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CO_2 laser cutting of slate

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Abstract

Slate is a natural stone which has the characteristic that shows a well-developed defoliation plane, allowing to easily split it in plates parallel to that plane which are particularly used as tiles for roof building. At present, the manufacturing of slate is mostly manual, being noisy, powdery and unsafe for the worker. Thus, there is a need to introduce new processing methods in order to improve both the working conditions and the quality of the products made of slate.

Following the previous work focused on the drilling and cutting of slate tiles using a Nd : YAG laser, we present in this paper the results of the work carried out to explore the possibilities to cut slate plates by using a CO_2 laser. A 1.5 kW CO_2 laser was used to perform different experiments in which, the influence of some processing parameters (average power, assist gas pressure) on the geometry and quality of the cut was studied. The results obtained show that the CO_2 laser is a feasible tool for a successful cutting of slate.

Keywords: Slate; Laser cutting; CO_2 laser

1. Introduction

Slate is a natural stone formed as result of the sedimentation of fine material deposits subjected to the action of high temperatures and pressures [1]. The slate is mainly used as architectural element: roof building, flooring, paving, etc. There are many varieties of slates, depending on the density, coefficient of water absorption,

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mechanical flexure strength, resistance to frost, colour, etc. But the principal characteristic of this stone is the planar structure that allows splitting the slate in thin plates, which can be used directly as tiles.[2]

The main components of the slate are: quartz, chlorite and sericite; it is also frequent to find iron oxides and sulphides, carbonates and clayey minerals. The manufacturing of this product is mostly manual, being noisy, powdery, and unsafe for the worker; therefore, there is a need of an alternative method of manufacturing slate, to improve the working conditions and the processing procedures.

In previous work, we demonstrated the viability to drill and cut slate tiles with a Nd : YAG laser [3,4]. In this paper, we present the work carried out to explore the capabilities of the CO_2 laser to cut slate tiles.

2. Experimental procedure

From the large amount of different types of slate, we have selected for this work a representative slate variety named "Valdeorras", currently used as roof building. Commercial slate tiles exhibit a non-uniform thickness profile; thus, a careful selection of the slate tiles has been made, verifying their thickness in several points, in order to guarantee the uniformity of each slate plate. The thickness of the selected slate plates varied from 3 to 13 mm covering the commercial range.

The cutting experiments carried out during the present work were performed by means of an Electrox CO_2 laser delivering a maximum output power of 1.5 kW at a wavelength of 10.6 μm, operating in continuous wave. The laser beam was focused on the upper surface of the slate tiles. The lens system used to focus the laser beam onto the slate tiles consisted in a ZnSe lens with a focal length of 125 mm. The beam, together with the coaxial assisting gases, passes through a conical cutting nozzle with an aperture of 1.5 mm. A Laval nozzle was also used in order to compare its effects in the cutting process with respect to the conical nozzle.

An *X–Y–Z* table controlled by PC moved the work-piece material in relation to the stationary laser head. The basic experimental arrangement is shown in Fig. 1. The geometrical characteristics of the cuts were visualised and measured by means of an optical microscope and a CCD camera coupled to an *X–Y* micrometric table. Different processing parameters were varied in order to study their influence on the characteristics of the cuts. The average power was varied from 200 to 1200 W. Three different assist gases have been used: oxygen, nitrogen and argon. The range of pressure was 1–5 bar when using a conical coaxial nozzle and 1–7 bar with a supersonic Laval nozzle.

3. Results and discussion

A systematic study on the influence of the different variables involved in the cutting process has been conducted in order to find the adequate window of parameters to satisfactorily cut slate tiles. Therefore each parameter was varied while

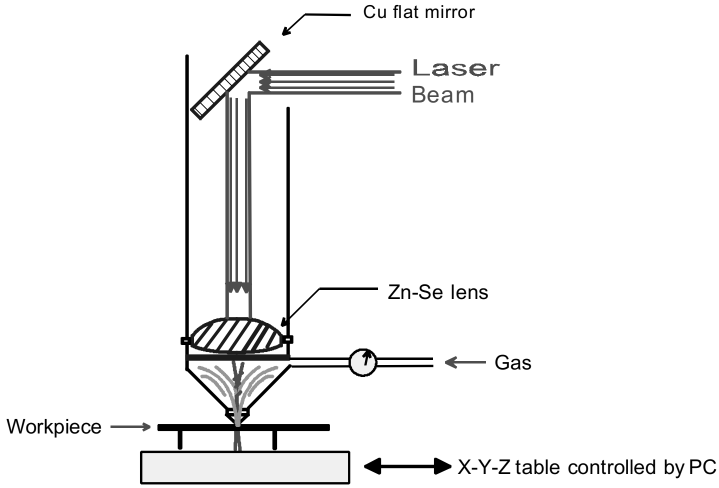

Fig. 1. Scheme of the experimental Set-up.

keeping all others constant and the process has been repeated for plates of different thickness.

It is well known that in laser cutting of materials using inert assist gases, the energy of the laser beam melts the material and the gas blows away the molten material; at the same time the gas contributes to cool the hot cut zone by forced convection [5]. If oxygen is used as assist gas, a chemical energy can be added to the cutting zone via exothermic reactions when the material to be cut has oxygen reagent components [6]. To investigate the influence of the nature of the assist gas in the CO_2 laser cutting of the slate tiles, a series of experiments using inert gases (nitrogen and argon) and a reactive gas (oxygen) has been conducted. Fig. 2 depicts the maximum cutting speed versus the average power for these three different assist gases, keeping all the other parameters constant. As can be seen in this plot, the use of oxygen leads to a slight increase in the processing velocity. This behaviour could be explained by the presence of impurities (i.e. iron suboxides) in the slate in a small amount, which will oxidise and contribute to enhance the energy coupled to the cutting zone thus increasing the cutting speed.

Fig. 3 shows the relationship between the cutting speed and the average power using oxygen as assist gas at a constant pressure of 2 bar. The behaviour is similar to that exhibited by other materials as reported in the literature [7,8]: the cutting speed increases with the increment of laser power and this result is confirmed by the experiments performed with slate plates of three different thickness: 3, 5 and 8 mm. It can be seen that when using the thin plates the cutting velocity could be at least 50% higher than that achieved when cutting thicker material. This is an interesting result from the commercial point of view, based on the fact that the slate tiles used currently as roof building are only 3 mm thick and this type of slate plate collects the biggest part of the global slate production.

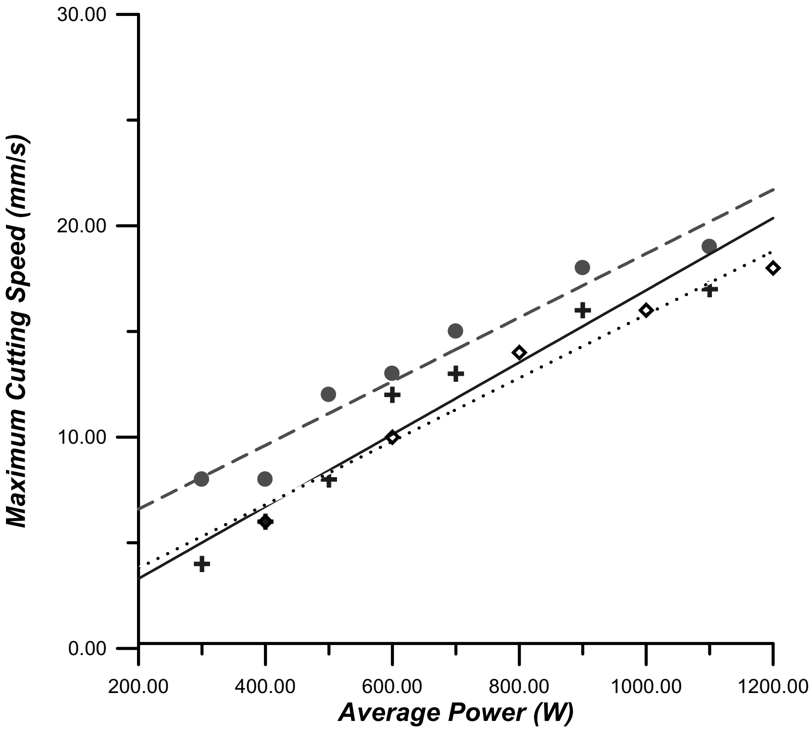

Fig. 2. Maximum cutting speed versus average power for three different types of assist gas: (◇) Argon, (●) Oxygen, (+) Nitrogen. The pressure was kept constant in all cases at a value of 2 bar. Thickness of the slate tile: 5 mm.

In Fig. 4, the maximum cutting speed is plotted as a function of the material thickness. In these experiments, the average power was kept constant at 1200 W using oxygen as assist gas at a pressure of 2 bar. The behaviour is similar to that reported for metallic materials [9]. For slate plates thicker than 13 mm the cutting speed decreases to levels of non-practical interest, because there is a disproportionate increase of the thermal losses by conduction when the thickness of the slate tile increases. Consequently difficulties appear to blow away the molten material, leading to a deterioration of the cut quality [10]. To illustrate this behaviour observation of the cut kerf and the cut edge of several slate tiles has been carried out.

Fig. 5 (a) and (b) shows the appearance of a 7.5 mm thick slate tile, that has been cut using a conical coaxial nozzle with oxygen as assist gas. As can be seen in Fig. 5(a) the geometry of the kerf corresponds to that of a clean cut, without the presence of molten material resolidified. This fact is corroborated in Fig. 5(b) that exhibits a uniform and clean cut edge. On the contrary, when trying to cut a thicker plate (13.5 mm) under the same conditions the results are poor, demonstrating that the critical thickness can be established at around 13 mm for these processing

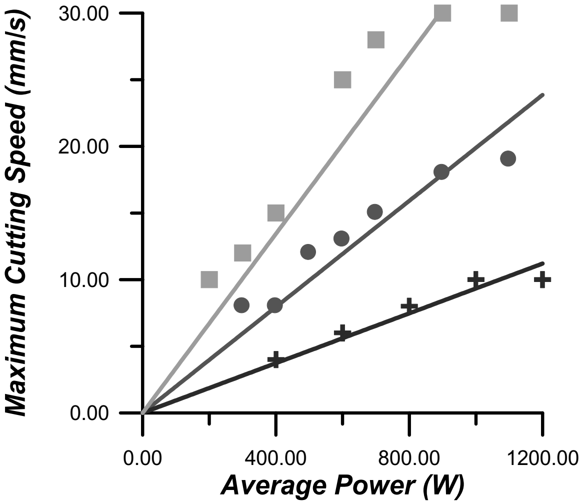

Fig. 3. Maximum cutting speed as a function of the laser average power for three slate tiles having different thickness: (■) 3 mm, (●) 5 mm, (+) 8 mm. In all experiments the assist gas used was oxygen at a constant pressure of 2 bar.

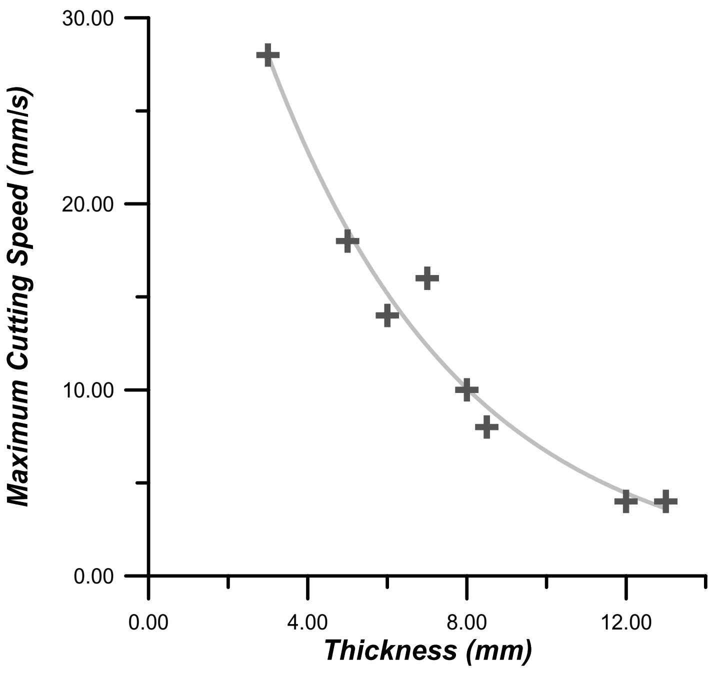

Fig. 4. Relationship between the maximum cutting speed and the thickness of the slate workpiece. Average laser power: 1200 W. Assist gas: Oxygen. Pressure: 2 bar.

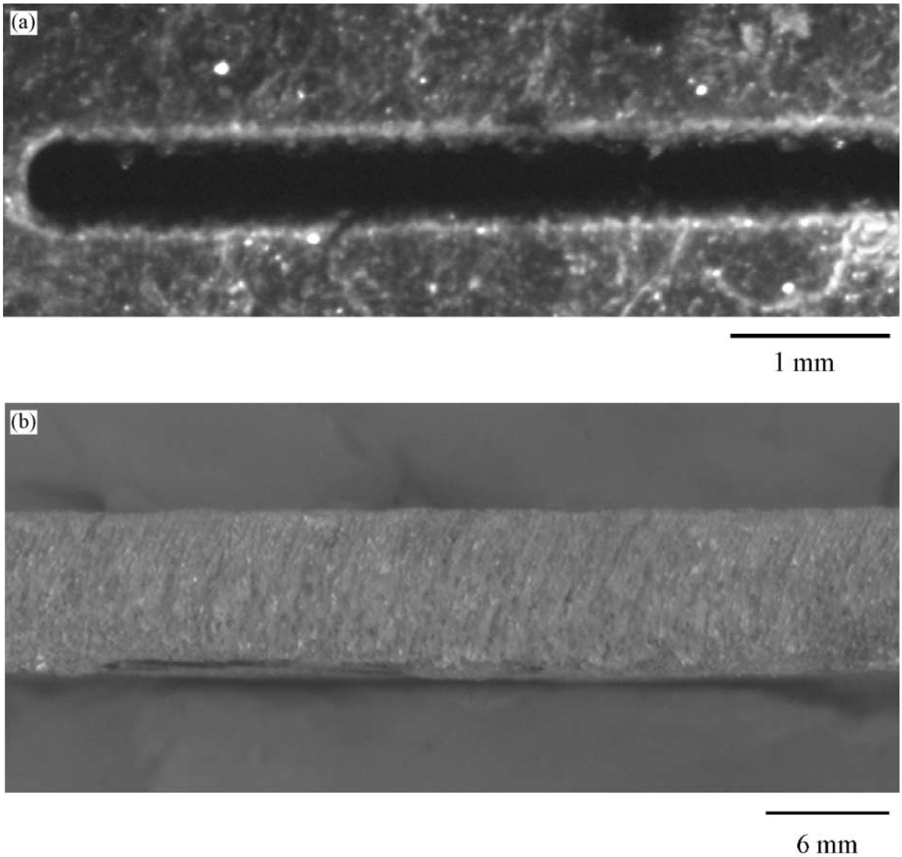

Fig. 5. Optical photographs showing the geometry of the cut: (a) top view and (b) edge of the cut. The thickness of the slate tile is 7.5 mm. Average laser power: 1200 W. Assist gas: Oxygen. Pressure: 2 bar. Cutting Speed: 6 mm/s.

conditions. Fig. 6(a) shows the geometry of the kerf, where it can be seen that molten material, which has not been efficiently blown away, was resolidified and collapse the cut zone. In Fig. 6(b), one can observe the cut edge exhibiting an irregular surface, with an inhomogeneous recast layer.

In Fig. 7, the average power to slate tile thickness ratio is plotted as a function of the cutting speed. It can be observed that most of the results follow a linear behaviour. This comportment can be explained under the considerations of the molten shearing mechanism involved in the laser cutting of slate. When cutting slate the material is mainly molten and blown off by a gas jet in a similar way than that reported in the literature for metals [11,12]. This process can be approximately modelled by a simple energy balance, assuming that all the energy which enters the interaction zone between the laser and the material will be absorbed and used to melt the interaction volume and the molten mass is blown away before significant

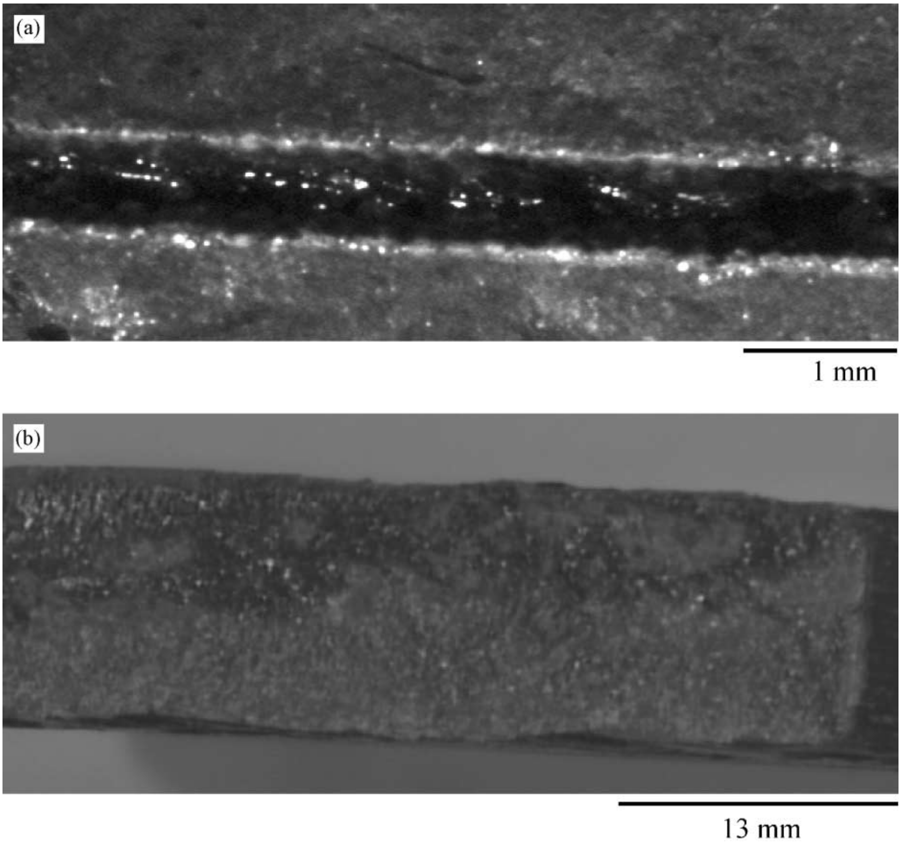

Fig. 6. Optical photographs showing the geometry of the cut: (a) top view and (b) edge of the cut. The thickness of the slate tile is 13.5 mm. Average laser power: 1200 W. Assist gas: Oxygen. Pressure: 2 bar. Cutting speed: 6 mm/s.

losses take place by conduction. This assumptions lead to the following expression [13,14]:

$$P/tv = A, \tag{1}$$

where P is the average laser power, t is the material thickness, v is the cutting speed and A is a constant which depends on optical and thermal properties of the material; furthermore, other parameters such as the laser spot diameter and assist gas are kept constant. The experimental data plotted in Fig. 7 are in accordance with Eq. (1), confirming that the assumptions made are also valid for the case of slate.

In order to study the influence of the pressure of the assist gas in the maximum cutting speed attained, a series of experiments were conducted using a conical coaxial nozzle placed at a distance of 1 mm from the slate plate (stand-off distance). Fig. 8 shows the results obtained in these experiments. As can be clearly observed the

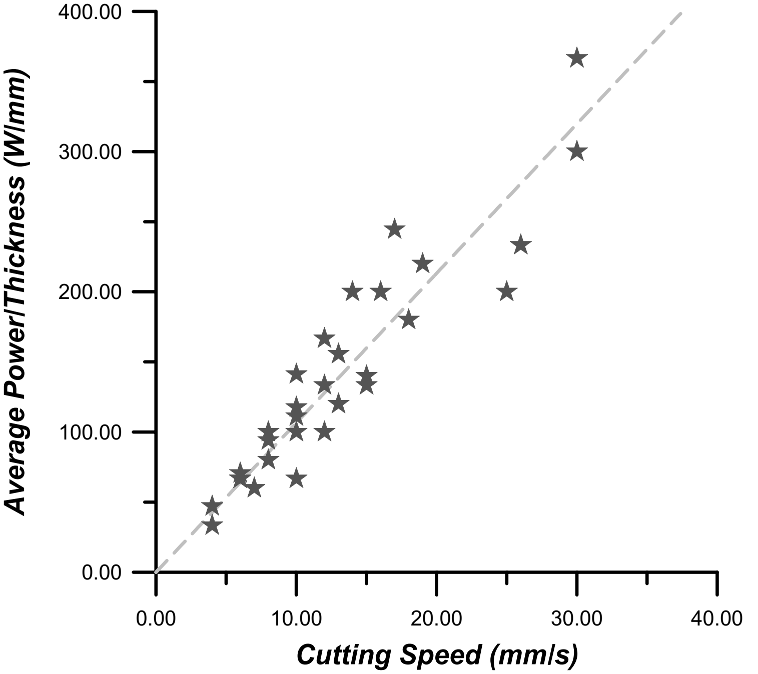

Fig. 7. This graph represents the average laser power to thickness ratio as a function of the maximum cutting speed for different slate plates covering the commercial range of thickness (3–13 mm). Assist gas: Oxygen. Pressure: 2 bar.

maximum cutting speed is obtained at a pressure around 2 bar. When increasing the gas pressure above 2 bar the cutting speed remains constant. This behaviour may be due to the existence of a density gradient field (DGF) under the nozzle, because the pressure distribution between the nozzle and the slate plate can change the ambient density, causing possible undesirable effects like variations of refraction index in the gas, or reflection of incident radiation [15].

As mentioned above when using the conventional conical coaxial nozzle there is an increase of the cutting speed when increasing the assist gas pressure up to 2 bar. A similar behaviour is observed when using a supersonic Laval nozzle, but in this case the increment of gas pressure leads to an increase of the maximum cutting speed up to a value around 5.5 bar. Fig. 9 shows the relationship between the maximum cutting speed and the assist gas pressure using a supersonic Laval nozzle. The use of this Laval nozzle allows the processing of the material with higher speeds than those attained when using a conventional conical coaxial nozzle working at the same gas pressure. These characteristics are attributed to the steady exit jet obtained with a Laval nozzle with an uniform distribution and without radial expansion, in opposition to the non-uniform and infra expanded gas flow produced by a conventional conical coaxial nozzle [16].

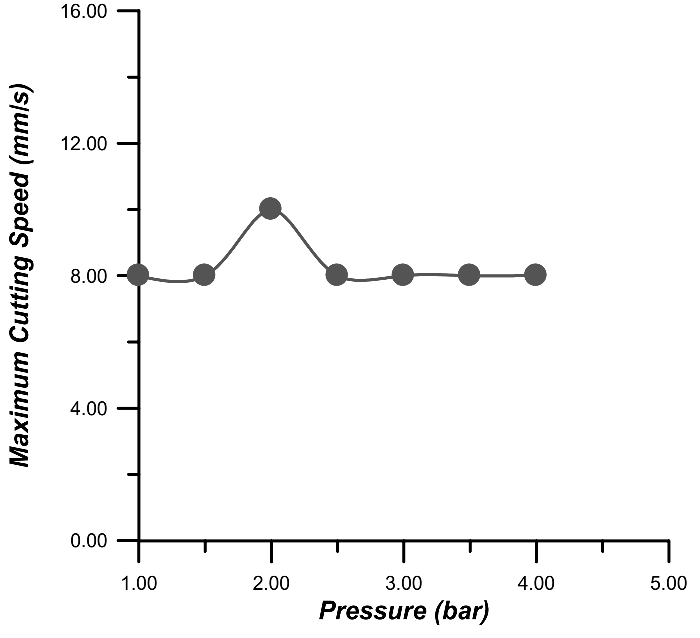

Fig. 8. Maximum cutting speed as a function of the assist gas pressure using a conical coaxial nozzle with oxygen. Pressure: 2 bar. Average laser power: 500 W. Slate plate thickness: 5 mm.

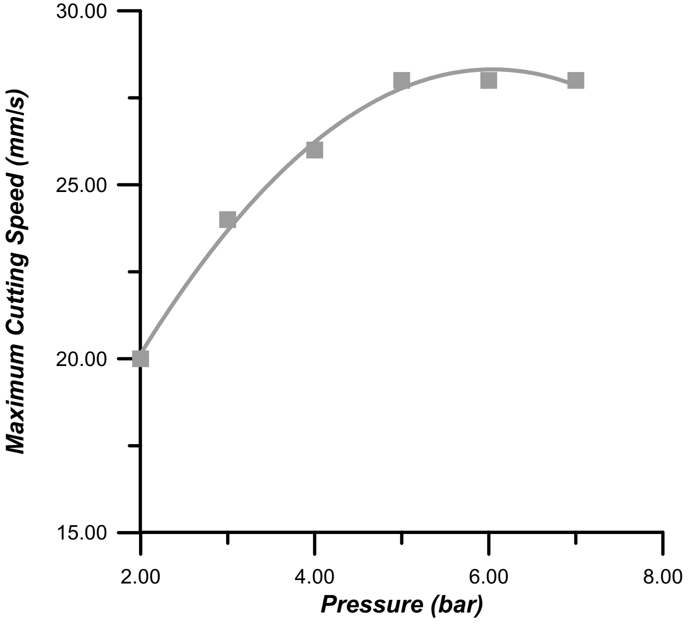

Fig. 9. Relationship between the maximum cutting speed and the assist gas pressure using a supersonic Laval nozzle with oxygen. Pressure: 2 bar. Average laser power: 1200 W. Slate plate thickness: 4.4 mm.

4. Conclusions

According to the results of the experiments performed in this work, a CO_2 laser is a feasible tool for a successful cutting of slate tiles. The main results can be summarised as follows:

- The mechanism responsible for the CO_2 laser cutting of slate tiles is similar to that of metals. The material is mainly molten and blown off by a gas jet, exhibiting a linear behaviour the plot of the maximum cutting speed as a function of the laser power.
- The use of oxygen as assist gas leads to a slight increase of the cutting velocity compared with the use of inert gases.
- Slate tiles of different thickness up to 13 mm can be cut with an acceptable cutting speed using a CO_2 laser delivering no more than 1200 W.
- The use of a supersonic nozzle leads to an increase in the maximum cutting speed with respect to the use of a conical one.

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