Europäisches Patentamt

(19) European Patent Office

Office européen des brevets

(11) EP 1 618 985 A1

(12) **EUROPEAN PATENT APPLICATION**

(72) Inventors:
  • **Soto Costas, Ramon Francisco**
    Universidad de Vigo
    Lagoas Marcosende 9
    36280 Pontevedra (ES)
  • **Jesus Perez-Martinez Y Perez-Amor, Mariano**
    Lagoas Marcosende 9, 36280 Pontevedra (ES)
  • **Quintero Martinez, Felix**
    Universidad de Vigo
    Lagoas Marcosende 9
    36280 Pontevedra (ES)

  • **Pou Saracho, Juan Maria**
    Universidad de Vigo
    Lagoas Marosende 9
    36280 Pontevedra (ES)
  • **Lusquinos Rodriguez, Fernando**
    Universidad de Vigo
    Lagoas Marcosende 9
    36280 Pontevedra (ES)
  • **Boutinguiza Larosi, Mohamed**
    Universidad de Vigo
    Lagoas Marcosende 9
    36280 Ponteverda (ES)

(74) Representative: **PROPI, S.L.**
    Jorge Juan, 19
    28001 Madrid (ES)

(54) **Method for cutting ceramic pieces or elements**

(57)   By means of the method object of the invention, it is possible to cut ceramic elements such as tiles, floor tiles, stoneware pieces, porcelain stoneware, traditional ceramics, refractory ceramics, advanced ceramics, etc... with the desired shapes, without breakages occurring therein, and allowing for the cutting of ceramic elements of a different composition or shape without needing to change the equipment or the tool.

      The method is based on the irradiation of a laser beam (1) on the piece (2) while at the same time applying a supersonic gas stream (4). This method implies a considerable improvement in comparison with the standard methods given that the noise is eliminated, the vibrations are decreased, the dust emissions and the use of cooling liquids are reduced.
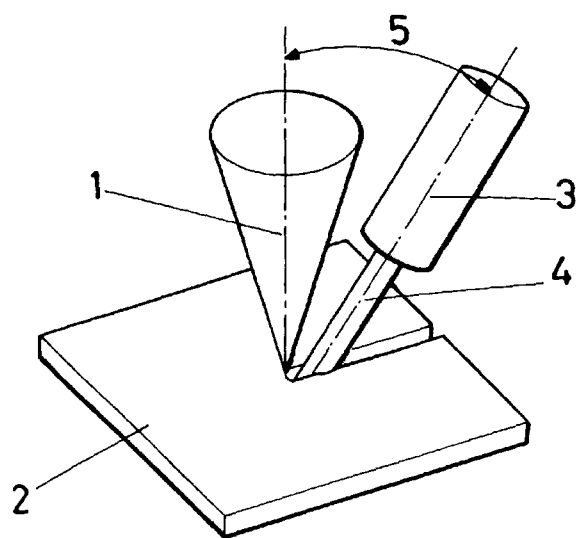
FIG.1

EP 1 618 985 A1

Description

OBJECT OF THE INVENTION

[0001] The present invention refers to a method for cutting ceramic pieces or elements by means of the application of laser radiation.

[0002] By means of the method object of the invention, it is possible to cut ceramic elements such as tiles, floor tiles, stoneware pieces, porcelain stoneware, traditional ceramics, refractory ceramics, advanced ceramics, etc... with the desired shapes without the production of breaks therein and allowing for the cutting of ceramic elements of a different composition or shape without needing to change the equipment or tool.

BACKGROUND OF THE INVENTION

[0003] For thousands of years, clay has been used as the fundamental raw material for manufacturing bricks, tiles, pottery pieces, etc.... The different types of ceramics currently encompass a wide range of applications: they serve as abrasives and cutting tools, as thermal insulators, as electrical insulators, as biocompatible materials, construction elements, catalysts, radioactive waste immobilizers, etc.... This variety of applications converts ceramics into materials commonly used in multiple fields of our life and, in turn, into indispensable materials in modern industry.

[0004] In all their applications, ceramic materials are valued for their excellent properties, mainly their capacity to resist heat and etching.

[0005] For the past decades, a special type of ceramic materials has been developed called technical ceramics or advanced ceramics, the properties of which make them specially indicated for those applications in which working conditions are more demanding (see, for example, the work edited by E. J. Brook, "Ceramics Materials Research". Elsevier Science Publishers B.V., Amsterdam, (1988)). This type of ceramics has the following properties.

- A thermal stability difficult to surpass.
- Resistance to wear that is considerably greater than that of metals.
- Excellent insulating power against the circulation of electrical current.
- High chemical stability.
- High resistance to corrosion.
- High degree of hardness and stiffness.

[0006] On the contrary, the main drawback of ceramics is their brittleness. The particular atomic structure of ceramic materials, which provides them with high chemical and thermal stabilities, also grants them great brittleness. Ceramic materials work very well under compression, but when they are subjected to tensile stresses or shear stresses, they have problems with the occurrence of cracks and breakage (see the work edited by M. Swain, "Structure and properties of ceramics". Materials Science and Technology. VCH Weinheim, (1991)).

[0007] One field in which advanced ceramics have implied great progress by opening new possibilities is in that of high temperatures. In those industrial systems in which it is necessary to support certain stresses at very high temperatures, advanced ceramics without a doubt imply the best currently available solution. The ceramics most used for this type of applications are alumina, zirconia, cordierite, mullite, silicon carbide or silicon nitride, among others.

[0008] One of the various problems in the entire manufacturing process of ceramic pieces for applications at high temperatures is that of the machining thereof once fired. As previously discussed, a common property of these advanced ceramics is their high degree of hardness and their brittleness. The combination of these two properties makes the ceramic element machining process very difficult once they are subjected to the firing process.

[0009] Machining of ceramic pieces is traditionally carried out by mechanical means using diamond tools (diamond bits, saws, mills). This type of machining has the following drawbacks:

- The high cost of diamond tools.
- The ceramic part is subjected to stress during the machining process. This may cause the occurrence of cracks reducing the useful life of the part, or even causing the breakage thereof.
- Necessity to cool.
- Slowness of the process.
- Generation of high noise levels.
- Wear of the tools.
- Release of dust.

[0010] In reference to the processing of materials with laser, this is a field of application of the laser which began a few decades ago and which has been very focused on the processing of metal materials (see the following works by way of example: M. Bass, "Laser materials processing", North-Holland, Amsterdam (1983); O.D.D. Soares and M. Peréz-Amor, "Applied laser tooling", Martinus Nijhoff, Dordrecht (1987) ; W.M. Steen, "Laser material processing", Springer-Verlag, London (1991)).

DESCRIPTION OF THE INVENTION

[0011] The present invention has an application of the laser for cutting pieces or elements manufactured with ceramic materials.

[0012] One of the advantages of the present patent is the possibility of carrying out treatments on ceramic pieces which are impossible to carry out by mechanical methods. The cutting of elements of any shape or geometry is thus possible, being able to carry out blind or intermittent cuts.

[0013] Another one of the advantages of the invention object of the present patent is the fact that the processing is carried out without making contact with the piece, thereby in no case being subjected to mechanical stresses during the laser treatment process, something which is inherent to mechanical processes. Furthermore, as no contact whatsoever is made between the piece and the tool, the latter undergoes neither wear nor corrosion, it therefore being unnecessary to sharpen it or replace it.

[0014] On the other hand, unlike the standard methods, the laser beam can be easily moved, making this cutting method have very broad possibilities of mechanization and integration in flexible manufacturing systems.

[0015] From an environmental point of view, the invention object of the present patent has the following advantages:

• Elimination of noise.
• Decrease of vibrations.
• Reduction of dust released into the environment.
• Reduction of cooling liquids.

[0016] Furthermore, from an economic point of view, the following advantages can be pointed out:

• Productivity increase.
• Improvement of the quality of the finished product, which can be assured within very narrow margins.
• Better use of the materials given the reduction of the wastes pertaining to machining.

[0017] The method for cutting ceramic pieces or elements by means of laser object of the present invention consists of subjecting said element or piece to the combined action of laser radiation and a gas stream working under supersonic conditions. The cutting process will preferably be carried out once the ceramic piece or element is fired, although it can also be carried out with the raw piece or element, i.e. prior to firing.

[0018] The main function of the assisting gas in laser cutting is the transfer of its kinetic momentum to the melted material in order to expel it from the piece and form the cutting groove. The efficiency with which the gas carries out this function is greatly influenced by the aerodynamic conditions existing in the acting stream and in the flow inside the cutting groove.

[0019] Standard laser cutting heads mainly consist of a cylindrical assembly enveloping the collimated beam and a converging lens which focuses it. Immediately after the lens, the pressurized gas is introduced in a convergent conduit of an approximately conical profile. The outlet is generally of a circular section, and the laser beam and gas stream emerge through this opening, such that their propagation directions are coaxial and perpendicular to the piece to be cut. Standard laser cutting systems thus have a convergent nozzle to carry out the injection of the assisting gas on the cutting face, which has a series

of limitations which will be discussed below.

[0020] One of the main problems posed by ceramic elements in laser cutting is that the liquid which they form when they melt is very viscous, which complicates its expulsion from the melting face to produce the grooving of the cut. When the melted material flows with difficulties, it is necessary to increase the speed of the gas to obtain a more energetic stream and to thus increase its entrainment capacity. However, by using a convergent nozzle, if the intention is to increase the kinetic energy of the gas stream by increasing the supply pressure, what is obtained is a flow with an invariable outlet rate but with an increasing pressure, this means that the stream will emerge in an underexpanded way. A range of expansion waves is formed at its outlet from the convergent nozzle which comes from the edges of the outlet section causing the divergence of the gas stream. It can be observed that this divergence is more notable the larger the degree of underexpansion is. As a result of this process, the pressure of the stream decreases until becoming equal to the ambient pressure adjacent to the border formed between the stream and the stationary gas surrounding it occupying the nozzle delivery site. However, due to the inertia of the fluid, after undergoing that axial and radial expansion, it expands excessively until a depression is produced in one region around the axis of the stream while at the same time it reaches its maximum cross section. Then the expansion waves are reflected on the border, being transformed into oblique compression waves; the fluid is compressed when traversing them to off set the overexpansion, such that its axial speed decreases and its radial component changes direction, causing the convergence of the stream. This process causes a degradation of the energy available in the assisting gas stream. If the degree of underexpansion is high enough, a normal shock wave abruptly compressing the flow with an energy loss will be formed in the area in which the oblique compression waves intersect.

[0021] This class of flows in which regions of supersonic speed and subsonic regions are combined are usually called transonic. The distribution of the stagnation pressure in them is not uniform, it undergoes heavy variations and decreases the material expulsion capacity.

[0022] On the other hand, cutting tests have been carried out in which it is observed that when increasing the pressure of the nozzle to increase the cutting rate, an improvement occurs only until reaching a maximum, after which consecutive increases of the pressure cause a decrease in the cutting rate. This fact can be explained by the presence of the normal shock wave in the previously mentioned stream. The intensity of this normal shock wave has a crucial effect on the aerodynamic features of the gas stream in the cutting face. The normal shock wave causes an irreversible compression of the flow, causing a loss of the total pressure and gas stream speed in a proportion that depends on the intensity of the shock wave itself. The increase of the nozzle pressure causes a reinforcement of the normal shock wave, which implies

a degradation of the kinetic momentum of the gas stream in the cutting groove and, accordingly, decreases the capacity thereof to expel the melted material. On the other hand, said shock wave implies an abrupt increase of the pressure and of the density of the fluid and, therefore, of its refraction index, such that the shock wave behaves like a lens which defocuses the laser beam and decreases its efficiency for generating an optimal cut.

[0023] On the other hand, it has been shown that the distance between the gas injection nozzle and the piece to be cut is a parameter of the process which has an enormous effect on the intensity of the normal shock wave and, therefore, on the efficacy of the assisting gas to entrain the melted material. Therefore it is necessary to maintain strict control of this process parameter which barely allows for a range of variation of about 1 mm. This implies a limitation of the standard cutting heads, as it is not possible to vary this distance to modify other process parameters, such as the position of the focus of the laser beam with regard to the piece for example, without altering the compromise between both effects.

[0024] Another one of the aerodynamic problems of the assisting gas in laser cutting is the blockage the stream from a nozzle undergoes when the intention is to introduce it into the cutting groove to expel the melted material found inside. This phenomenon is aggravated in the underexpanded streams which, with the divergence product of its radial expansion, increase its cross section.

[0025] Furthermore, this type of streams show a clear instability inside the cut with the presence of turbulences which occur before the release of the boundary layer of assisting gas adhered to the walls of the cut. The release of the boundary layer inside the cutting groove reduces the entrainment capacity of the material melted from the wall containing the fluid. The result is a profile of an irregular striated section, with the presence of recesses and of resolidified material, i.e. with a limited cut quality.

[0026] Unlike the standard laser cutting methods, in the method for cutting ceramic pieces or elements by means of laser object of the present patent, the assisting gas is injected in the cutting area by means of a convergent-divergent nozzle (also known as a De Laval nozzle). It is thus possible to achieve supersonic streams with a high kinetic energy and without the presence of the shock wave patterns or the wavy nature of the profile, both pertaining to the underexpanded streams from the convergent tubes when they work at high pressures. It is thus possible to obtain a perfectly expanded supersonic stream, thus preventing the formation of expansion or compression waves, in the same manner in which the radial divergence of the stream at the outlet is prevented, emerging with a cylindrical profile of parallel generators. The result is an improvement in the quality of the cut, the release of the boundary layer being eliminated, the depositing of melted material on the wall of the cut being prevented.

[0027] In addition to increasing the quality of the cut

and the performance of the process, the increase of the melted material expulsion capacity by the gas stream and the absence of adherences on the cut edges have another very important effect on the cut piece. Since an increase of the material expelled from the melting face occurs, the thermally affected area decreases. This results in a decrease of the residual thermal stresses and in the disappearance of the risk of microcrack formation, which implies a great advantage in comparison to the results obtained with the standard laser cutting methods.

[0028] Another one of the advantages of the method for cutting ceramic pieces or elements object of the invention is the capacity to carry out an adjustment of the focal distance of the laser beam and of the distance between the piece and the nozzle. In other words: it is possible to focus the laser beam on the surface of the piece and move the assisting gas injector nozzle, maintaining the laser beam focused. This is impossible to do by means of standard laser cutting heads. A series of possibilities for the machining of pieces of different shapes and geometries is thus opened.

DESCRIPTION OF THE DRAWINGS

[0029] To complement the description being made and for the purpose of helping to better understand the features of the invention, according to a preferred practical embodiment example thereof, a single sheet of drawings is attached as an integral part of said description, in which, with an illustrative and non-limiting character, a ceramic piece undergoing the effects generated by the cutting system corresponding to the method of the invention, has been schematically shown in perspective view.

PREFERRED EMBODIMENT OF THE INVENTION

[0030] The cutting of ceramic pieces or elements by means of laser object of the invention is carried out in a suitable system, an example of which is shown in Figure 1. This method basically consists of the following: the ceramic piece or element (2) to be cut is situated on a support adjusted to its dimensions in a movable system. Said system can consist of a robot of any type, of a co-ordinate table of any type, or of a combination of both systems. This system will be connected to an automatic control system of the position of the piece, which, being of common use in industrial equipments, is not shown in the figure. The laser beam (1) is conducted by means of a suitable beam guiding system (which can be either a system of mirrors or optical fiber, according to the type of laser source used) towards the ceramic piece or element (2). To carry out the cutting of the ceramic pieces or elements, the joint action of the laser beam (1) and of a gas stream (4) working under supersonic conditions is needed. This gas stream (4) is provided to the area of interaction between the laser beam (1) and the ceramic piece or element (2) by means of a supersonic nozzle (3). The assisting gas stream is directed to the cutting

area forming an angle of inclination with regard to the axis (5) of the laser of between 25 and 50°. Said gas stream (4) is a short distance behind the laser beam (between 1 and 5 mm) in order to obtain a better removal of the melted material.

[0031]   To carry out two- and three-dimensional cuts, the supersonic nozzle (3) must be connected to the automatic control system of the position of the piece (not shown in the figure due to being of industrial use) in such a manner that the nozzle rotates synchronously with the movement of the movable system, while at the same time maintaining the angle of inclination fixed with regard to the axis (5) of the laser.

[0032]   The laser radiation can come from a laser equipment of any wavelength, such as a CO_2, CO, N_2, Nd:YAG, Er:YAG, Nd:glass, ruby, HeNe, HeCd, HeHg, Cu, I, Ar, Kr, diode, chemical, excimer, alexandrite, emerald or dye laser. In any case, the best results have been obtained using CO_2 or Nd:YAG lasers. The power necessary for this type of lasers can be between 50 and 3000 W, the best results having been obtained when working with a power between 300 and 1000 W.

[0033]   The laser beam (1) is focused by means of a lens (not shown in the figure). This lens will be carried out in such a manner and in a material such that it allows for the transmission of the energy of the laser beam (1). This lens will have a focal length between 100 and 300 mm.

[0034]   The assisting gas injected through the supersonic nozzle can be an inert gas (Ar, He, Ne, N_2), or an oxidizing gas (O_2, CO_2, compressed air) .

[0035]   A practical example of cutting of ceramic elements by means of laser is the following: alumina mullite plates of 4 mm thick are cut by means of an Nd:YAG laser (λ = 1.06 μm) working in a pulsed mode at a frequency of 120 Hz, with a pulse width of 1 ms, with argon gas at a pressure of 8×10^5 Pa and with a power of 500 W. High-quality cuts were obtained under these conditions at a rate of 5 mm/s.

[0036]   Having sufficiently described the nature of the present invention as well as a manner of carrying it to practice, all that remains to add is that it is possible to introduce changes in shape, materials and arrangement in the assembly thereof and parts forming it as long as these alterations do not substantially vary said invention.

Claims

1. A method for cutting ceramic pieces or elements, **characterized in that** the following operative phases are established therein:

    a) Positioning of the ceramic piece or element to be cut on a support adjusted to its dimensions, in a movable system connected to any type of control equipment of the position of the piece.
    b) Irradiation of the ceramic piece or element to

be cut by means of a laser beam and a simultaneous injection of a supersonic gas stream into the cutting area, forming an angle with regard to the axis of the laser beam.
    c) Relative movement between the ceramic piece or element and the laser beam.
    d) Removal of the melted material such that the wall of the cut is clean of adhesions, castoff melted material and with a minimum thermally affected area.

2. A method according to claim 1, wherein the assisting gas stream is directed to the cutting area forming an angle of inclination with regard to the axis of the laser of between 25 and 50°.

3. A method according to claims 1 and 2, wherein the incidence of the gas stream on the cutting area is a short distance behind the laser beam, preferably between 1 and 5 mm, in order to obtain a better removal of the melted material.

4. A method according to claims 1 to 3, wherein the power supplied by the laser beam is comprised between 50 and 3000 W, preferably between 300 and 1000 W.

5. A method according to claims 1 to 4, wherein the supersonic gas stream is constituted of any type of gas, with any chemical composition (Ar, He, Ne, N_2, CO_2, compressed air, etc...) .

6. A method according to claims 1 to 5, wherein the movable system connected to any type of control equipment of the position of the piece consists of a robot of any type, of a coordinate table of any type, or of a combination of both systems.

7. A method according to claims 1 to 6, wherein the laser beam comes from a laser of any wavelength, power, frequency or beam quality, such as a CO_2, CO, N_2, Nd:YAG, Er:YAG, Nd:glass, ruby, HeNe, HeCd, HeHg, Cu, I, Ar, Kr, diode, chemical, excimer, alexandrite, emerald, dye laser, or any other type of laser.

8. A method according to claims 1 to 7, wherein a ceramic piece or element of any shape, type, chemical composition and dimensions is cut following a trajectory of any shape.
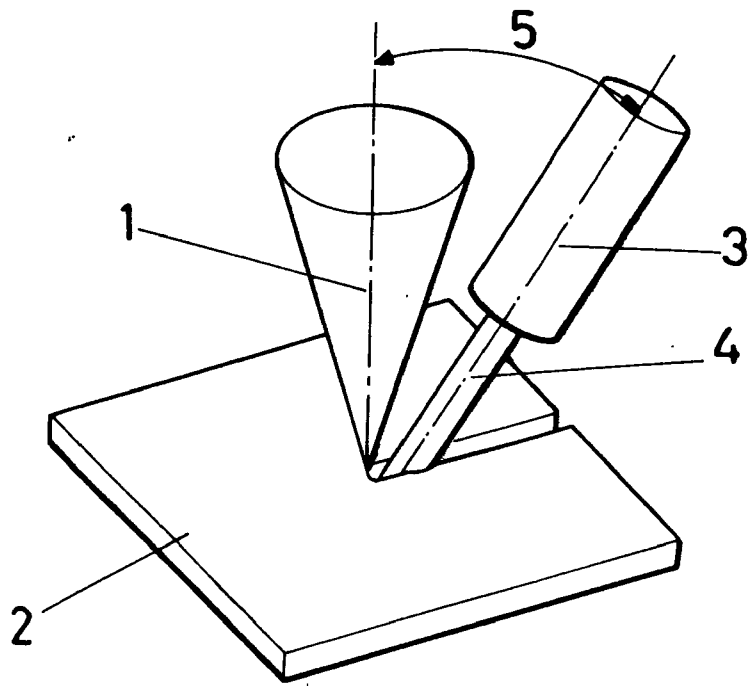
FIG.1

European Patent Office

EUROPEAN SEARCH REPORT

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
Y	FR 2 589 780 A (OUEST TOLERIE) 15 May 1987 (1987-05-15) * the whole document * -----	1-8	B23K26/14 B23K26/40 B28D1/22
Y	WO 93/16838 A (ALTEC SRL) 2 September 1993 (1993-09-02) * the whole document * -----	1-8	

TECHNICAL FIELDS SEARCHED (Int.Cl.7)

B23K
B28D

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	3 December 2004	Caubet, J-S

ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.

EP 04 38 0154

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

03-12-2004

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
FR 2589780	A	15-05-1987	FR	2589780 A1	15-05-1987
WO 9316838	A	02-09-1993	IT	1256680 B	12-12-1995
			IT	1256681 B	12-12-1995
			IT	1256682 B	12-12-1995
			WO	9316838 A2	02-09-1993
			EP	0627971 A1	14-12-1994
			JP	7503904 T	27-04-1995
			JP	6277865 A	04-10-1994
			JP	7075892 A	20-03-1995

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82