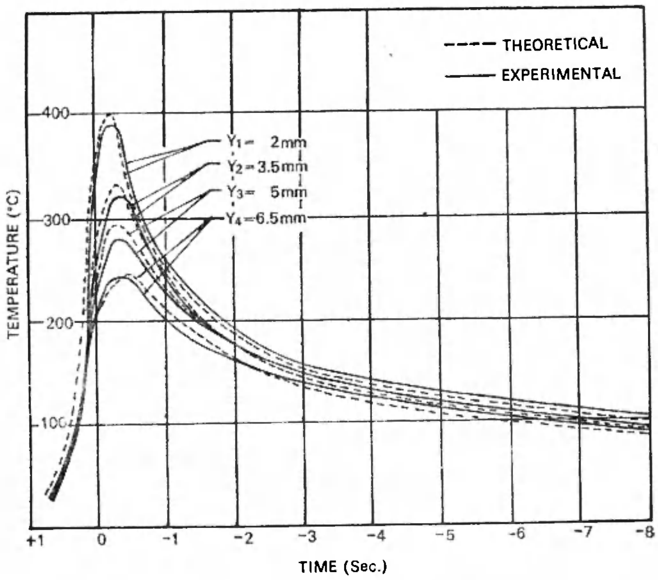


Plate Thickness : 6mm
Heat Imput : 1812 Cal/Sec.

Material : Al.
Cutting Speed : 1000 mm/min.

Fig. 2. Temperature distribution in Plasma Cutting.

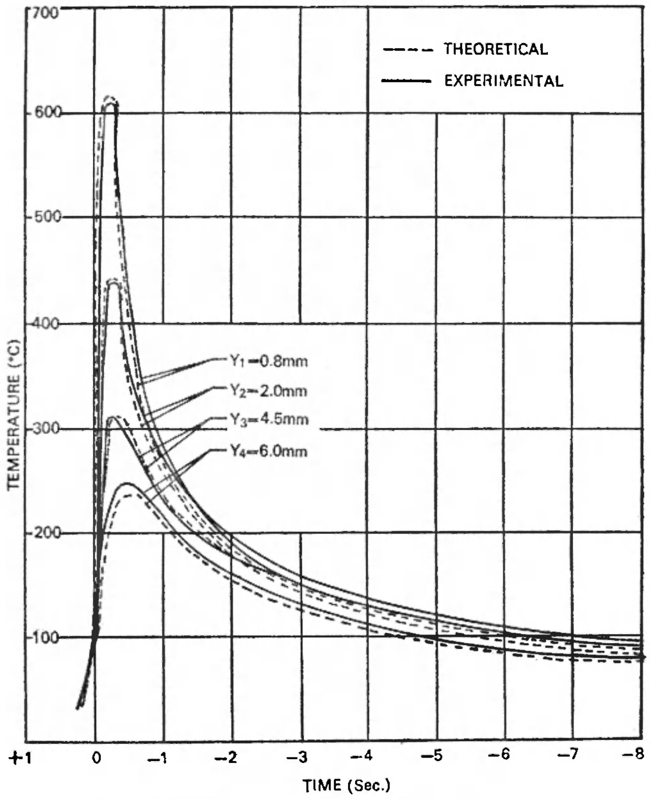


Plate Thickness : 6mm
Heat Imput : 3165 Cal/Sec.

Material : Al.
Cutting Speed : 2000mm/min.

Fig. 3. Temperature distribution in Plasma Cutting.

Fig. 4 shows the maximum temperature in relation with the distance from the edge of cut. By extrapolating the graph, we observe that the maximum temperature in the vicinity of the cut is 760°C, which is more than the melting point of aluminium. This may be due to super heating of the molten metal by the high intensity plasma flame.

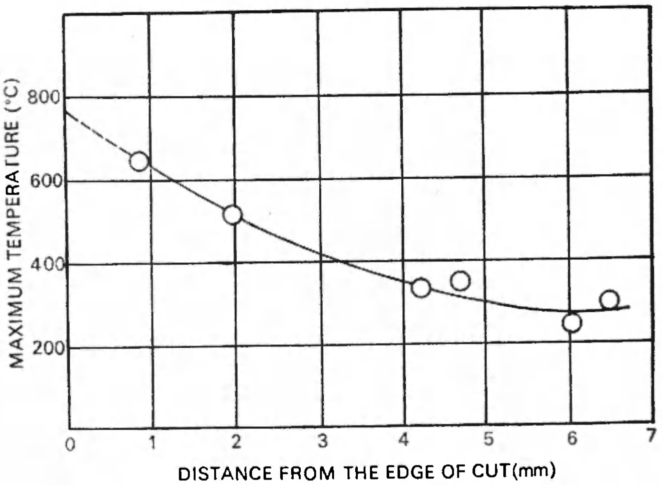


PLATE THICKNESS = 6mm CUTTING SPEED = 2000mm/min.

Fig. 4. Maximum temperature in relation with distance from cut edge.

3.2 *Residual Stresses :* Fig. 5 indicates the distribution of residual stresses in the zone of cut at a cutting speed of 2000 mm/min. The stress very near to the edge of cut was found to be tensile and is of the order of 2.74 kg/mm^2, which is only 80% of the yield stress where as in the case of welded or oxygen cut steel plates it is equal to yield stress. Kazimirov and Nedoseka (10) have also observed that the longitudinal surface residual stress is equal to 75-85% of the yield stress in the welded plates of aluminium alloy. The tensile residual stresses changes to compressive at a distance of only about 0.85 mm away from the cut surface.

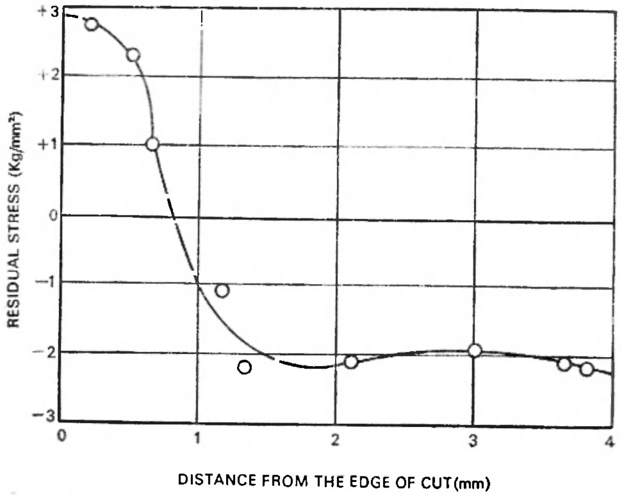


Fig. 5. Distribution of residual stress in Plasma Cut Zone.

3.3 *Microhardness and microstructure* [8]

Two specimens were prepared from the middle of the plate where the thermocouples were attached. One was used for microhardness surveys and the other for microstructure studies.

Microhardness measurements were made at the top, middle and bottom of the surface of cut. These values are illustrated in figures 6 and 7, for the two cutting speeds mentioned above. Results show that the variation of hardness in these zones is practically negligible. The cutting speed has no substantial effect on the hardness. The depth of heat affected zone was found to be around 0.1 mm.

Fig. 8 shows the microphotograph of the heat affected zone. HAZ comprises of two regions, one outer cast metal formed as a result of incomplete removal of the metal from the cavity of cut, the other region adjacent to it has not undergone fusion even though the structure of the metal has been altered. These results are in confirmity with the results obtained by Vasil'ev and Kokhlikyan (5).

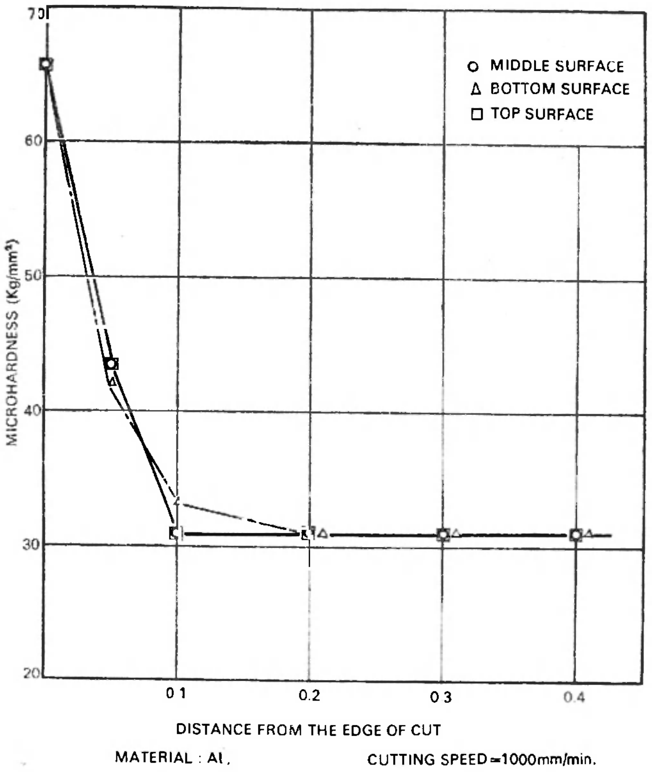


Fig. 6. Variation of microhardness in the Plasma Cut Zone.

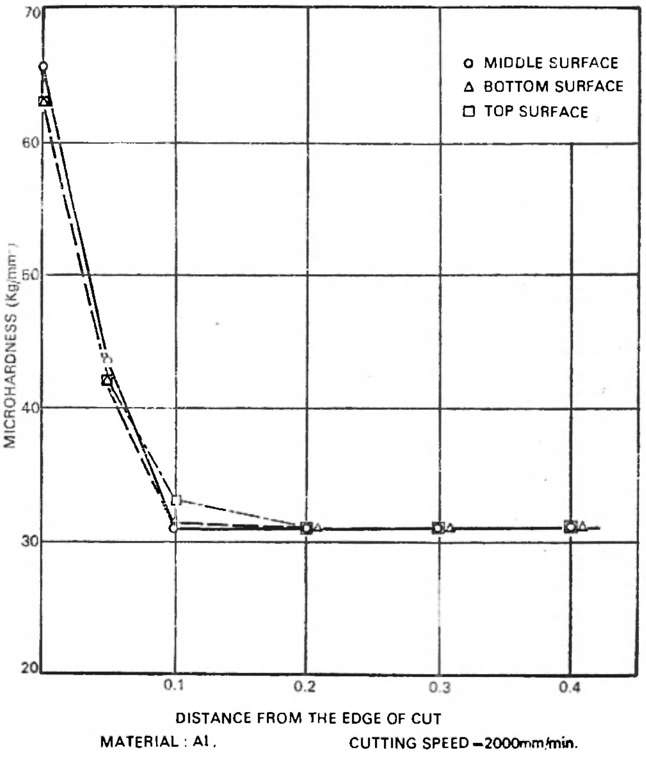
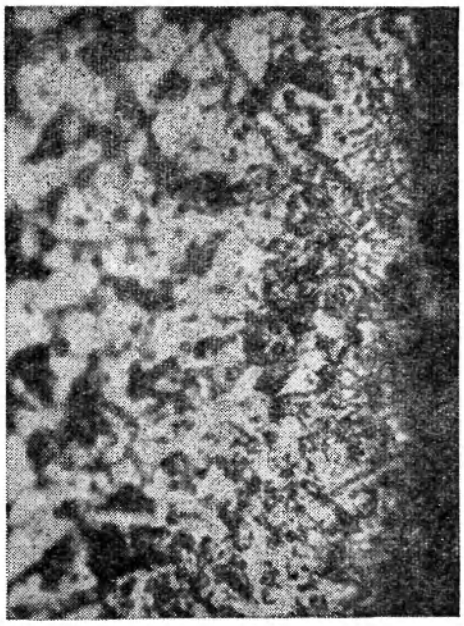


Fig. 7. Variation of microhardness in the Plasma Cut Zone.



Magnification 8300 and enlarged to twice while printing Etched in Aqueous HF Material: At cutting speed 1000 mm/min.

Fig. 8. Microstructure in HAZ.

4. Conclusions :

The following conclusions are drawn from the present investigations :

(1) Rykalin's theory for the temperature distribution in a plate when a line source of heat moves over it describes very closely the temperature distribution that can be expected when a plate is cut by a plasma source. This follows from the fact that the experimental and theoretical temperature distribution agree fairly closely.

Maximum temperature reached in the vicinity of the plasma cut zone is 760°C. As compared to oxygen cutting, the rise and fall in temperature is very steep in plasma cutting.

(2) Tensile residual stresses are encountered on the surface of the cut. The value of the stress in the vicinity of the cut zone is 2.74 kg/mm^2. The tensile residual stresses change into compressive stress in a distance of only 0.85 mm from the cut edge.

(3) Microhardness does not vary with the speed of cutting and practically remains constant along the width of the cut surface and variation along the depth is not appreciable.

(4) HAZ comprises of two distinct zones, the outer cast metal and the adjacent region where the structure has been altered. The width of the HAZ is around 0.1 mm.

5. Acknowledgements :

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