Influence of Power Density and Exposure Time on Laser Drilling Hole

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ABSTRACT

laser drilling play an important role in special applications with high accuracy dimensions, this paper was focused on two types of ceramics; aluminum oxide (Al_2O_3) and zinc oxide (ZnO) of 4 mm thick have been drilled by using continuous wave (CW) CO_2 laser. the exposure times applied were (20, 40, 50) sec and the other laser parameters were kept constant and to avoid large distortion, A comparison between the two kinds of ceramic are carried out to determine the effect of laser parameters on them. It founds that ZnO holes are cleaner than Al_2O_3 holes. Experiments proved that Exposure time at 50 sec resulting in similar penetration depth of 1.5 mm for both materials. Also for exposure time 41 sec gives the same taper angle.

Keyword: Laser drilling, Exposure Time, Power Density, entrance diameter, depth, Alumina (Al_2O_3), Zinc Oxide (ZnO), Taper angle.

تاثير كثافة الطاقة وفترة التعرض على التثقيب بالليزر

الخلاصة

التثقيب بالليزر يلعب دورا مهم في التطبيقات التي تتطلب دقة ابعاد عالية, في هذه الدراسة سنركز على نوعين من السيراميك ;اوكسيد الالمنيوم (Al_2O_3) و اوكسيد الزنك (ZnO) بسمك 4 ملم حيث تم ثقبهما باستخدام ليزر مستمر الموجة. وكانت فترات التعرض المستخدمة (20, 40, 50) ثانية وتم ابقاء المتغيرات الاخرى ثابتة وذلك لتجنب حدوث تشوه كبير. وقد تم اجراء مقارنة بين النوعين لايجاد تاثير متغيرات الليزر عليهم. وتبين من خلال التجارب ان ثقوب اوكسيد الزنك انظف من ثقوب اوكسيد الالمنيوم وتم اثبات انه عند فترة تعرض لمدة 50 ثانية ينتج نفس عمق الاختراق لكلا المادتين وكذلك ان فترة التعرض لمدة 41 ثانية يعطي نفس زاوية التدرج.

INTRODUCTION:

Laser is widely used in applications as varied as entertainment, surgery, motion sensing, and uranium enrichment. The most important application of the laser in industry is as heat source. This is not a new idea for using light as a heat source; it has been used by Archimedes in which a laser parabolic mirror was used for focusing the sun rays to a small spot [1, 2].

The discovery of the laser with its highly directional property makes it possible to achieve easily the above idea. So the energy in a beam a few mm in diameter can be concentrated into an area of a few square microns and so increase the energy

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density more than six times which make the laser to separate widely in laser material processing fields [2].

Laser material processing include huge family of processes for material removing, or machining, heat treating, local surface modifications, etc. Now days, laser has been used widely in manufacturing of small components for electronics, aerospace, biomedical, and other applications, the reason behind that is its ability to provide rapid, precise, clean, flexible, and efficient process [3].

The first industrial use of lasers was the drilling of holes in diamond wire drawing dies in the 1960's, some lasers types that are widely used in Laser drilling has continued to be of important industrial process and is currently used to form small holes in a wide variety of materials. An important point of view should be considered when drill with laser is the selection the suitable type of laser, which produces the power density required to form high quality holes. [4]

Laser drilling process is associated by basic parameters classified as beam characteristics (pulse energy, pulse duration, number of pulses, beam quality), drilling characteristics (hole diameter, depth, drilling angle) and process defects [5].

Laser drilling not only used for drilling through holes but also for drilling blind holes which have wide uses in industrial applications such as drilling blind holes in ceramic substrates for surface mount technology devices, drilling holes in printed circuit boards (PCBs) to allow electrical interconnections between circuit layers and Scribing (series of closely spaced blind holes) [6]. Although laser drilling is very desirable in industrial processes but it has limitations such as high cost, tapers', drilling of blind hole to precise depth, thickness of material drilled is restricted to 50mm and Adherent materials at the exit of the hole [7].

Experimental work:

This section deals with machines and equipments which are used to perform experiments. In this study two types of ceramic Alumina (purity 99.97) and Zinc Oxide (purity 99.95). They prepared by mixing the ceramic powder with polymeric binder (PVA) solved in distilled water at a ratio of 2-5 wt% then the mixture dried using oven at 100°C for 24 hour, after drying the agglomerate powder was grinded by ball-mall. The resulting powder was pressed by steel mold and hydraulic press at 240 Kg/cm^2 for 3 minutes to a disc shape with 4mm thick and then heat treated by electrical furnace. The obtained ceramic discs were drilled using continues wave laser system manufactured by SIGNKEY company model SK-1290L. Drilled samples were cross-sectioned using diamond saw and then examined by optical microscope.

Results and Discussion:

The effect of changing the laser parameters applied to the laser beam were examined on the hole dimensions (depth, entrance diameter), hole shape and taper angle of the hole side walls for both ceramic materials Al_2O_3 and ZnO.

1-Exposure Time

In this experiment the exposure times applied are (20, 40, 50) sec and the other laser parameters were kept constant to avoid large distortion each exposure time was divided to periods each period is two seconds duration and between periods one second rest for example for the first exposure time which is 20 sec it means that laser was (on) for 2 sec then (off) for 1 sec then (on) for 2 sec and so on until the (on) time reaches 20 sec and it’s the same for the other exposure times.

Figures (1), (2) and (3) show that hole depth, entrance diameter and taper angle increased with increasing of exposure time for both ceramic types. On the other hand the shape of the holes start to be distorted with increasing of exposure time from U-shape in Al_2O_3, V-shape in ZnO to irregular shape, that's also applied to the circularity of crater entrance as illustrated in Figure (4).

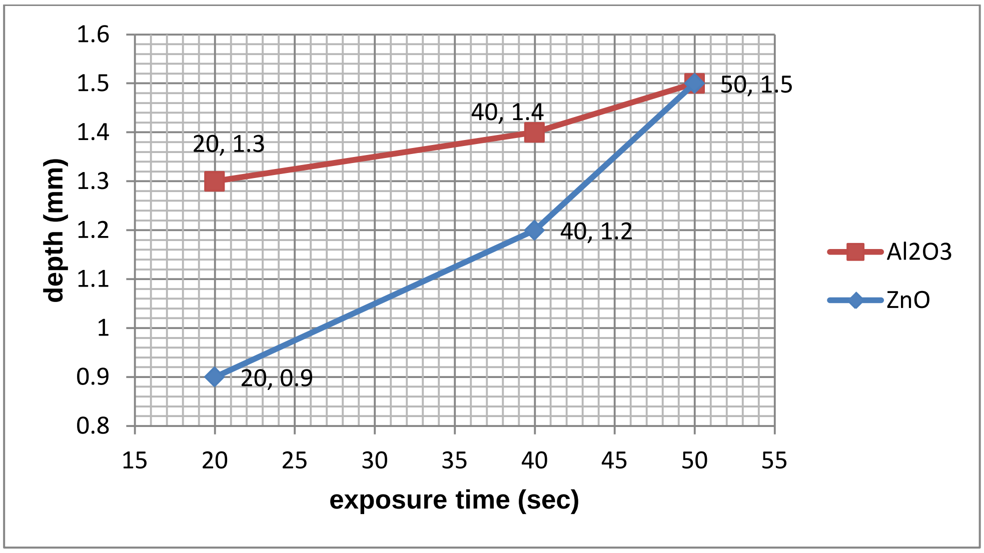

Figure (1) Variation in depth as a function of exposure time at 2mm focal position and power of 100 W or 109.5 W/mm² power density.

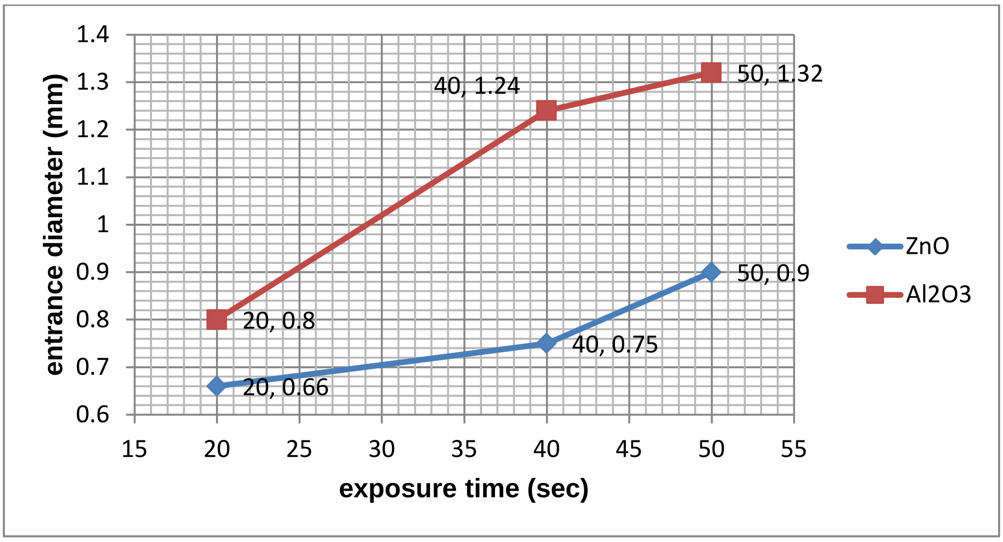

Figure (2) Variation in entrance diameter as a function of exposure time at 2mm focal position and power of 100 W or 109.5 W/mm² power density.

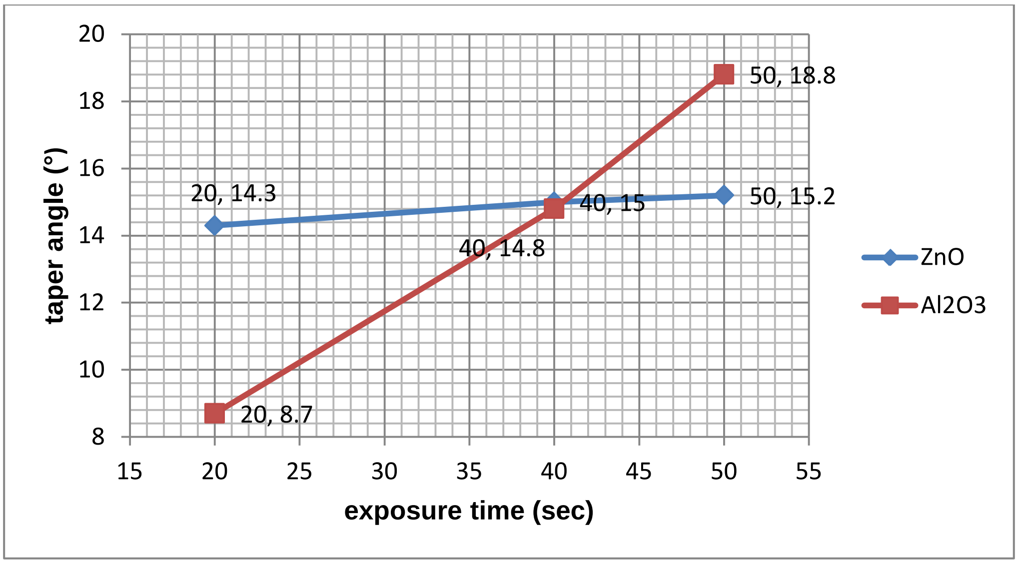

Figure (3) Variation in taper angle as a function of exposure time at 2mm focal position and power of 100 W or 109.5 W/mm^2 power density.

In this case the power density has a constant value. The increased in penetration depth return to fact that the same power density which incident to the surface of target material remove more material with increasing of time causing the increase of depth. A molten material is formed where the power density is high enough to melt the material at the entrance and surrounding walls, but insufficient to cause drilling. Complete or partial expelling via vaporization which produced by recoil pressure of this molten material can cause widened the hole entrance and increase tapering at the beginning of drilling process or there is another mechanism is when the removed material from the hole cavity flowing out of the hole flow over, and erodes by drag effect the molten material surrounded the hole entrance. A similar result has been noticed when comparing our results with reference [8].

The shape of the cavity and the hole entrance distorted with increasing of exposure time and at 50 sec it become irregular because of condensed huge amount of resoildified material at the side wall and entrance. As it seen in Figure (4) at 20 sec barreling defect is appeared in Al_2O_3 there are two reasons the first is the resoildified layer thinner at the bottom of the cavity than side walls far from the interaction zone, the second is insufficient recoil pressure to expelled molten material because the mechanism of material removal in Al_2O_3 is mostly melt ejection which cause material spatter on cavity side walls. For both ZnO and alumina holes it is obvious the formation of recast layer inside the hole and spatter at the entrance of the hole. The recast layer in ZnO is thinner and less in amount than Al_2O_3 which make us conclude that the dominant material removal mechanism in ZnO is vaporization this different between both materials is depend on their thermal properties.

As we can see in Figure (1) at 50 sec both material with similar drilling parameters is giving the same depth, the alumina ceramic has higher melting temperature than ZnO so the amount of material removed in the ZnO is larger than Al_2O_3, the gathering of resoildified material at the crater after the recoil pressure decay at the end of the process causing decreasing the effect of power density at the beginning of the new period while for ZnO the dominant material removal mechanism is vaporization, the same case at Figure (3) where at 40 sec the both materials give almost equal taper angle, laser drilling holes in alumina ceramic with (109.5W/mm^2) gives holes having lower aspect ratio (depth to diameter) than ZnO due to high melting temperature and thermal conductivity of alumina which cause heat diffusion to the surrounding area and generation of melt layer.

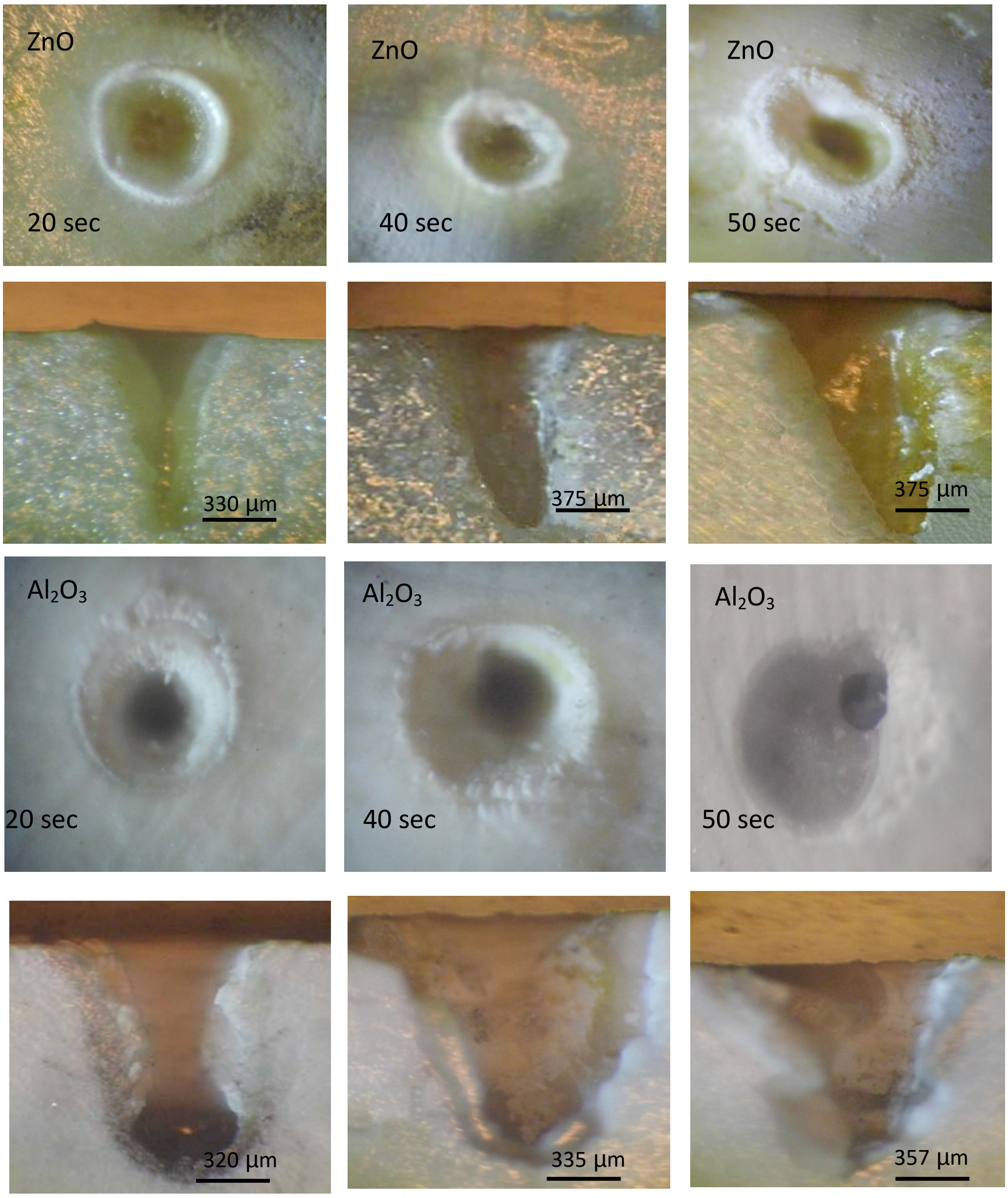

Figure (4) Hole entrance and crater shape.

2- Power Density

Power density has great affect on heat generated during drilling process; it can be determined by dividing incident power on the size of focus beam. The beam size, in case of Gaussian distributed laser beam, is known as the redial distance which the intensity of the laser is reduced to $1/e^2$ or 13.5% of the max intensity about 87.5% of beam energy [5].

In this section will demonstrate the effect of power applied on the power density required for drilling process also effect of the last on depth, entrance diameter and taper angle. The powers used in this experiment are (50, 70, 90) watt and the power density generated is (54.7, 76.6, 98.5) W/mm^2 for these powers respectively. As shown in Figures (5), (6) and (7) that the depth, entrance diameter and taper angle increased with increasing of power, on the other hand the shape of the cavity malformed at 54.7 W/mm^2 and for alumina only a cavity is formed and start to regulating with increase of power density and its noticeable the gathering of resoildified material at the side wall of the cavity and hole entrance see Figure (8).

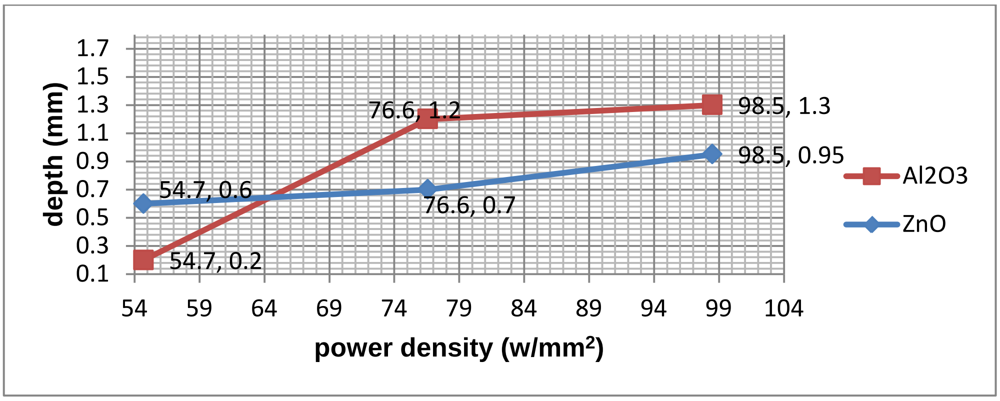

Figure (5) Variation in depth as a function of power density at 2mm focal position and 30 sec exposure time.

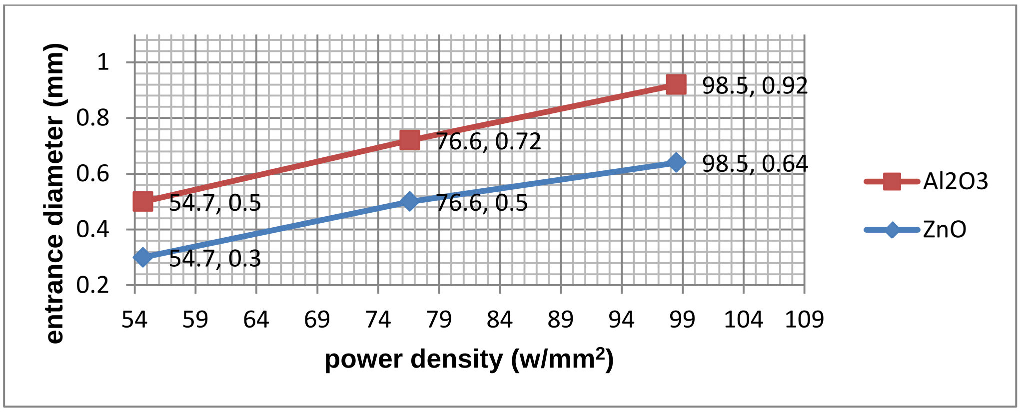

Figure (6) variation in entrance diameter as a function of power density at 2mm focal position and 30 sec exposure time.

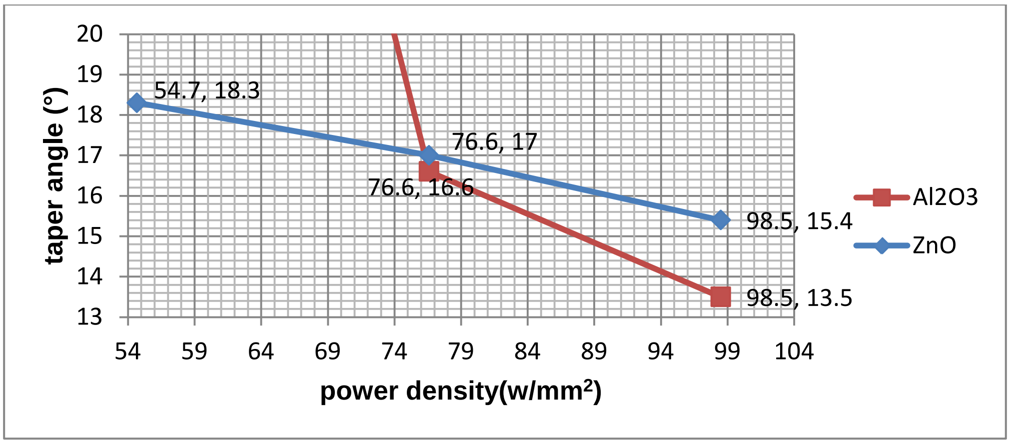

Figure (7) Variation in taper angle as a function of power density at 2mm focal position and 30 sec exposure time.

As mentioned earlier the power density has great effect on hole parameters. In this case the beam diameter is constant but the power of incident beam is changed. The increasing of power density increased the penetration depth but, decreased the taper angle because the energy absorbed by surface material is much more and the heat elevated faster at the surface and the temperature reach melting point as the material start to evaporate a recoil pressure generated and start with it material removal mechanism either by melt ejection or vaporization.

Figure (5) shows that at (64.5 W/mm^2) power density both materials have the same depth. Alumina ceramic has high melting point but in change have also high thermal conductivity. Also the dominant material removal mechanism for alumina ceramic is melt ejection due to high melting point while for ZnO vaporization is the dominant material removal mechanism, vaporization required much higher energy than melt ejection. The increasing of entrance diameter return to the low intensity (wings of Gaussian distribution) which affect the material surrounding the hole causing formation of melt layer that can be dragged during the flow of the material expelled from the hole bottom during drilling process. At 54.7 W/mm^2 power density the hole shape is irregular. For alumina, the power density was insufficient to reach vaporization point.

Figure (7) shows that the taper angle at 54.7 W/mm^2 is very high because of the power density was not enough therefore there was no drilling process only the formation of small cavity.

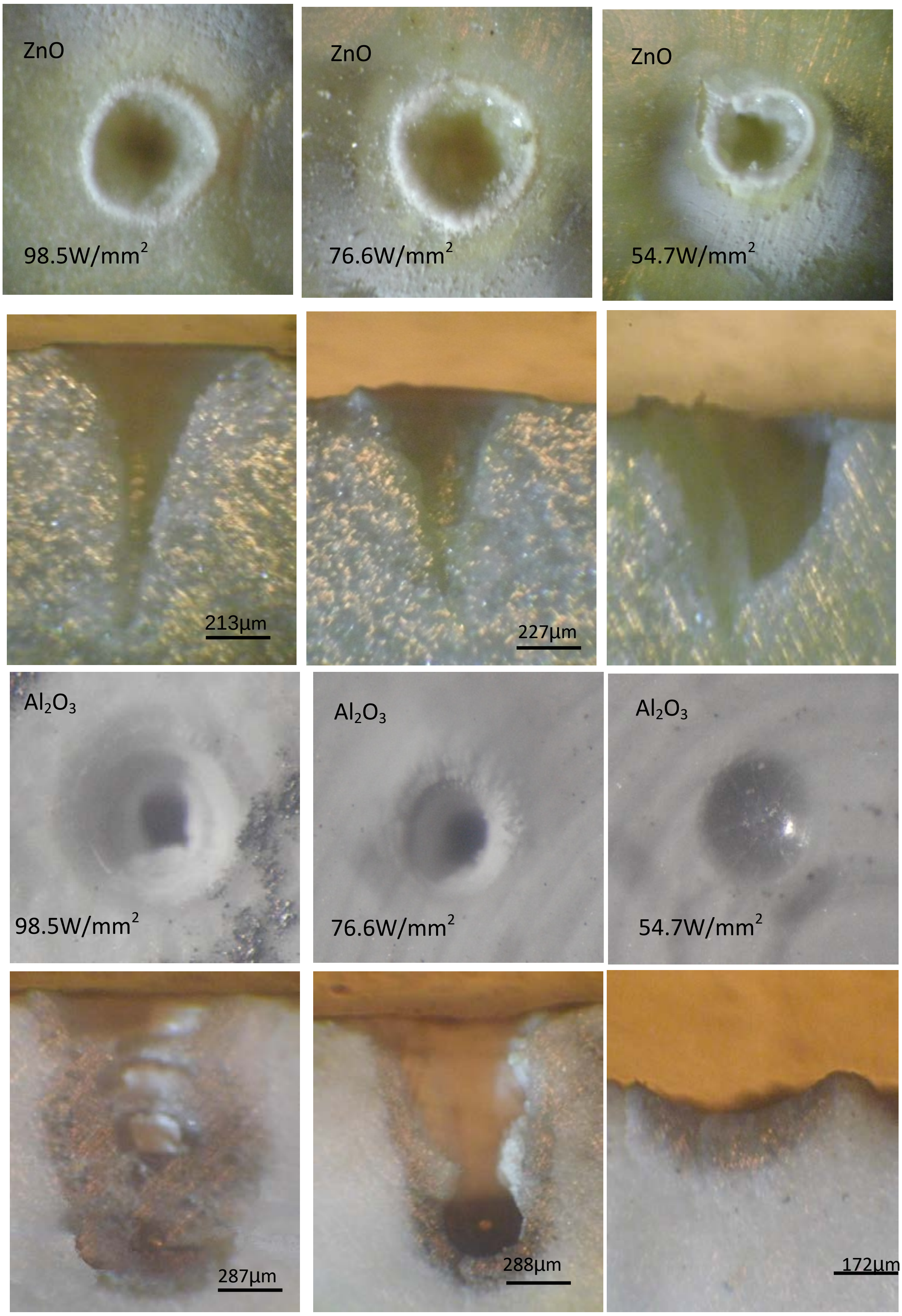

Figure (8) hole entrance and crater shape.

CONCLUSIONS

Continuous wave CO_2 laser with 10.6 µm wavelength was employed to drill two types of ceramic Al_2O_3 and ZnO to determine the effect of changing laser parameters such as exposure time, focal position and power density on hole dimensions (depth, entrance diameter), taper angle and hole shape. In general, the results show:-

1. Increasing exposure time increases depth, entrance diameter and taper angle. Also malformed hole circularity and crater shape due to formation of resoildified materials.
2. Increasing the power density increases penetration depth and entrance diameter but, decreases taper angle.
3. Exposure time at 50 sec resulting in similar penetration depth of 1.5 mm for both materials. Also for exposure time 41 sec gives the same taper angle.
4. At 64.5 W/mm^2 power density, both materials produced equal penetration depth of 0.64 mm and at 54.7 W/mm^2 the taper angle resulting from drilling Al_2O_3 is very large.
5. The geometry of hole shape has direct relationship with laser beam distribution (laser beam profile).
6. Material properties have great effect on the holes produced from laser drilling process and their response to laser parameters.
7. Difficulty to produce precision blind holes. Lasers are more suitable for producing through holes.
8. Hole depth produced by laser drilling are small, few millimeters deep. As depth of the hole increases, the entrance diameter enlarged due to beam expansion, producing tapered hole.

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