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Laser Cutting of High Density Poly Ethylene (Hdpe) Pipes Pe100 using Co_2 Gas Laser

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Abstract: ***High Density Poly Ethylene (HDPE) is one of the best materials for use in different environmental conditions. This is due to the mechanical, chemical and electrical specifications of this type, in terms of thermal insulation, lightweight, low cost, and most importantly the time factor. The molecular structure of the High Density Poly Ethylene material has made it the ideal choice for use in the pipe industry, and the transportation of various liquids, compared with the metal pipes and especially in the transportation of water, oil, and gas. And because of the frequent use, especially in the workplace. The need to use the cutting for these pipes has become necessary for the purpose of establishing networks for the transfer of fluids. In this research, the construction of holes in the pipes and measurements and angles of different for the purpose of taking advantage of these openings in the construction of networks. The laser was used as one of the modern cutting methods for the purpose of studying the efficiency and performance of CO_2 laser cutting on High Density Poly Ethylene, especially on pipes, PN 16 PE 100, 110 mm diameter, and tested under a CO_2 laser machine, by using a three different kinds of gases, such as the air and the nitrogen N_2, to estimate the changing and evaluate the quality of cutting with striation and kerf width of the High Density Poly Ethylene.***

Keywords : High density polyethylene HDPE, CO_2 laser cutting, assistant gases, striation and kerf width.

I. INTRODUCTION

Polymers are considered organic substances (1), because it contain the carbon (C) and hydrogen (H). Polyethylene (PE) is classified as part of polymers. Where polymers have many characteristics, making them easy to use in many applications(2). Polyethylene was discovered in 1900, where various types of polyethylene were developed and produced, including high density polyethylene (HDPE)(3).
Which was discovered in 1990, where it became an alternative to many metals because of its mechanical properties and high efficiency in the performance of this product. (4), which is considered one of the composite materials capable of rivaling metals. In use (5), Where he succeeded as a producer, in the manufacture of conveyor pipes for water, oil, and gas (6).
In this study, we use the high density polyethylene (HDPE) pipe (PE=100), for cutting different forms to evaluate the effect and performance of the (CO_2) laser cutting on the (HDPE) pipe in the ambient temperature.
The laser cutting process for high-density polyethylene products has evolved significantly in the past years (7), although it appeared in the late 1960s (8).
One methods of cutting metals and polymers, using the fast axial flow laser, is through the use of carbon dioxide (CO_2) and with assistance gas nitrogen (N_2) and helium (He), where (CO_2) represents the main gas in cutting (9).
The cutting by (CO_2) laser is effective for polymers(10), because of the thermal conductivity and polymer absorption of the (CO_2) laser(5).

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II. LITRETURE REVIEW

A. HDPE Temperature Effecting

The standard design of (HDPE) pipes is 25° C(11), where these pipes are affected by the high temperature due to the transformation of the series of buildings from the linear to the cross(2), It is possible to observe this at a temperature of (200°-220°) degrees Celsius, that changes the shape of that parts(12).

- Thermoplastic and thermosetting polymers: HDPE is thermoplastic, and thermosetting polymers, which is mean, it behaves like thermoplastics soften when heated and thermosetting harden when cooled processes, it is reversible and could be repeated. HDPE is linear polymers and having some branched structures with flexible molecular chains, and generally less hard and less stronger than thermosetting polymers, as it is cross-linked and network polymers, for example the Epoxies(2).

B. HDPE Mechanical Properties

The high density polyethylene (HDPE), has a large crystalline area more than the low density polyethylene (LDPE), and because of the high density, molecular distribution with very little branches, the (HDPE) Characterized a tensile strength and environmental stress crack resistance, while, the (LDPE) has a structure along branched chain(3), with a less molecular distribution, which is mean, highly flexible with less strength.

The mechanical behavior for (PE) changes depends on its molecular structure and copolymers, as the structure contains thousands of (CH_2) (13), (linear, branched), and the (HDPE) is a linear molecular structure with small branches, and the (LDPE) is the branched molecular structure (2),(6).

- HDPE Density: The Polyethylene density (0.910–0.965 g/cm³). The density of high density polyethylene (HDPE) depends on the polymerization of the molecular weight and the degree of crystalline(13), which means, increasing molecular weight, and greater carbon branches chain length, will make the crystallinity decreases and the final density will decrease(3),(11), because of (HDPE) is a kindly crystalline polymer.
- HDPE Molecular weight distribution: Molecular weight or molecular mass will be found in polymers(2), during the polymerization. It is different and depends on the polymer chain length, the molecular weight or the average of molecular weight which provide changing in the melt viscosity which means the increase of molecular weight has increase melt viscosity (13). However, polyethylene has a different molecular chain length which gives a different molecular weight, this clearly explains the properties of the (HDPE), which mean for obtaining a better mechanical characteristic should have a high molecular weight.

C. CO_2 Laser

The laser definition (Light Amplification of Stimulated Emission of Radiation) (14), is a unique light used in many different purposes in the industry, and the laser cutting by (CO_2) is a kind of thermal separation method used to shape the materials (15).

In this study, only one system will be included since the (CO_2) lasers cutting systems are commonly used for the cutting process because of the cost less, and having best beam quality and providing low and high output power than the other types of laser cutting (9).

Many researchers are worked on (CO_2) laser cutting with the different kind of polymers since it is discovered and provide the information about that such as all kind of polymers and especially the PE can be cut with a low power of laser 500 W; (16), and according to (17), the plastic board requires no more than 60 watts of (CO_2) laser energy depending on his experiment. The energy of (CO_2) laser cutting provides this statements with the ability of movement around the cutting depending on the required shape with high efficiency (10).

The (CO_2) laser system also provides high power reach to 8000 W; using to cut a different kind of material such as Stainless Steel and high alloy materials(9). However, the final shape of the materials depends on the laser power and the cutting speed of the machine to produce the high quality values (10), because of the factors which appears on the cutting area and the heat affect zone (HAZ) depending on high laser power and laser cutting velocity (7). In laser cutting, it is possible to predict the pressure and temperature fields by the ABAQUS element code by adopting experimental conditions(18). In some applications, the quality of the finished product is determined by the laser cutting process. The CO2 laser material is used to the laser beam axis, and the final quality of the product is compared with the thermal cutting of international standards. Where cutting quality is affected by the energy intensity of the laser beam(19) In CO2 laser cutting, the position of the beam has a significant impact on the width of the incision and material thickness, where the beam position changes to the minimum kerf width (20).

The sources had been differenced in estimating the mixing ratios of the (CO_2) laser system, according to(21), (CO_2) laser system contain a mixture of (5% CO_2, 10% N_2 and 85% He) gas into a 2.5 cm; diameter and 2 m; long water cooled tube but " (5)", provide another ratio with a (CO_2) laser mixture contain (CO_2 6%, N_2 20%, and He 74%). The Nitrogen particles in this system will provide the energy to the particles of (CO_2), the gas mixture is ionized by the high density electrons flowing and vibrational level appear toward to make the transition between the upper level which is called the cathodic and the lower level which is called the anode, and through the high voltage applied to the electrodes to release the photons which make the laser beam, while the Helium will work to help the (CO_2) particles to steady state and back again to the storage to be used again(9). In general, most of the nonmetals and composite materials using (CO_2) laser cutting because of the fiber structure inside the matrix and the huge absorption for the radiation infrared during the process(5).

- Working Principle of Laser beam: The laser beam is one of the significant element in the laser cutting machine(22). Firstly, it will be clear, that the high power was the reason to emit the light from the quartz streak tube by energizing a percentage of the atoms in the ruby Precious stone with a higher power line, after that, the toward a particular power line, a few atoms radiate particles for light to become photons. The photons at the beginning would be moving on the whole directions, when some photons starting to quit from atoms and that will make some emanation, these movements from the photons become after that the first principle of light which is mean the light force is quickly amplified. However, that will be clarify the using of mirrors on both sides with a limitation reflect to force the photons moving between the mirrors forward and back. Furthermore, this moving of photons become the procedure of stimulation of emitting and amplification. Finally, the last methodology will be those photons clear out through the incompletely silvered mirror to become the laser beam(23).
- Laser Cutting Methodology:

Inert gas: This kind of method which is called the inert gas generally worked to transfer the materials along the cutting area under the molten state by warming with laser power, the high pressure inert gas jet in this systems, working to throughout the molten materials from the cutting area.

The main heat power of the cutting methodology is the laser beam. However, the inert gas has the main category of the heated area (melted ejection) also the jet gas which is generally nitrogen alternately with the argon may be additionally responsible for protecting the warmed material starting with the encompassing air and also securing the laser optics.

The method can be generally used with all the different kinds of metals stainless steel, and different high alloy steel, titanium, aluminum also nonmetal materials such as the polymers. The fusion method provides a perfect cutting in spite of the low speed of cutting compared with active gas using in other instruments. This methodological feature is characterized by being free from oxidation, which is even more so, cutting does not require pre-welding preparation when used(9),(24), (25).

III. METHODOLOGY

A. Experimental and Materials

The commercial HDPE, pipe PE=100, PN=16, 4 inch Diameter, and 1 m; length, and 5 mm thickness. The laser beam system which manufactured the energy required for the analyses provided from the carbon dioxide (CO_2), which is imitation the ray in a constant mode from the (CNC laser cutting machines AMADA – FANUC – AF2000E – LC 2415 alpha III, working range X-Y-Z: with a maximum laser power: 2000 Watt, Fanuc FS 160i-L, (CNC) control, maximum speed 80/80/60 mm/min, with a cooling systems, the machine contain a mixture of 5% (CO_2) and 55% assistant gas of (N_2) what is more 40% (He) gas, (the Air and N_2) will be the gas assistant to the operation) into a 2.5 cm; diameter and 2 m; long, water cooled tube, Amada is used for cutting a different kind of materials with low and high power, we are working to test the (HDPE) pipe PE=100 to a (CO_2) laser cutting. In Amada machine after prepare the information about pipe thickness , the focus area and cutting speed to the machine to provide the three kind of pieces (circle 20 mm; diameter, 20 x 20 mm^2; square and 20 x 20 x 20 mm; triangle) perfect cutting. The beam rising from the laser pit, throughout of the window yields in the shade mechanism, and may reflect by 5; folding mirrors. The laser beam coming out from the laser pit is straight polarized and, concerning illustration such has one direction laser cutting. the second collapsing mirror, which may be also a quarter wave plate, reflect this straight polarized laser beam under a circularly polarized beam to allow cutting in all directions just as great, after that, it is focused eventually inside 25.4 mm; diameter, covered with (Zn-Se) lens for a central length from claiming 127 mm. The focusing area of the laser beam will be computed should make 0.2 mm. To secure those lenses, what is more, for during laser produce, an assistant jet gas may use. The nozzle at the end of the procedure will provide the last step from the laser beam cutting operation, and have been used a standard spout with 2.0 mm; gap diameter, and constructed from copper. With a 2 mW; of the helium gas, which will be used in this area, by flooding throughout the gap for adjustment.

B. Experimental variables and measurement

Laser cutting performance in this research had been studied by testing the kerf width, the heat affected zone (HAZ) for the high density polyethylene (HDPE) materials, what is more, the surface roughness and the striation frequency also the perpendicularity deviation of cutting edge. A portion of these variables needs aid those material being the reduction such as the size, what is more, the thermal conductivity properties, and laser control output, velocity of the laser beam, the assistant gas (Air and N_2), the pressure, and the laser beam performance, also the focusing optics. Some from these variables are claiming to this study and will need more introduced below.

The laser beam energy:

The (CO_2) laser had been used in the study was provided form a laser energy of 2000W; with constant output and because of the many different properties which affect the laser cutting procedure there was the uneasy process to choose a range of energy values from the previous researches had been published. However, the logically cutting had been used depending on a reasonable laser energy values. Therefore, the three experiments value, we used a laser beam energy with 500 W.

The laser beam speed

Laser beam speed had been constant also would not be changed but the laser beam head above the material of (HDPE) had been moved into three dimensions at speed of 100 mm/min; The movement of the head at a constant speed would provide the same action as let the head constant.

The arm table movement

The arm table worked under Amada controller program. Generally, the process starts when the materials become on the table, the first step of the arm is pressing the materials preventing it from moving and the control program started by ordering the arm table movement at a speed of 42.33 mm/s; to the laser beam position.

The lens focal

The lens focal straight utilized measures the focal diameter section. In spite of, a little focal diameter provides a bigger flux, the cutting methods prefer the lens with little focal length. Generally, the research was worked with 25.4 mm; diameter and (Zn-Se) lens of 127 mm; long, this brought about a central spot of 0.2 mm; diameter, this resulted in a focal spot diameter of 0.2 mm.

The gas pressure

The gas had been used as helping or assistance on the cutting procedure. The nozzle that has been used within those examinations was a standard. Furthermore, the gas providing in the process make turned on alternately off from the controlling system. There is a cylinder of (N_2) gas with a gauge pressure which controlled the pressure used from the cylinder. However, in this experiment we used two kinds of gases (Air, and N_2) with a pressure of 1 bar.

In this experiment, we note that Amada equipment machine need at minimum 30 minutes time to be ready, such as the infrared sensor and the data systems

C. Experiment Data Base

Below table 1 provides the data base which has been used in this experiment.

Table- I: The parameters required to start the experiment

Parameters	Details
Laser type	CO_2
Laser operating mode	PULSE
Distribution of power density	Wave
Polarized beam	Circular
Power density of beam	105 watt/mm^2
Laser Power	2000 watt
Laser beam energy (air)	467 watt
Laser beam energy (N_2)	470 watt
Laser beam energy (O_2)	218 watt
Cutting speed	100 mm/min
Assist gas	Air, N_2
Gas Pressure	1 Bar
Focal Length of lens	127 mm
Focal Diameter	0.2 mm
Focus Position	Surface of work material
Spot diameter	2 mm
Standoff distance	0.2 mm
Nozzle Diameter	1.5 mm
Nozzle Pressure	1 Bar
Materials	HDPE pipe
Material Thickness	5 mm

D. Material Cutting

One of the majority parameters used in the laser cutting is the inert gas, it helps to understand the form shape of the materials. In this research we used to cut the (HDPE) under different parameters of (CO_2) gas laser, gas assistance (Air and N_2) to produce the shapes required circle, triangle and the square.

Using Air as Assistance Gas:

Table II. The parameters of air assistance gas under (CO_2) laser cutting

Shapes	Feed mm/min	POWER (watt)	Frequency	Duty %	AWP (watt)
Circle	100	2000	100	25	467
Triangle	100	2000	100	25	467
Square	100	2000	100	25	467

Figure1. The inner face of samples under CO_2 laser cutting using air as assistance gas

- Using (N_2) as assistance gas

Shapes	Feed mm/min	Power (watt)	Frequency	Duty %	AWP (watt)
Circle	100	2000	100	25	470
Triangle	100	2000	100	25	470
Square	100	2000	100	25	470

Figure2. The inner face of samples under (CO_2) laser cutting using (N_2) as assistance gas

E. Cut Quality Evaluation

Laser power and cutting speed what is more the gas assistant are the most important parameters of (CO_2) laser cutting in the industrials. However, the roughness and the striation frequency what is more the heat affected zone (HAZ) are the parameters which are used to evaluate the quality of cutting.

Striation Frequency: Striation is the fluid layer appear because of the unstable connection for the dynamic characteristic of laser cutting, also it is a kind of line appear on the workpiece surface during the laser cutting and the movement of the laser beam. However, this mechanism

phenomena are not understandable even many researchers worked on it(26).

The striation can be an effect on the roughness of the workpiece, which is mean, reducing the roughness makes the striation reduce, what is more, in the less thickness there is a possibility to control the striation(27).

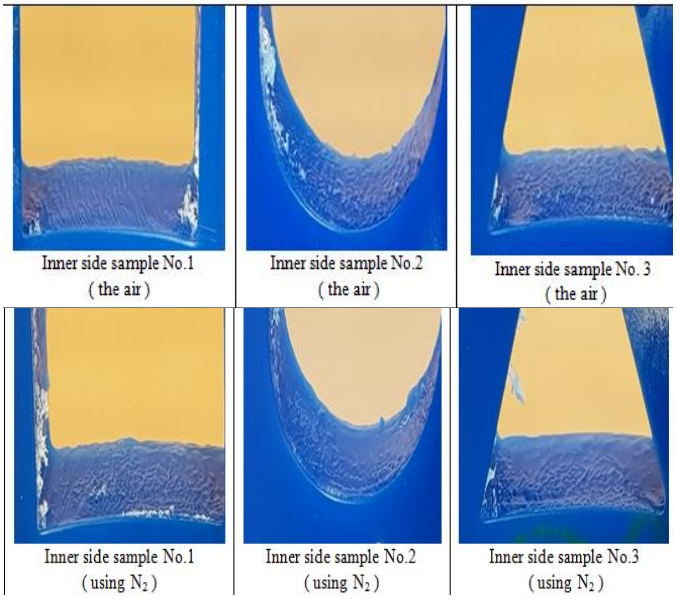

Figure3. The striation shows the melted area of the (CO_2) laser cutting under 100mm/min; and power 470 W; the Air and (N_2) as the assistant gas

IV. RESULT AND DISCUSSION

A. CO_2 Laser Kerf Width

The (CO_2) laser cutting for the kerf width produced the different measurement between the inside surface. Furthermore, the outside surface of the pipe. We can notice that, the cutting procedure may be accepted and will be more stable at the beginning position than the end position for the two kinds of gases, and for the three kinds of shapes, as a result, it takes a few seconds of the time for stabilization the cutting velocity, which is mean, we can neglect the kerf width at the inside position (Figure 4.1.).

In this experiment, we notice a lower distinction (CO_2) kerf width cutting between the inside, what is more, the outside kerf width, with the 5 mm; thickness of the high density polyethylene (HDPE) material, this might be because of the laser beam effect during the centered of spot area. Furthermore, concentered for the high temperature in the workpiece throughout those cutting transform.

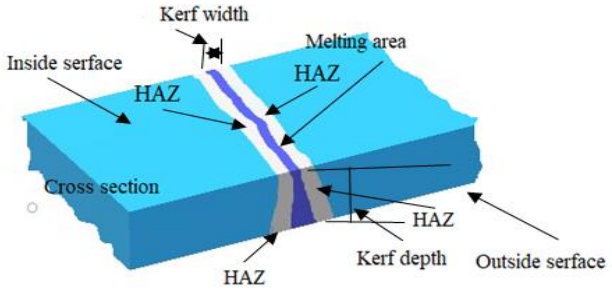

Figure 4. Kerf width and depth

B. Cutting Edges Perpendicular

It is the distance between the outside real surface edges cutting and the inside area of the reduced edge. It can characterize of the linear line and flatness. The (Figure4.2.) present the cutting edge perpendicular demonstrated. In this experiment we notice, that the Perpendicular style estimations for the (CO_2) laser cutting edges had been little deviation for 5 mm; thickness of the (HDPE), which can be neglected for the three kinds of cutting (the circle, the rectangular, and the triangle) for the two different assistant gases (Air and N_2).

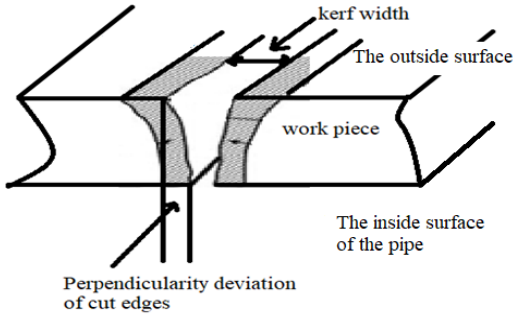

Figure 4. Perpendicular style deviation of (CO_2) laser cutting edges.

C. Striation Frequency

Figures 3. Provide the details about (CO_2) cut quality at the power 470 W; with a constant cut velocity 100 mm/min; for the two kind of assistant gases (air and N_2) (non and semi fusion cutting), under this power we could observe, that the striation had been appeared even with constant power and speed, as the striation appear during the unstable parameters upon the thickness of the liquid film for the cutting during melting ejection.

D. Experimental Discussion

- **Maximum Cutting Speeds**

The cutting speed does not consider in this experiment, as it is under a fixed parameter because the experiment was evaluated with a different assistant gases, as in this experiment we have used 100 mm/min; and that would find the agreement with(10), which concluded in their study that there is an inverse relationship between the speed cutting with quality of polymers, also(16), and (17), which conclude that ultimate 100 mm/min speed cutting in their experiments, with low conductivity materials and polymers could provide a good performance and quality.

- **Kerf Width**

In this experiment, we had examined the kerf width at the 100 m/mm; and (CO_2) laser cutting on a 5 mm; of workpiece, even with the two kinds of assistant gases for the (HDPE) materials are appeared on Figures (3.1.) and (3.2.), which is provide a very small kerf created due to the fixed parameters of cutting speed, and the center spot measure, which gives us an indication that the different kinds of the assistant gases do not appear any effect on the kerf width, and the small kerf had appeared due to the center spot measure, that related with the quality of the laser beam of the (CO_2) laser cutting.

We notice also in this experiment, even with the very small kerf width, the inner kerf was smaller than the outer kerf, due to the lost gases pressure over the perpendicular depth for the 5 mm; of workpiece sample material, which mean, the highest beam performance and cutting speed conclude in a little center spot estimate a little kerf width, while the low cutting velocities would worm up and melting the cutting area from the inside causing more extensive kerf at the inner side, this may related, to the conductivity and the properties of the (HDPE), and the inner kerf became little increasing with the laser cutting, and because of that, we cannot evaluate the kerf width in this study even with the different assistant gases, which mainly used to throughout the melting liquid from the area of laser cutting, and with this result we can conclude, that the kerf width is effected by the frequency and pulses power, also we can notice that(16), had the agreement with the result found in this study, which he concludes, that the correct parameters of cutting speed, power and gas assistance could reduce the kerf width.

- **Perpendicularity Deviation of Cut Edges**

In this experiment, we can observe, the lowest perpendicular path. This probably due to the parameters of the operation, which made the correct effect significant upon the cutting edge perpendicular. However, for this experiment, we would justify the power to vary with the different assistant gases pressure to obtain the results. Under this conditions, we could find that, the effect of different assistant gases on the perpendicular path cannot be affected.

- **Striation Frequency**

The phenomena, that produce the striation upon the inside cutting surface could be explained, by understanding the heat transfer during the operation from the top of the materials to the molten materials, what is more, the initial vaporization at the top of the materials. We can also find, that the instability of the different kinds of assistant gases during the laser cutting of the (HDPE), due to the variance of the temperature inside the materials throughout the process of cutting, this temperature change of the workpiece will be the conduct of the liquid melted layer, which is the behavior for the thermoset materials. Likewise, this behavior for the thermoset materials in this procedure, would be effected by the energy of the (CO_2) laser cutting, causes the slowdown of temperature during the process, and due to the high resistance of the assistant gas, then the temperature will drop, what is more, at the moment when the layers need to be developed on the right thickness it will be launched out down that kerf exposing clean the surface, after that, the temperature once more start increase again, due to the expanded accessibility to the assistant gas, and the reaction of power energy. This behavior instability in the conducting technique of the layer might have been the reason for the striation creation in the assistant gases for the (CO_2) laser cutting.

In this experiment, using the (CO_2) laser with phenomenal parameters, show up the easy effectiveness to reach the steady state administrative promoting striation path. This will provide the irradiance uniform path to the kerf, anyway, we can result that, the striation path coming because of the viscosity melting, and what is more, the high tension on the surface will create a uniform stream.

V. CONCLUSION AND RECOMMENDATIONS

A. Conclusions

All the conclusions and results obtained in this study had been taken under special factors of choice and circumstances, from the type of the inner gases to the constant speed and power cutting, as well as the substances involved in the experiment, and it will be limited for this test.

The conclusions were represented in the following below:

The using of (CO_2) laser cutting proof it, to be an effective process in producing clean models of different forms like rectangle and triangle, also the circle and different angles 90° degrees and 45° degrees, what is more, the curve shape.

- The Cutting of the (HDPE) pipe by the (CO_2) laser cutting required 100 mm/min; speed and power depending on the kind of the assistant gas, and the thickness of the material.
- The (HDPE) pipe provides, an impressive rate and good quality under (CO_2) laser cutting, and this could be observed with the sharp shape of the angles in each sample.
- The (CO_2) laser cutting provides a very good indicator with the thickness of 5 mm; (HDPE) pipe.
- The different kinds of the assistant gases do not provide an effect on the thickness of 5 mm; for the high density polyethylene (HDPE) under 1 bar, which gives us the indication that, the other parameters have the real effect on the (CO_2) laser cutting.
- The 1 bar pressure of the assistant gas with the two different kinds of gases provides an effect on the quality of cutting.
- The improvement of the speed cutting quality, in connection to the most extreme cutting, was 100 mm/min. This accomplished for 5mm (HDPE) pipe thickness, as observed, by the lowest estimations of the kerf width, (HAZ), perpendicularity and the striation.
- The (CO_2) laser cutting provides smooth, and excellent surface performance in the application for the (HDPE) with no deformation to the thickness of the pipe.
- The inner kerf width less than the outer kerf width, and thus belong to the type of the materials, as the speed and cutting power are constant.
- The procedure does not appear smoking on the workpiece.

B. Recommendation

For the future experiment, by using the high density polyethylene (HDPE) the experimenter can use a different thickness from the materials with the a different type of the laser cutting, to study the cut evaluation and performance to compare the evaluation of the kerf width, the roughness, the heat affected zone, perpendicularity and the striation, to provide the market with quality and less cost production, as we already proved that the (CO_2) laser cutting had the potential to provide the good quality and performance to the high density polyethylene (HDPE) with the 5 mm; thickness.

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