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Research paper

Effect of laser processing parameters on the efficiency of material: a review in industrial application field

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Abstract

There is considerable interest in reducing the cost of alloy components that are highly resistant to corrosion. Therefore, low-cost laser energy was used compared to other treatments, where this energy was used to enhance surface resistance of the alloy. In this paper, the advantages of surface treatment using laser energy have demonstrated, in addition, analysis of the effect of the treatment parameters on the material properties. Surface treatment methods for laser materials were classified in thermal processes and thermal chemical processes. The chemical thermal process shows a change in the surface composition of the treated material. The initial state of hydration for cement paste can be identified by analyzing the changes resulting from the intensity of the laser processor. Alumina samples in Ceram proved more soluble areas and became more homogenous and smooth with fewer openings and cracks, especially with energy higher than 10 W CO2 and higher power density than Excimer 6.2 J / cm laser devices. The optimum power of the laser used to remove the material is 40-200 W / cm2.

Keywords: *Corrosion Resistance; Laser Surface Processing; Glazing; Hydration; Laser-Chemical Treatment.*

1. Introduction

The treated area of the different materials using laser energy can be divided into three main areas namely heating, melting and evaporation. These areas depend mainly on the value of the laser energy used and the time period of treatment. The intensity of the laser energy and the reaction time / pulse are clearly selected in each process, so the material in question is subject to the required degree of heating and phase transition. the low power density is required for surface heating in which the the transformation hardening, bending and magnetic domain control is produced . On the other hand, some industrial processes such as glazing, welding, and cladding require high laser energy. Similarly, the material removed in the form of vapor requires superior laser energy during a short period of reaction, as in the drilling and cutting operations. For convenience, energy density (J / mm^2) is useful for measuring different processes with the aid of laser. However, practice is not recommended because the specific combination of power and time can only reach the desired thermal and material effect. [1-3].

The alloys that have high resistance to corrosion and good hardness are highly needed in industrial applications. Therefore, the interest of researchers in reducing the cost of alloys processing to acquire these characteristics using laser technology. Surface treatments of materials using laser can be classified into processes that do not need fillers but only melting the surface of the material "called glazing processing". Another treatment that needs filling "called cladding process", and finally, a treatment that directly related to the rendering process. Laser surface engineering is an excellent technique for improving surface properties of materials. [2-4]

Surface engineering with lasers covers various applications mainly related to the refinement of one of the surface-dependent characteristics, such as hardness, wear resistance friction, corrosion, and fatigue, etc. The accelerated development of the high-energy laser has been introduced into industrial applications that are used for surface processing of materials. Surface treatment methods using laser materials were classified into two types:

a) Thermal process: Without changes in surface structure,, such as tempering, laser cutting, annealing, welding, enameling, melting, and hardening by transformation.
b) Thermochemical process: this process differs in the metallurgical structure of the surface, such as laser alloys, coating.

Surface processing includes the capability to handle small spaces without affecting other parts. [3-5].

2. Efficiency of material laser processing

Several research teams studied the different effect of laser treatment parameters on the efficiency of material removal by surface fragmentation and glazing. Several research teams studied the different effects of laser treatment parameters on the efficiency of material removal by surface and glass fragmentation. Several samples were tested for 3-inch high-density concrete cubes and 3-inch low-density concrete cubes of different cement: sand and thermal bricks. These samples were processed with a CW / Pulsed 3.5 kW and 10 KW CW CO_2 laser systems. Laboratory results showed that laser treatment gave a large area of fragmentation and the rate of removal of the material is paramount. Fragmentation is the predominant factor in concrete rich in cement. In addition, the results show that the pulse laser works to enhance the cutting process. The spalling of the surface of the material is reflected at the laser power density of 40-200 W / cm^2. At 1.5 kJ/cm^2 laser power density the concrete glaze depth is increased. the material removal rate is directly proportional to the large area beam. The highest removal rate is recorded within the scanning speed range 300-600 mm / min for the laser beam. One of the results of the concrete glazing process is the formation of porosity in the material's surface, where it has been shown that porosity is inversely proportional to the increased speed of the laser beam figures (1 - 3). In addition to the statement that the color of the surface of the concrete after the process of laser treatment depends on the proportion of cement / sand used. [6]

Preliminary results of molecular structural changes in cement and concrete caused by laser radiation at 10.6μm are reported by M. R. Moreno Virgen, et al. researcher's team (2006). Glazes surfaces of material are one of those structural changes generations.

There is a direct relation between supplied laser power and size and shape of glazes layer, in which at low laser powers, the glazes are small and lined up while at high powers, the glazes are bigger and randomly distributed. In the not exposed to laser radiation concrete, the Raman spectrum is shown in figure 4, presented weak peaks at 200cm^{-1}, 550 cm^{-1}, 700 cm^{-1}, 750 cm^{-1} and 1150 cm^{-1}. The peaks intensity are dependent on laser radiation power. [7]

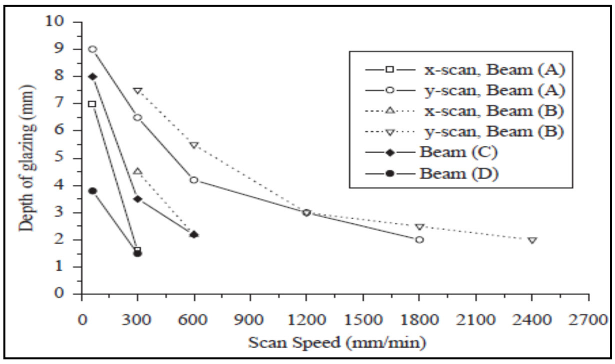


Fig. 1: Glaze Depth Variation for Different Beam Scans with Scan Speed [6].

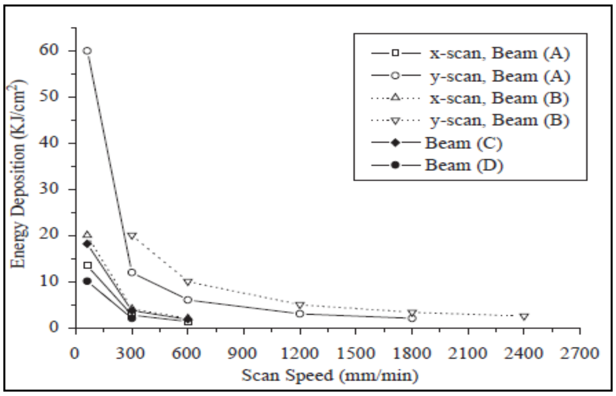


Fig. 2: Energy Deposition for Different Beam Scans with Scan Speed [6].

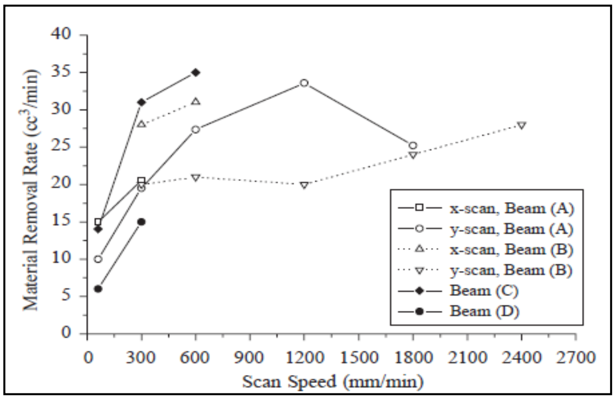


Fig. 3: Glazed Material Volume Rate Variations with Scan Speed [6].

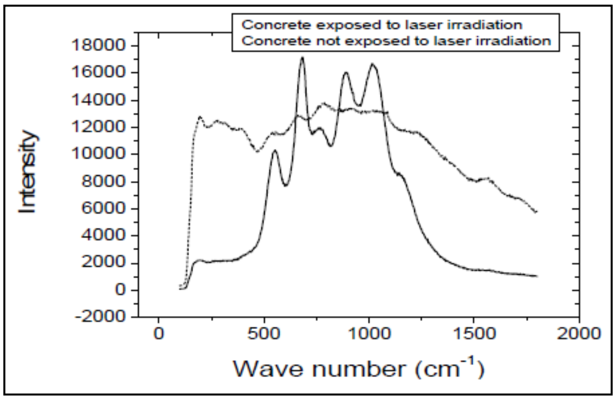


Fig. 4: Raman Spectra of Concrete Samples with and Without Exposition to CO_2 Laser Radiation [7].

The metallurgical industry uses a refractory based on Al_2O_3 in the internal coatings of

Furnaces, reactors, kilns and other vessels to contain, slag, and transport metal. In non-metallurgical industries, refractories are mainly installed in hydrogen reformers, electric heaters, cracking furnaces, primary and secondary ammonia reformers, catalytic cracking units, incinerators, service boilers, sulfur furnaces, coke calcinatory, and air heaters. The amelioration of mechanical and chemical resistance characteristics of the refractory surface based on Al_2O_3 is studied by J. Lawrence, and L. Li researchers team (2003) using CO_2 and high power diode lasers (HPDL). [8]

The material used in the experiments was an Al_2O_3 based refractory containing various impurities, and two types of laser are used CO_2 laser (Rofin-Sinar, RS1000) emitting at 10.6 mm and HPDL (Diomed, D120) emitting at 810 ±20nm with an output power of 1 kW and 120 W respectively. It has been observed that the properties of material corrosion can be improved by the use of laser treatment for the surface of heat-resistant material based on Al_2O_3. Also, it has been concluded that laser surface treatment outcomes in an increase in refractory life based on Al_2O_3 under normal and corrosive environmental conditions (NaOH and HNO_3).

In figure 5 and according to standard measurements, clearly shown the refractory wear rate based on Al_2O_3 received was 7.13 mg/cm/h. A significant increase to 51.25 and 78.75 mg / cm2 / h by processed with sodium hydroxide and HNO is clearly shown in Figure 6, respectively. In contrast, laser-treated surfaces recorded only a slight increase in corrosion rate during testing in corrosive environments. Based on Al_2O_3, the thickness of the enamel layer resulting from HPDL leads to the prolongation of thermal life increasing from 1.27-13.44 times. [8].

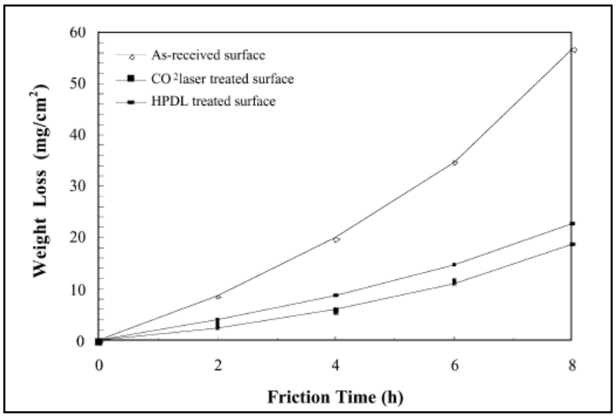


Fig. 5: Relationship between Weight Loss and Friction Time for the As-Received and Laser Treated Al_2O_3-Based Refractory [8].

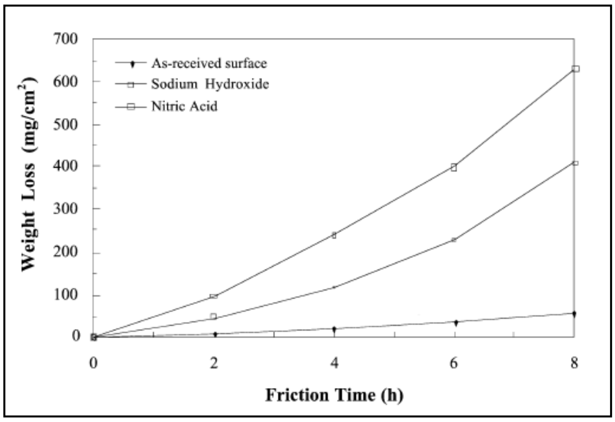


Fig. 6: Relationship between Weight Loss and Friction Time for the As-Received Al_2O_3-Based Refractory with Different Reagent Types at the Maximum Concentration (80%) [8].

Changes in surface size measured in cement paste samples after irradiation using CO_2 laser were examined by Moreno Virgin MR, et al (2010). In their laboratory experiment, they used a 40W CO_2 laser that was connected with an external lens with a focal length of 0.6 cm to a 0.1 cm laser point on the sample surface. The irradiated area of the paste surface with different laser energy 20, and 30 watts is

0.0078 cm^2. The researcher team finds out that the applied laser power changed Raman peaks intensity at $187.5cm^{-1}$, $563cm^{-1}$, $695cm^{-1}$, $750cm^{-1}$, $897cm^{-1}$, $1042cm^{-1}$and $1159cm^{-1}$ as shown in figures 7, 8, and 9. Also, the initial hydration can be determined by investigating the state changes in the cement paste which depend on the intensity of the laser. [9]

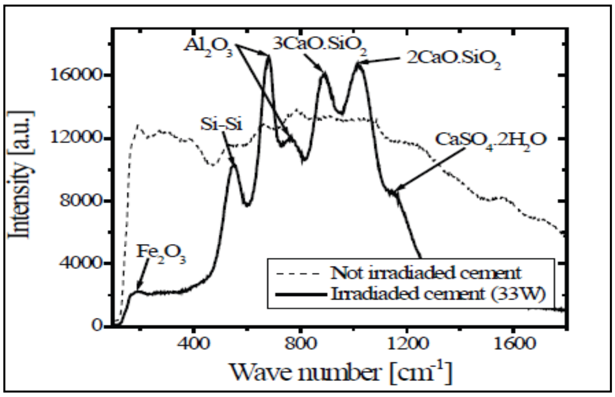


Fig. 7: Raman Spectra from an Untreated Cement Paste and A Sample Irradiated with A 33W 10µm CO_2 Laser. Identified Origin of Vibration Modes are Indicated [9].

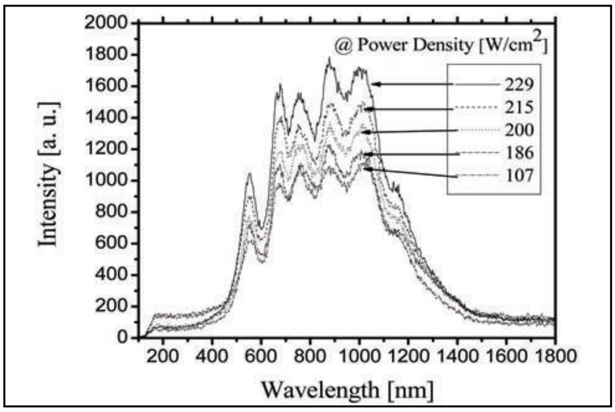
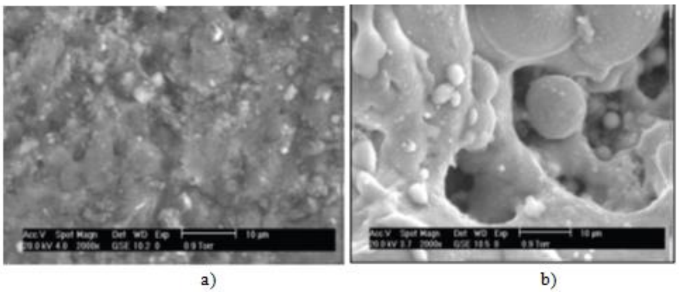


Fig. 8: Raman Spectra of Cement Paste Samples Irradiated at Several Laser Powers Two Days after Preparation. A). 107W/Cm^2, B). 186W/Cm^2, C) 200W/Cm^2, D) 215W/Cm^2, E) 229w/Cm^2 [9].



a) b)

Fig. 9: SEM Micrographs from the Surface of Cement Paste, A). Cement Paste without Laser Treatment, C). Cement Paste Treated with Laser Radiation with Power of 33W [9].

3. Effect of processing parameters on the laser glazing

The effect of processing parameters on the laser glazing of plasma-sprayed alumina–titania ceramic was the subject of attention of Sridhar, G. et al. researchers' team (2001). The coating is glazed with a pulsed ND-YAG laser (1064nm wavelength) with 200W laser power; a dichroic mirror is used to focus the beam to a spot diameter 4, 5, and 6 mm at the surface of the coating. The substrate, low carbon steel in the form of an 80mm 30mm 5mm plate is grit blasted with alumina grits with a blasting pressure of 0.25MPa with lay to increase the contact of the band coating to the substrate. The study of the parametric effecting on the response of plasma-sprayed ceramic coatings to glazing is produced the following achievements:

a) With high beam scanning velocity, laser glazing is fairly good with the minimum tendency to cracking, while, reducing beam scanning velocity, because of the possibility of higher absorption of heat flux, surface cracks occurred leading to exfoliation of surface material.
b) Polishing of grains during glaze appears in the form of a lattice-related lattice as illustrated by x-ray (XRD).
c) To prevent formation of a compound similar to a ceramic compound, the glazing process must be carefully controlled.

For improving the lifetime of die-casting dies, 1.5kW CO_2 laser glazing technique to glaze H13 steel, this work is executed by Wenping Jiang (2002). The researcher finds out for glazing process that 500W and a traverse speed of 127mm/sec are the optimum laser parameters. In addition, the glazing thick layer was 0.65mm and the rigidity was 30% higher than that of the heat-treated substrate. Nanocrystal line powder alloying caused a pronounced improvement in the surface finish of the alloyed layer and in resistance to corrosion and erosion. [10-11]

Another researcher named Syarifah Nur Aqida Syed Ahmad, in 2011, studied the modification of the laser surface of H13 tool steel using the pulse laser processing mode. The experimental projects of initial selection conducted lead to more optimized detailed projects. A carbon dioxide (CO_2) laser system with a wavelength of 10.6 μm was used. In the experimental projects examined, three different sizes of laser points used were 0.4, 0.2 and 0.09 mm in diameter. The other parameters controlled were the peak laser power, the pulse repetition frequency and the pulse superposition; The configuration of the laser surface modification process is shown in Figure 10. The laser processing was constantly assisted by argon gas in line at a pressure of 0.1 MPa.

The H13 samples were roughened and chemically etched before processing to improve the surface absorbance at the CO2 laser wavelength. The laser treated samples were prepared for metallographic study and characterized by their physical and mechanical properties. [12].

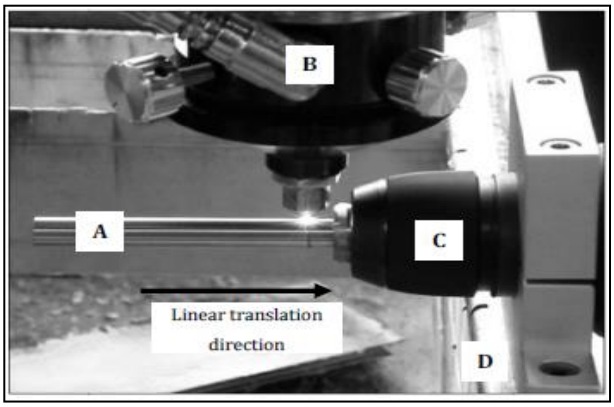


Fig. 10: Experimental Setup: A). 9.4 Mm Diameter H13 Sample, B). Laser Head, C). Rotating Chuck, and D). Linear Translation Platform. [12].

The impact of the CO_2 continuous wave laser-glazing process parameters on the morphology and microstructure of the ZrO_2 -8%Wt coatings is reported by C. Batista, et al. research team (2006). The samples used in this study consisted of a conventional TBC system comprising a disk of atmospheric plasma spraying, substrate discs (Ø3 × 0.3 cm) previously sanded with alumina particles to roar the surface, which guarantees a better adhesion of coatings and CO_2. and an industrial pulse laser Nd: YAG. The reduction of surface roughness, the elimination of open porosity and the creating of a fractured and open crack network for the material surface were successfully achieved through the laser glazing process indicated by the researchers through improved thermal barrier coating (TBCs). [13]

The application of lasers for material processing presented by J Dutta Majumdar and I Manna (2003), the researcher is reviewed the major material processing routines that are either routinely used in the industry or are slated for future exploitation. The processes discussed are broadly categorized into laser-assisted forming (bending, coloring, rapid prototyping, etc.), joining (welding, soldering, brazing, etc.), machining (cutting, drilling, cleaning, etc.) and surface engineering (hardening, annealing, alloying, etc.). The materials considered include metallic, polymeric, ceramic, semiconductor and various combinations thereof. Comprehensive lists of notable and current studies in the relevant areas are documented in separate tables for ready reference. The focus of this review centers on the basic principles, scope and mechanism/methodology of a given process. [14]

J. Kusinski, S. et al. (2012), they report on the status of laser treatment in the modification of surface materials in Poland, according to their own experience, the results of collaborators and co-authors. They concluded that the industrial application of surface laser engineering is growing rapidly in Poland. [15]

An analytical model for the laser fusion of non-homogeneous parts with parabolic geometry of the fusion assembly for the quality control of marking / laser incision of clay tiles using a high power diode laser (HPDL) developed by A.A. endangered, e. Zhou, d.

Morton and L. (2001) researchers team, the theoretical results were compared with the experimental data as shown in figure 11. The predicted depth of the fusion set and the experimental values were in close correlation with the parameter $(P_L/\sqrt{dv})$ for values less than $15Wmm^{-1}s^{-1/2}$, despite the simplifications introduced in the model. At relatively large values of the parameter $(P_L/\sqrt{dv})$, the assumption of the shape of the parabolic and unidimensional fusion set. The heat transfer is no longer valid. [16]

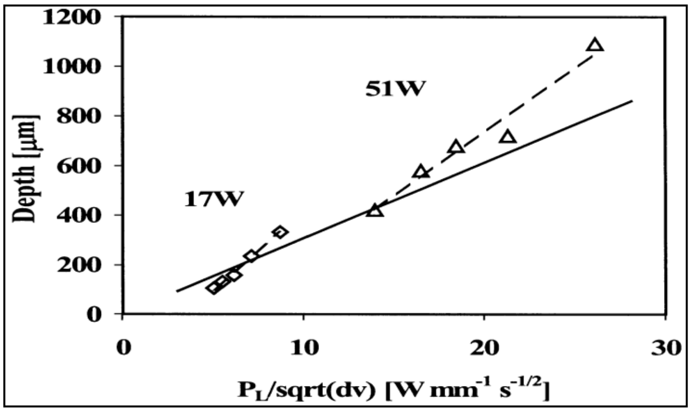


Fig. 11: Measured (Tick Marks) and Calculated (Solid Curve) Melt Pool Depth for Clay Tiles [16].

An analytical model to simulate the CO_2 laser beam in transverse electromagnetic mode (TEM01) using two parallel laser beams and investigate the geometry of the melting depth of the pool in the MgO-PSZ after irradiation with CO_2 laser. This model presented by L. Hao, J. Lawrence (2006) [16], in which the prediction of the effects of CO_2 laser irradiation on zirconia partially stabilized with magnesia is modeled. The predicted depth of the fusion set and the experimental values were in a relatively good disposition in a certain range of laser energy density. The deviation between the calculated results and the measured results, shown in Figure 12, is attributed to the difference between the real effects of the TEM01 beam mode and two simulated parallel beams, neglecting the lateral conduction energy and the significant difference between the diameter of the fusion pool and the diameter of the laser beam.

The erosion resistance of thermal coatings by spray with thermal zirconium oxide and plasma has been improved by laser glazing. This work was carried out by Pi-Chuen Tsai, et al. (2007) research group. The researcher used stainless steel coupon substrates that were first sprayed with a Ni-22Cr-10Al-1Y bond coat and then weighing 19.5. Top layer stabilized zirconium oxide (YSZ) with an air plasma spray system. Thermal zirconium plasma and aerosol coatings (TBC) are enameled using a pulse laser CO_2. The results of this study show that the laser glazing process has increased the microhardness from approximately 550 Hv for the sprayed layer to approximately 1550 Hv for the glazed layer. The erosion rate increased as the angle of impact increased for both the plasma-sprayed TB and the enameled TBC laser. Laser glazing has improved the erosion resistance of TB sprayed with plasma approximately 1.5-3 times with an impact angle between 30° and 75°, while erosion resistance did not improve significantly when the angle of impact reached 90 ° as shown in figure 13. [17]

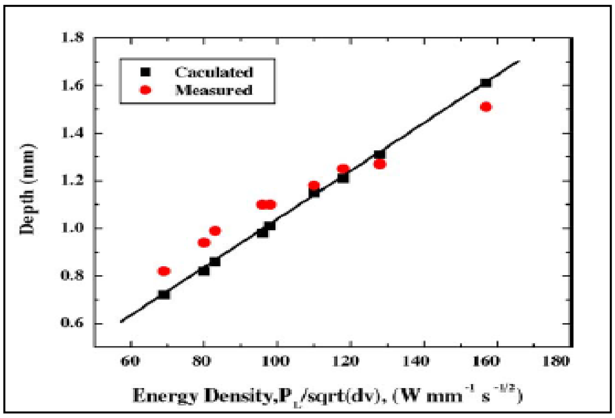


Fig. 12: Measured and Calculated Melt Pool Depth for MGO–PSZ Following CO_2 Laser Treatment [16].

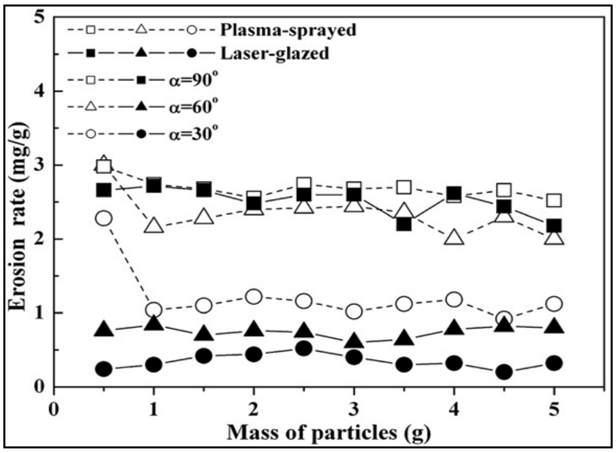


Fig. 13: Incremental Erosion Rate of Some Selected TBC Top Coat Tested at Different Impingement Angles (A) [17].

The erosion morphology analysis clearly indicates that the erosion of the TB sprayed with plasma was considered the erosion of the protuberances and the sprinkled symbols. It has been shown that the erosion of TB coated with laser is the spallation of the enameled layer. Spallation occurred at the interface of the plasma spray / laser enamel layer. The explanation of the effect of the Nd: YAG laser, equipped with an optical fiber beam transmission system, the treatment of the surface on corrosion and the wear resistance of the ACM720 Mg alloy is reported by A.K. Mondal, et al. Team of researchers (2008). It was found that this treatment was beneficial for the corrosion and wear resistance of the alloy. Long-term linear polarization resistance and electrochemical impedance spectroscopy confirmed that the polarization resistance values of the alloy treated on the laser surface were twice those of the untreated alloy. The greater resistance to corrosion has been attributed to the absence of the second phase of Al2Ca at the grain boundary, to the microstructural refinement and to the extended solid solubility, in particular of Al, in the α-Mg matrix due to the rapid solidification. The laser treatment also increased the hardness of the surface twice and significantly reduced the rate of wear due to the refinement of the grain and the strengthening of the solid solution. [18-20]

Pedro Balaguer, et al. (2009), suggests the use of dimensional analysis to model the glazing process of ceramic tiles to design the automatic control system. Simulation examples have shown that it is possible to control the deposited enamel mass simply by measuring the enamel temperature. However, the measurement of enamel flow is a critical variable if a high precision is achieved in the mass deposited. [21]

R. Mohammed Abdallah, et al. (2010), the research group studied the hardness of the surface of dental ceramics (dental porcelain and In-Ceram alumina materials) after its enameling with XeCl excimers and CO_2 lasers. They discovered that the glazing of ceramic surfaces improves the physical properties of dental ceramics compared to conventional methods for the treatment of surfaces of dental ceramic materials that can not create a smooth surface without microcracks. Figures 14 show the surfaces of the In-Ceram alumina samples, both with CO_2 and excimer, have a much larger number of melted melt zones and have become more homogeneous and uniform with a reduced number of craters and fissures, in particular with a power of more than 10 watts of CO_2 lasers and a higher energy density of 6.2 J / cm^2 than excimer lasers. The ceramic surfaces acquire solidity and smoothness with good glazing, keeping the internal structure unaltered. [22]

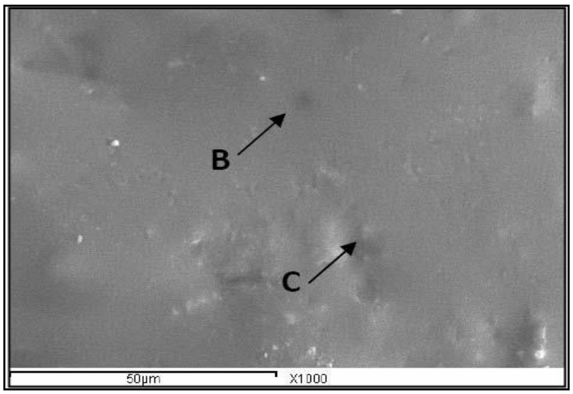


Fig.14: Scanning Electron Micrograph of Porcelain Specimen Subjected to 6.2 Joule/Cm^2 Excimer Laser Glazing. B, C: Refer to Shallow Splodgy Areas of Melting [22].

J. D. Majumdar and I. Manna (2011), presented a review on the processing of laser material that involves intense heating of the objectives / solid components by laser to allow different types of Ultra-fast, innovative and economical material processing that stands out from its conventional counterparts in terms of quality, productivity and efficiency. This review deals exclusively with surface engineering based on the philosophy that the performance and durability of a component can be improved or expanded by adapting the microstructure of the surface and/or

Composition without altering the bulk. The laser is particularly suited to achieve this goal of surface engineering due to the exponential energy deposition profile of the laser in any solid and the associated advantages of the non-contact, ultra-fast, precise, fully automatic and flexible mode of operation level manipulation, which includes material removal (processing and cleaning), addition (coating and deposition) or simply modification (heating/cooling, hardening, casting and alloying). The irradiated area is extremely small and, therefore, the distortion is the minimum. In the process, laser surface engineering can greatly improve the surface dependent properties, such as hardness, friction, fatigue and resistance to wear, corrosion, etc. [23]

Jyotsna Dutta Majumdar and Indranil Manna (2013) provided the principle of laser material processing and a general description of the engineering application of laser material processing. The production processes covered have been divided into four main categories; Namely, laser formation, conjunction, mechanical processing and surface engineering. And they described the scope and the principle of a single process. [1]

Reza Ghasemi, et al., (2014) research group, performs another evaluation of the microstructure and thermal insulation capacity of the thermal barrier coating sprayed with laser enameled plasma. The nanostructured thermal barrier (TBC) coatings consisting of a zirconium oxide ceramic top layer (YSZ) stabilized with yttria and a NiCrAlY metal coating were Prepared by atmospheric plasma spraying (APS). The pulsed Nd: YAG laser is used for the laser treatment of the surface of the upper layer. After laser enamel, all the main features present in TB in nanostructured plasma have disappeared. The laser glazing process has reduced the roughness of the surface, eliminated the porosity of the surface and produced network cracks perpendicular to the surface. The experimental results of the thermal insulation capacity test indicated that the enamel coatings had a slightly lower thermal insulation than the spray coatings due to the microstructural change in the glass layer of the upper layer. [24]

The improvement of the ablation resistance through laser glazing of the thermal barrier coating with heat treatment based on LaTi2Al9O19 is obtained from S.R. Dhineshkumar, et al. (2016) research group [24]. The functional thermal barrier (FG) coating of LaTi2Al9O19 (LTA) and 8% zirconium oxide stabilized with Yttria (YSZ) in nickel alloy C263 was deposited by plasma spray and NiCrAlY was used as the coating adhesive. To produce a dense and porous free surface layer to improve the ablation resistance of the coatings, as shown in Figure 15, the sprayed plasma samples were enameled using a 3kW CW CO_2 laser, the laser power was varied to three

Power levels of 200W, 500W, 800W, and keeping the scanning speed constant at 800 mm / sec with an attempt to generate a dense surface and a smooth layer. The removed coatings have a typical rough surface with pores, cracks, and inclusions. The process of laser enameling reduces the roughness of the surface by eliminating pores and cracks through the complete dissolution of the surface. [25].

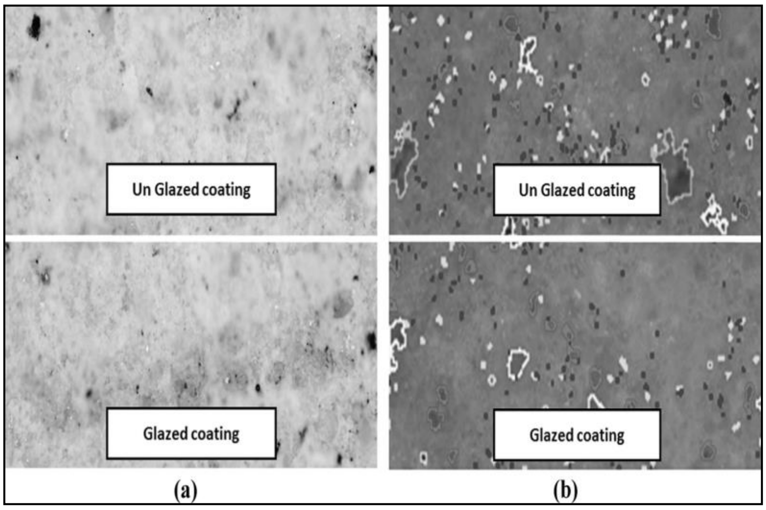


Fig. 15: A). Optical Microscope Image, B). Porous Morphology Using an Image Analyzer [25].

4. Conclusion

The purpose of processing materials using laser in industrial applications is to improve the surface properties of materials, so that the treated surfaces gain good corrosion resistance, high hardness. In this research, surface treatment methods for laser materials were classified in thermal processes and thermal chemical processes.

The chemical thermal process shows a change in the surface composition of the treated material. In addition, it has the flexibility and ability to handle small spaces, leaving the other parts unchanged. The optimum power of the laser used to remove the material is 40-200 W / cm2. The initial state of hydration for cement paste can be identified by analyzing the changes resulting from the intensity of the laser processor, where spectroscopy, microscopic electron microscopy and X-ray space are used.

Alumina samples in Ceram proved more soluble areas and became more homogenous and smooth with fewer openings and cracks, especially with energy higher than 10 W CO_2 and higher power density than Excimer 6.2 J / cm laser devices. Laser coating improves surface hardness and softness of ceramic surfaces without affecting internal structures.

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