COMPARISON OF METAL-CUTTING METHODS

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Abstract:

The arcticle deals about the comparison of the most used cutting technologies in respect to achieved cut quality. It was compared cut quality in terms of the achieved roughness and damage zone. It is offen heard the question around the metal fabricating world: What metal cutting technology makes the most sense? But the answer is unfortunatelly not as simply. The answer depends on the material being cut, the metal thickness, requirements of cut quallity or the performance of single metal-cutting method. All of this variables makes the reason for comparison of the metal cutting technologies.

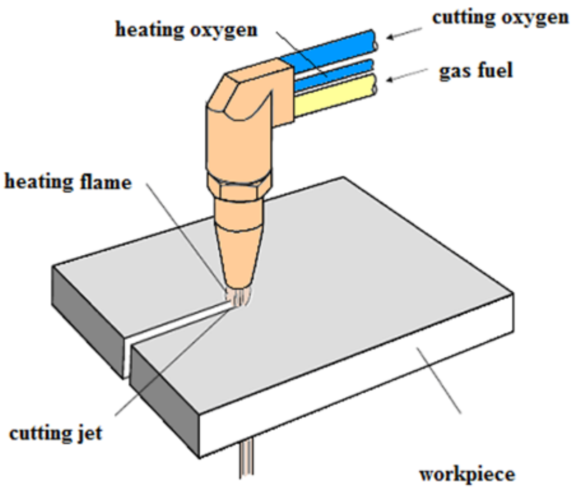
THERMAL CUTTING

Thermal cutting processes are apllied in different fields of mechanical engineering . They are classified into different categories according to DIN 2310, that contains the classification according to the physics of the cutting process :

- **Flame cutting** –the material is mainly oxidised-burnt
- **Fusion cutting**- the material is mainly fused
- **Sublimation cutting**- the material is mainly evaporat

OXYFEUL GAS CUTTING

Oxyfeul gas cutting includes a group of cutting processes that use controlled chemical reaction to remove preheated metal by rapid oxidation in a stream of pure oxygen. This process begins by heating a small temperature of 760 to 870˚C with an oxyfuel gas flame. Upon reaching this temperature, the surface of the metal will appear bright red. A cutting-oxygen stream is then directed at the preheated spot, causing rapid oxidation of the heated metal and generating large amounts of heat. This heat supports continued oxidation of the metal as the cut progresses. Combusted gas and the pressurized oxygen jet flush the molten oxide away,exposing fresh surfaces for cutting. The metal in the path of the oxygen jet burns. The cut progresses,making a narrow slot, or kerf through the metal. [1]



Principle of oxygen cutting

EQUIPMENT

During cutting, oxygen and fuel gas flow through separate lines to the cutting torch at pressures controlled by pressure regulators, adjusted by the operator. The cutting torch contains gas ducts, a mixing chamber, and valves to supply an oxyfuel gas mixture of the proper ratio for preheat and a pure oxygen stream for cutting to the torch tip.

ELEMENTS OF OXYFUEL CUTTING

Preheat Flame – composed of fuel gas and oxygen at proper mixture to product maximium flame temperature for greatest heating efficiency. Heat distribution in the flame is a good indication of a potential performance of a particular gas. Acetylen is the most widely used cutting gas.

Oxygen stream – as the single most important factor in cut quality – contains those desired characteristics :

- **High purity** – quality cutting 99,5% - 100% purity

  – decreasing quality 99,5% - 95,0% purity

  – cutting operation ceases 95,0% and below

- **High pressure –** is used to provide adequate quantities of oxygen to react sufficiently with a narrow band of steel and blow slag clear of the cut

- **Long uniform stream –** the stream must be columnar in shape. Nozzle design, cleanliness of oxygen orifice and operating pressure control stream quality.

Torch and cutting nozzles – torch variations in lenght, number of hoses and valves, mixing devise and capacity – Lenght can vary and has no impact on cut quality, but has capacity limits. What concerns about the number of valves, some torches do not contain any valves, and also this characteristic has no impact on cut quality. The number of hoses depends upon whether there are separate regulators for preheat oxygen and cutting oxygen or they are both operated from one sour.

Cutting speed - The speed of cut is broken up into categories such as ”High Quality”, ”Quality” and ”Rip Cut”. Within cutting ranges for each thickness, quality increases as speed is decreased.

Material being cut – oxyfuel gas cutting processes are used primarily for severing carbon and low – alloy steels. High alloy steels, cast iron do not oxidize and so do not provide enough heat for a reaction.

The best quality of oxyfuel cutting
To understand the best cut quality of oxyfuel cutting it is useful to consider those factors:

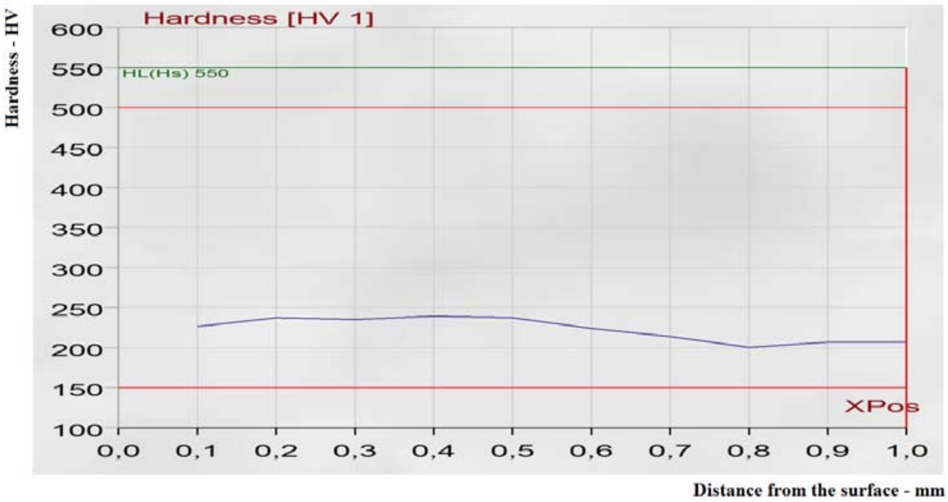
- Square top corner
- Cut face flat top to bottom
- Cut face square with respect to top surface
- Clean smooth surface
- Little slag on bottom edge

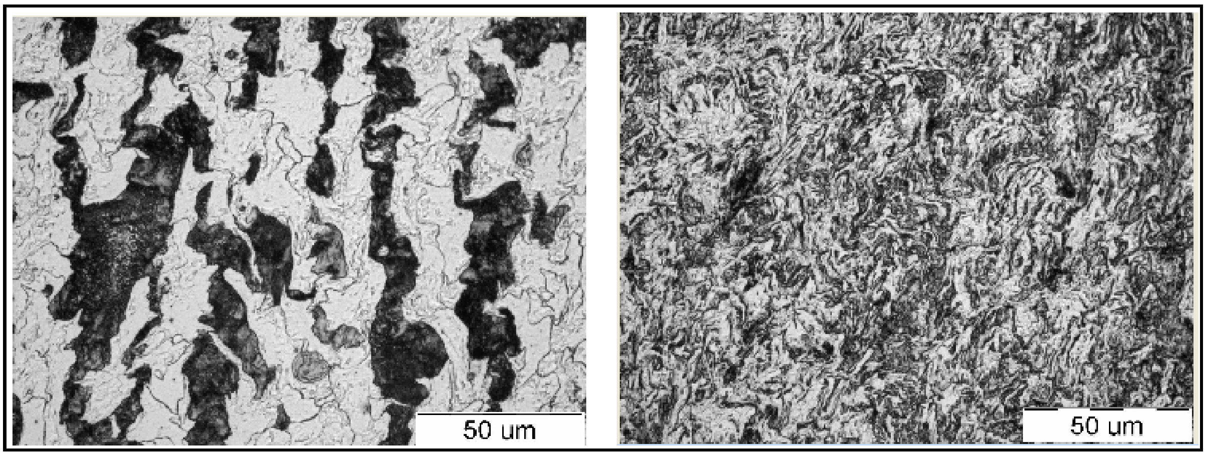


Those specimens were cut by **Multitherm 3100,** high efficient machine intended for oxygen as well as for plasma cutting with high demans on quality. A resolidified layer along the cut edge characterizes the HAZ. The used material was the low carbon steel **S355J2G3** (EN 10025- 93).

EFFECTS OF OXYFUEL CUTTING ON MATERIAL

During cutting of this steel were observed setting parameters of used machine. The experiment was claimed to achieve the effects of oxygen cutting on material of S355J2G3 in metallographic investigations. It is evident just low increase in microhardness as it is seen below – approximately about 50[HV1](Vicker´s measurement). The damage zone – heat affected zone was about 0,8 mm. Structural changes along the cutting line are low – depending on the amount of carbon and on the rate of cooling, steel transforms into microstructures ranging from acicular or spheroidized carbides in ferrite to the harder troostit constituent. Measurement and analysis of each cut sample were made using optical microscopy, whereby it was used such as magnification to permit measurement of HAZ features and analysis of HAZ phase content.





Damage created by a oxygen torch cut. Microstructure was originally a banded pearlite and ferit. Original magnification 500 x.

OBTAINED ROUGHNESS

Measurement of the surface roughness was carried out by **Taylor Hobson Subtronic**, which works on electroinduction principle. It is one of the most accurate sensor. The numerical values of the roughness are shown in table. The roughness was measured several times on different spots and subsequently was calculated the average value.The approximate range of Ra values varied in the range of 5 -8,5 µm.

Speed - 417mm/min

sample	surface	Roughness Ra [µm]					Average of T	Average of D	Average of T & D
		Nr.1	Nr.2	Nr. 3	Nr.4	Nr.5			
1.	T	8,19	7,79	9,28	6,03	8,15	7,80		6,62
	D	7,26	5,69	6,85	9,70	4,56		5,40	

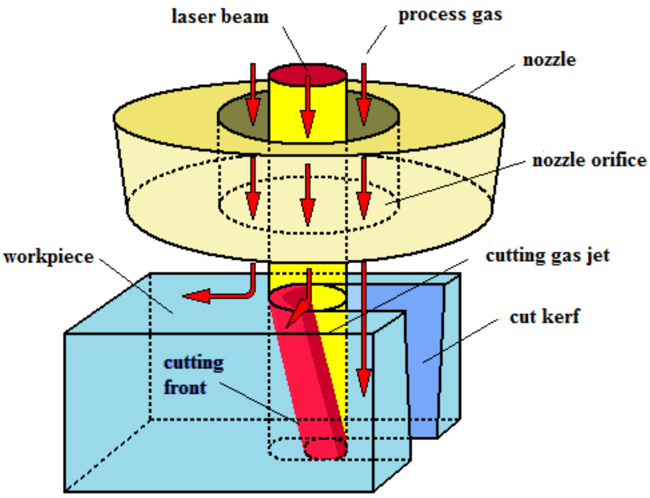
T – top, D – down

LASER CUTTING

Laser cutting technology plays very important role in the fabrication world. Its flexibility makes the laser an ideal tool for prototype or production work. Because laser cutting is a noncontact process, no tool wear occurs. Laser cutting is ideal for batch processes, just – in time , or low to medium- volume production.

GENERAL CUTTING PRINCIPLE AND LASER CUTTING APPLICATION

The mechanism for cutting steel with a laser is basically the same as cutting steel with an oxygen – fuel process in which the fuel gas acts to heat the material so the oxygen can oxidize and react exothermically with the steel to produce the cutting action. The oxygen helps to sweep the molten material out of the kerf. The main effects which influence material removing during laser cutting are illustrated below.



Principle of laser cutting

By laser can be cut any material. **All carbon** and **alloy steel** can be laser cut to over 13 mm thick with an oxygen assist gas. The exceptions are the alloys that have very dense alloying elements, such as tungsten. Stainless steel alloys are also readily cut using a laser. The thickness of **nonferrous alloys** is limited (for example by aluminum alloys- where aluminum has high reflectivity and thermal conductivity).

Material	Features
etals	At room temperature, most metals are highly reflective of infrared energy, the initial absorptivity can be as low as 0.5% to 10%. But the focused laser beam quickly melts the metal surface and the molten metal can have an absorption of laser energy as high as 60~80%. Fusion cutting assisted with gas jet is used.
Non-Metals	Non-metallic materials are good absorbers of infrared energy. They also have lower thermal conductivity and relatively low boiling temperatures. Thus the laser energy can almost totally transmitted into the material at the spot and instantly vaporize the target material.

FEATURES OF LASER CUTTING

Mode – a very important parameter, commonly referred to as a cross section of a laser beam,for cutting is ideal mode TEM_{00} , or Gaussian mode. TEM_{00} decreases the heat input to the part, which allows faster cutting speeds and smaller HAZ.

Output Power- a significant role in respect to feed rates and thickness

Speed – laser cutting feedrates have been found to fit empirical formulas based on the available laser power density and the properties of the material being cut.

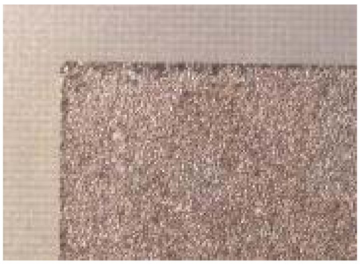
Use of oxygen as the assist gas – for cutting steel and stainless steel increases cutting speeds

The nozzle design & standoff distance – determines the laminar or turbulent flow

The optics and focused settings – affects the power density of the beam

Cut Quality.

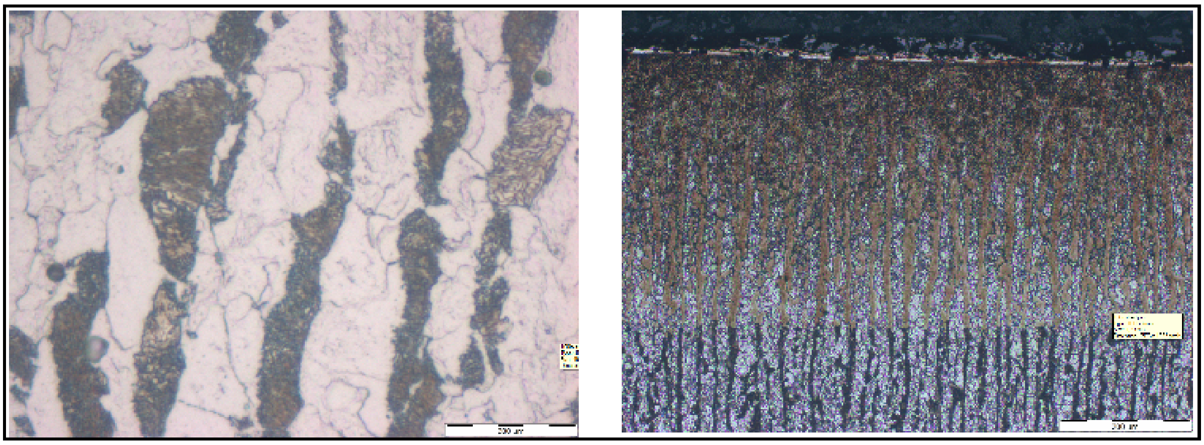
In laser cutting, cut edge be sufficiently clean and smooth, finish cut quality can be achieved in single process, the cutting kerf is very small. Sharp angles, small radius rounds and comlex curves can be cut with high speed and flexibilty. Edge burr and dross adhesion can be avoided. A small heat affected zone exists for laser cutting, but it is of micron scale, which means negligible thermal and mechanical distorsions. For thin layers (<20mm) laser cutting of many materials is a faster and high quality process compared with other processes.



Those specimens were cut by **Platino 2040 / CP 3500 – high precision cutting machine.** The used material was as well as in prior cutting technology the steel of **S355J2G3** (EN 10025- 93). The thickness of the material is 20 mm. The picture below shows the same material of the thickness 25mm, so it is evident the worse cut quality when the thickness increases.

EFFECTS OF LASER CUTTING ON MATERIAL

The experiment was provided under the same conditions – with the aim to find out the effects of laser cutting. The below table shows the range of microhardness changes, which were aproximatelly 0,5 mm.



Damage created by a laser. Microstructure was originally a banded pearlite and ferit. Original magnification 500 x.

Metallographic investigations showed the formation of favorable structure in terms of its breadth as well as structural composition. Microstructure of narrow high – hot zone constists of polyedric ferrite, ferrite segregated by original austenitic grains and acicular ferrite.

OBTAINED ROUGHNESS

The conditions for roughness measurement were the same. The numerical values of the roughness are shown in table. The approximate range of Ra values varied in the range of 4 -9 µm.

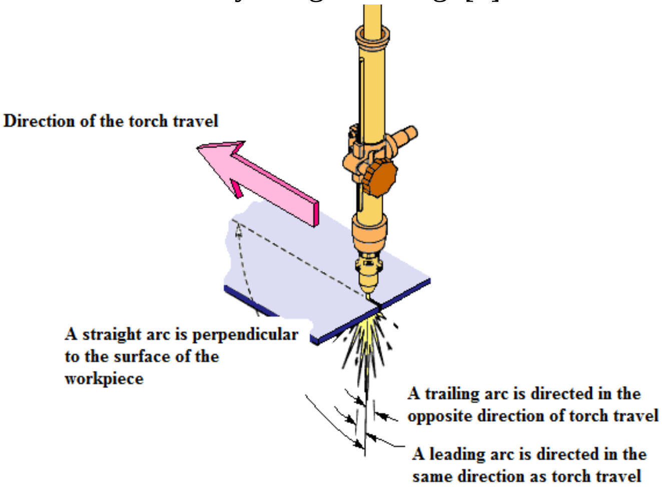
Speed – 760 mm/min

sample	surface	Roughness Ra [µm]					Average of T	Average of D	Average of T & D
		Nr.1	Nr.2	Nr. 3	Nr.4	Nr.5			
1.	T	4,17	5,18	4,65	4,13	4,2	4,46		5,98
	D	9,11	6,66	7,17	6,33	8,02		7,5	

T- top, D- down

PLASMA ARC CUTTING

Plasma arc cutting is an erosion process that utilizes a constricted arc in the form of a high – velocity jet of ionized gas to melt and sever metal in a narrow area. The arc is concentrated by a nozzle into a small area of the workpiece. The metal is melted by the intense heat of the arc and then removed by the jet gas stream from the torch nozzle. All the process relies on heat generated from electrical arc between the torch electrode and the workpiece. Plasma arc cutting can be used on almost any material, that conducts electricity, including those that arc resistant to oxyfuel gas cutting. [2].



Plasma cutting - characteristics of PAC torch

APPLICATION OF PLASMA CUTTING

Plasma arc cutting is used in a variety of industries. Plasma arc cutting can be used to cut any metal. Most application are for carbon steel, aluminium and stainless steel.

Quality of cut.

Quality of cut includes surface smoothness, kerf width, degree of parallelism of the cut faces, dross adhesion on the bottom of the cut, and sharpness of top and bottom faces. Beisdes the

HAZ – heat affected zone, the quality of a plasma arc cut involves [2] :

- **Cut angle** – PAC usually results in an angle on the cut surface of approximately 1 to 3˚ on the „good side“ and 3 to 8˚ on the „bad side“.

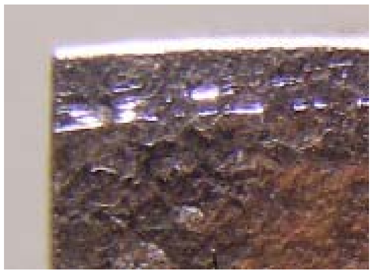
- **Dross** – is the resolidified metal taht adheres to the bottom edge of the plasma cut. The amount of dross that forms is a result of the type of metal being cut, the cutting speed and the arc current. The concentracion of the dross will be heavier on the bad side of the cut.

- **Surface finish** – the cut surface from the plasma arc process is normally rougher than that achieved by oxyfuel cutting on carbon steel and is more rough than the most machining processes.

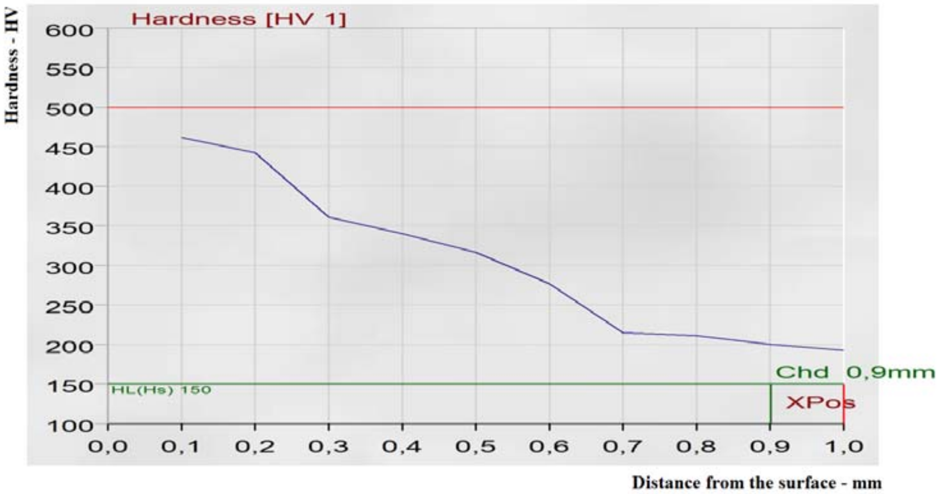
- **Top- edge squareness –** using the PAC results in top – edge rounding. This is more pronounced on the thinner metals. It rises due to a higher heat concentration at the top of the cut and can be minimized by using a gas – shielded PAC process.

- **The kerf width –** is greater as that obtained by other processes, such as abrasive cutting. Width of kerf is about two times to the kerf of oxyfuel gas cutting.

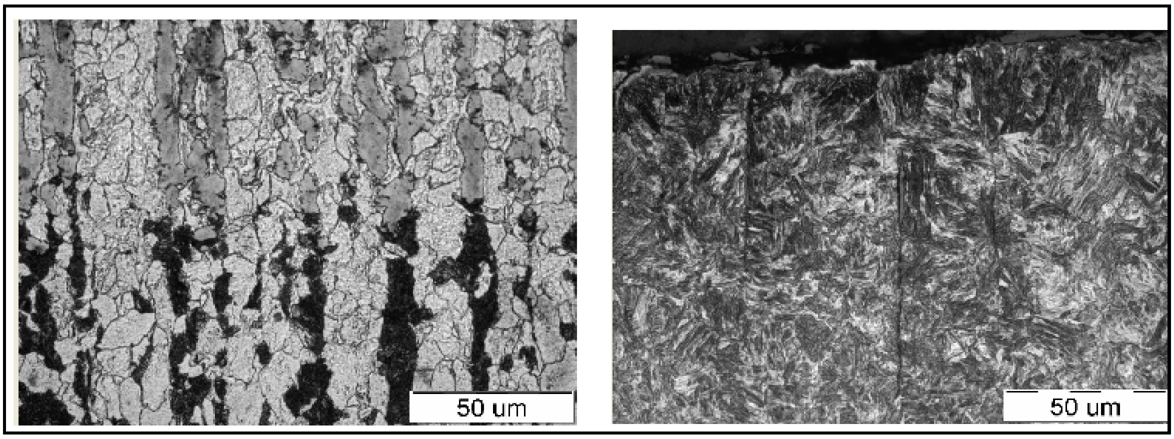




Those specimens were cut by **Plasma Cutting System Advanced HD3070** – System **Hyperformance .** The used material was the same steel of **S355J2G3** (EN 10025- 93). The thickness of the material is 20 mm.



The table shows the range of microhardness changes, which were aproximatelly 0,7 mm.



Damage created by a plasma. Microstructure was originally a banded pearlite and ferit. Original magnification 500 x.

Due to the rapid quenching effect of the air used to remove the metal, the HAZ undergoes hardening. This HAZ hardening must be considering when a finish machining operation follows, especially when working on high – carbon steels. Some materials cracking when gouged.

Obtained roughnees.

The numerical values of the roughness are shown in table. The approximate range of Ra values varied in the range of 1,4 -3,7 µm. This results shows that as the best cutting method relating to the roughness.

Speed – 1000 mm/min

sample	surface	Roughness Ra [µm]					Average of T	Average of D	Average of T & D
		Nr.1	Nr.2	Nr. 3	Nr.4	Nr.5			
1.	T	3,67	3,05	4,16	3,77	3,6	3,65		2,6
	D	1,5	1,4	2,1	1,7	1,6		1,66	

Results:

The main conclusion to be drawn from this study may be summarised as follows: Each of this cutting – method has ist advantages and disadvantages. The microstructural damamage zone of a laser was the less in comparisson with others, the less roughness was achieved by plasma cutting. Even though the oxygen cutting has its place in metal fabrication world, especially due to costingness.

Reviewer: prof. Ing. Jozef Zajac, CSc.

References

[1] In *Welding, Brazing & Soldering*, Volume 6 of ASM Handbook, 1993.

[2] Kearns, W., H., Ed. In *Welding Handbook*, Vol.2, Welding Processes – Arc & Gas Welding and cutting.