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A Review on Characteristics of Concrete Surface Laser Processing

Thikra Kadhim Ibrahim[1], M. S. Salim[2], Naseer Sabri[3], S. Fouad[4]

[1,2]School of Laser & Optical Elect. Engineering, Al-Nahrain University, IRAQ

[3]School of Computer & Communication Engineering, University Malaysia

Perlis, 01000 Kangar, Malaysia

[4]School of Microelectronics Engineering, University Malaysia

Perlis, 01000 Kangar, Malaysia

Abstract

This present work describes the review gathered information of investigate the laser processing of concrete. The unique characteristics of lasers, so they have the propensity to be employed for the noncontact processing of materials which are otherwise difficult to process. In order to generate a durable and long-lasting surface seal on the concrete, thereby extending the life and applications base of the concrete, many researchers were successfully demonstrated glazing of the (OPC) surface of concrete by using different types of lasers. In addition the wear characteristics of a glaze generated on the (OPC) surface of concrete within both normal and corrosive environmental conditions. A comparison results of the mechanical and chemical tests performance of the OPC glaze over untreated OPC are presented.

Keywords: Keywords: *HPDL, CO_2 Laser, Concrete, Glazing technique.*

1. Introduction

The lasers have many industrial applications, such as welding, drilling, cutting, and heat treating of materials. High power densities and adaptability to automated processing are responsible for their success. In one laser method the surface of a material is superficially melted, then rapidly cooled. In this method, a thin surface layer is rapidly melted and solidified to give fine grained microstructures different from that of the bulk material. High cooling rates of the molten surface layer can advance the formation of amorphous material, and fine grained microstructures resulting in enhanced surface properties such as corrosion, wear, and fatigue resistance [1].

The principal advantage of laser glazing is that it changes microstructures without changing the composition; as compared to laser surface alloying and cladding which are intended to alter the composition of the surface [2]. The technique of laser glazing is inherently simple, including the rapid traversal of a surface with a laser beam at a power density of 〖10〗^4- 〖10〗^7 W/cm^2[3].

The concrete, which is a composite material consisting of an array of fine (sand) and coarse (gravel) aggregate pieces embedded within a hardened ordinary Portland cement (OPC) paste[4].The advantages of using engineering concrete in comparison to metal and alloys are inexpensive, lightweight, durable, easy to install, fireproof, low maintenance, and could be ornamented [5].

The manuscript is described different studies related with glazing technique, including characteristics of concrete surface laser processing.

2. Characteristics of Concrete Surface Laser Processing

The selected architectural materials or inhomogeneous materials are clay quarry tiles, ceramic tiles and ordinary Portland cement (OPC) [6]. Many studies have been carried out to investigate the laser glazing inhomogeneous materials. The possibility investigation, of laser glazing technique for the concrete surface to form an impermeable layer is proved by Blair K.J. et al. (1996) researcher team [7]. The purpose of impermeable layer generation is to prevent water leaching of such material to other sites by "tie-down" the particulate contamination of layer. The effect of a laser is to provide a heat source which will melt the surface of the material and thus achieve the "tie-down" case. Several experimental were carried out using both CO2 and Nd:YAG lasers to process the material in which several achievement are presented:

- The movement limitation of the radioactive particles produced by coating layer that generated using laser glazing technique.
- A continuous vitreous (glassy) surface coating was achieved with relatively low power density (200 W 〖cm〗^(-2)) and low traverse speed (3 mm s^(-1)).
- No glazing layer (solely dehydration of the surface) is presented during used of lower powers or higher traverse speeds.
- While using of higher powers or lower traverse speeds resulted in fracturing of the surface, with ejection of pieces of material.

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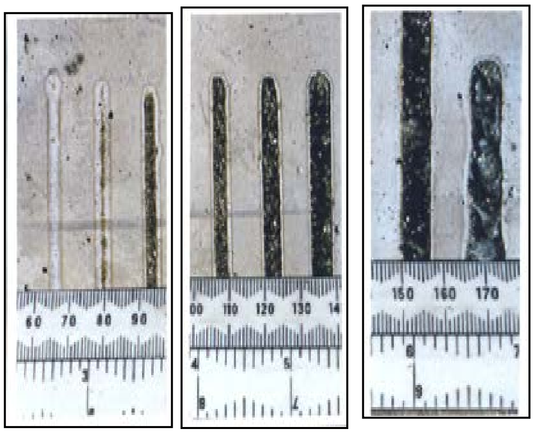
- Color of affected area, the color will change from dark to light grey, with some brown charring around the edge of the affected area as shown in figure 1.
- The depth and width to which the concrete is heat affected. The glazing width and depth are proportional to the laser power, and inversely proportional to the traverse speed as shown in figures (2 to 5).



(a) (b) (c)

Fig. 1 Photograph to show effect of laser beam on concrete surface at varying power levels (spot diameter (5mm), traverse speed (2mm/ sec), and laser power (top to bottom): a) (20, 35,50W), b) (75,110, 210W), c) (460, 840 W) [7].

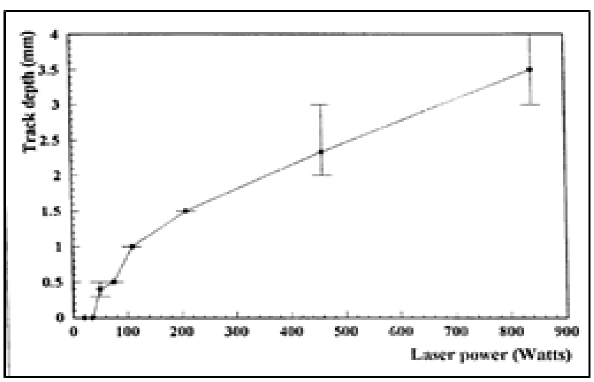


Fig. 2 Graph to show increase in track depth with increasing power (spot diameter (5mm), traverse speed (2mm/sec)) [7].

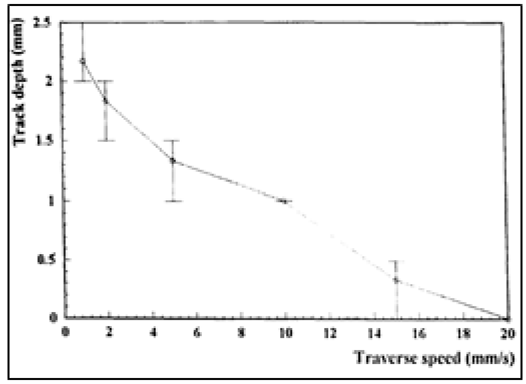


Fig.3 Graph to show increase in track width with increasing power (spot diameter (5mm), traverse speed (2mm/sec)) [7].

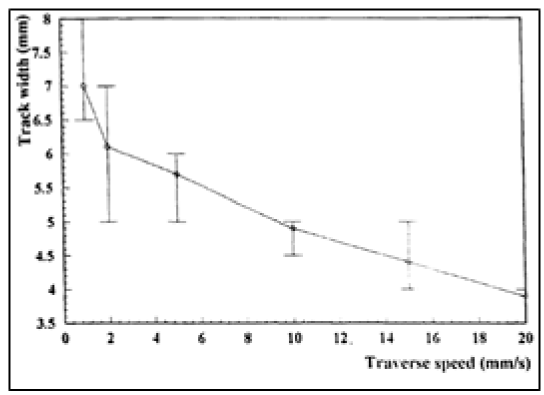


Fig. 4 Graph to show decrease in track depth with increasing traverse speed (Power (160 W), spot diameter (5mm)) [7].

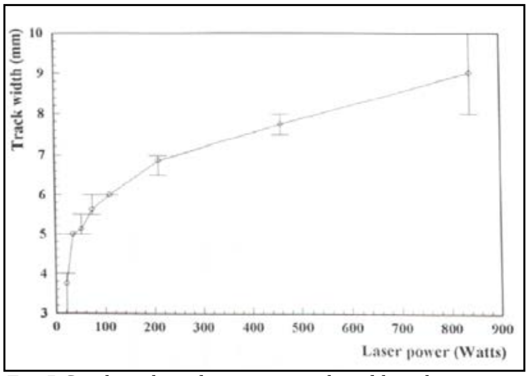


Fig. 5 Graph to show decrease in track width with increasing traverse speed (Power (160 W), spot diameter (5mm)) [7].

Blair K.J. et al. (1996) researcher team, explained that the heat affected zone is produced which includes the glazed layer and the dehydrated material below it. Also researcher registered the low speeds and powers (<200 W 〖cm〗^(-2), <3 mm s^(-1)) for the most successful samples processed [7].

3. Concrete glazing processing based HPDL

Extending the life and applications base of the concrete are ultimate aim of J. Lawrence and L. Li (1999) researchers team [8]. They produced novel surface glaze generation on the OPC surface layer of concrete based on high power diode laser (HPDL). The mechanical, physical and chemical properties of generated surface were investigated and analyzed.

The concrete studied in the experiments is the OPC based concrete. The laser used in the study was a surgical HPDL (Diomed Ltd.), emitting at 810nm ±20nm and operating in the CW mode with rated optical powers ranging from 0-60 W. The concrete sample blocks were irradiated using the defocused high order mode HPDL beam with a beam spot diameter of 2mm and laser powers of 20-55 W.

The glazing of the ordinary Portland cement (OPC) surface of concrete is successfully demonstrated with power densities of high power diode laser (HPDL) as low as 750 W/〖cm〗^2, and at rates up to 480 mm 〖min〗^(-1) as shown in figure 6.

A series of experiments were conducted with an O_2 shield gas for a wide range of traverse speeds, whilst the power density was fixed at 1, 2 and 3 kW/〖cm〗^2 with a spot diameter of 1mm. Figure 7 shows the inverse proportional relationship between the depth of the laser treatment on the OPC surface of the concrete and the traverse speed for the stated power densities.

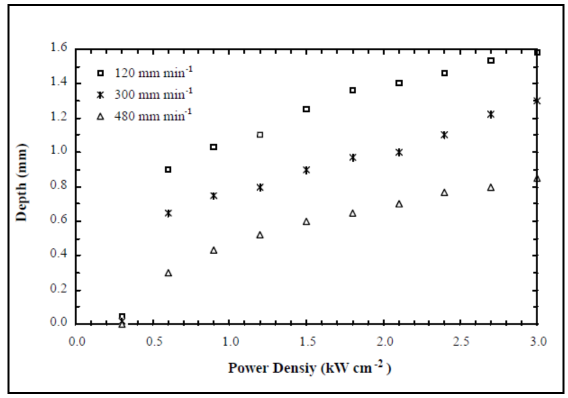


Fig. 6 Relationship between OPC surface of concrete laser melt depth and laser power density [8].

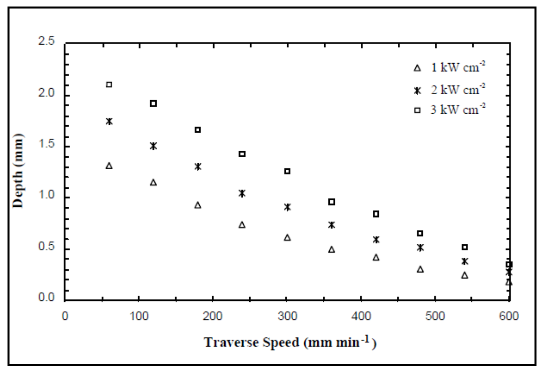


Fig. 7 Relationship between OPC surface of concrete laser melt depth and traverse speed [8].

Thermal analysis techniques were used to identify the degradation reactions and the temperatures at which they occur. In particular, the dehydration of $Ca(OH)_2$ in the cement matrix was ascertained as forming the heat affected zone (HAZ). Cracks and porosities are common features of the laser glaze. Cracking is identified as being due to the generation of thermal stresses in excess of the fracture strength of the glaze [8].

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The determination of laser beam absorption lengths of CO_2 and a high power diode laser (HPDL) radiation for the ordinary Portland cement (OPC) surface of concrete is provided by J. Lawrence research team (2000) [9]. In this work a CO_2 laser (Rofin-Sinar) emitting at 10.6µm with a maximum output power of 1 kW and a HPDL (Diomed) emitting at 810±20nm with a maximum output power of 60 W were employed. Both lasers produced a multi-mode beam. The OPC surface of the concrete had a thickness of 2.5 mm. concrete blocks were sectioned into squares (120 x 120 x 20 mm) prior to laser treatment. The cement is treated with both lasers at room temperature and in normal atmospheric conditions.

J. Lawrence team employing Beer-Lambert's law, the laser beam absorption lengths of CO_2 and a high power diode laser (HPDL) radiation for concrete were determined. The absorption lengths for concrete of CO_2 and a HPDL radiation were 470±22 µm and 177±15 µm respectively. Absorptivity measurements made at room temperature using spectrometers suitable for each laser wavelength revealed that the OPC surface of the concrete absorbed around 75% of CO_2 laser radiation and around 69% of HPDL radiation. As illustrated in figures 8 and 9.

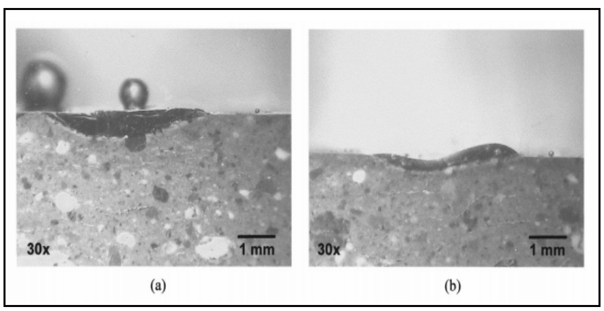
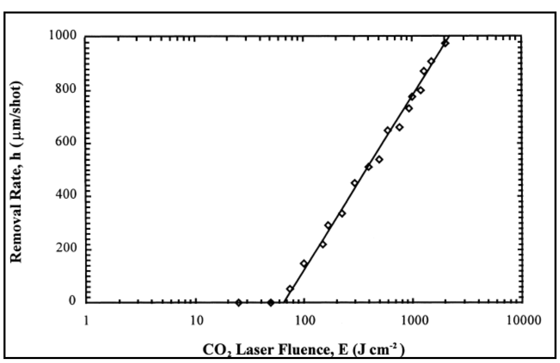
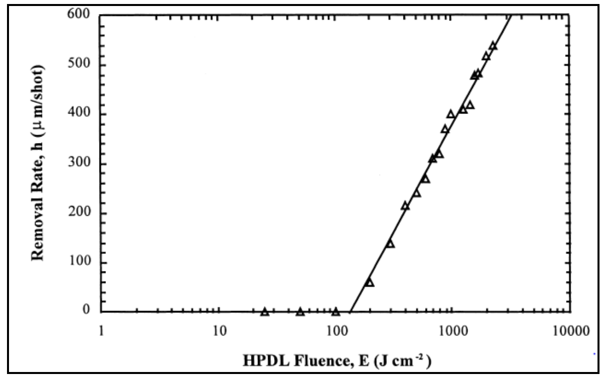


Fig. 8 Cross-sectional optical micrograph of the melt region produced with (a) CO_2 and (b) high power diode laser radiation. [9].



(a)



(b)

Fig. 9 Removal rate per shot, h, as a function of: a) CO_2 laser fluence, E, b) HPDL fluence, E.[9].

4. Improvements in Wear and Corrosion Resistance of Concrete

The economic implications of wear are a cause of considerable concern to building and civil engineers alike who employ concrete in a broad area of applications. Furthermore, in the present and foreseeable world economy, material conservation is becoming a matter of increasing importance. Wear is a major cause of concrete wastage in many application areas where over time and as a direct consequence of the operating environment, the concrete becomes corroded and/or contaminated. J. Lawrence and L. Li researcher team (2000) are showed that the generation of a surface glaze resulted in the considerable enhancement of the wear characteristics over an untreated OPC surface of concrete [10]. The wear characteristics of a glaze generated on the OPC surface of concrete using a 60W high power diode laser (HPDL) operating in the CW mode have been determined. Within both normal and corrosive (detergent, NaOH and HNO_3) environmental conditions the wear rate of the HPDL generated glaze was 3.5 mg 〖cm〗^(-2) 〖h〗^(-1). In contrast, the untreated OPC surface of concrete exhibited a wear rate of 9.8 mg 〖cm〗^(-2) 〖h〗^(-1) in normal environmental conditions as shown in figure 10, and 18.5, 73.8 and 114.8 mg 〖cm〗^(-2) 〖h〗^(-1)when exposed to detergent, NaOH and HNO_3 as shown in figure 11, respectively. Life assessment testing revealed that the HPDL generated glaze had an increase in wear life of 1.3–14.8 times over an untreated OPC surface, depending upon the corrosive environment. It is believed that the economic and material benefits to be gained from the deployment of such an effective and efficient coating on OPC could be significant.

The reasons for these marked improvements in the wear resistance and wear life of the HPDL generated glaze over the untreated OPC surface of concrete can be attributed to:

i. The verification of the OPC surface after HPDL treatment which subsequently created a much more dense and consolidated surface;
ii. The generation of a surface with improved microstructure and phase which is more resistant in corrosive environments.

The surface glaze characteristics of concrete treated with CO_2 and high power diode lasers is presented in a comparative study by J. Lawrence and L. Li researchers (2000) [11]. The researchers describes the differences in the characteristics of glazes generated on the ordinary Portland cement (OPC) surface of concrete by means of CO_2 and high power diode laser (HPDL) radiation.

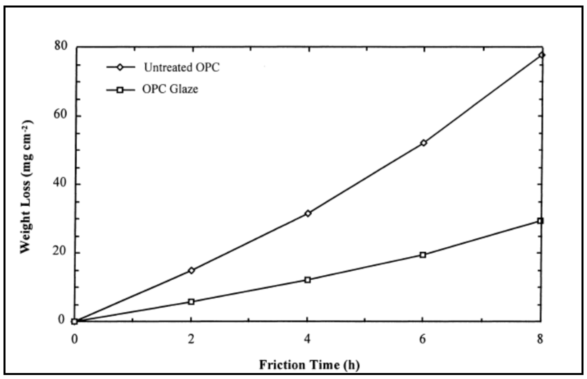


Fig.10 Relationship between weight loss and friction time for the untreated and HPDL generated glaze on the OPC surface of concrete [10].

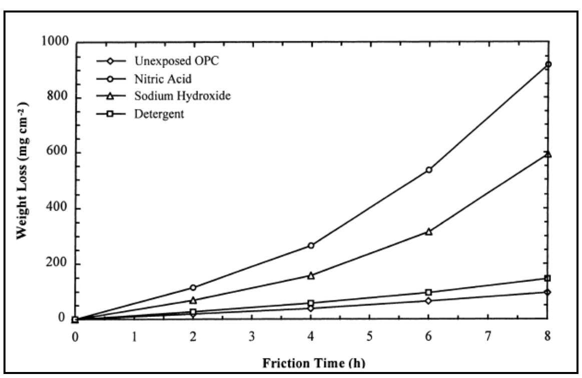


Fig. 11 Relationship between weight loss and friction time for the untreated OPC with different reagent types at the maximum concentration (80%) [10].

The concrete studied in the experiments is the OPC based concrete. For the purpose of experimental convenience the as-received concrete blocks are sectioned into squares (120 mm x 120 mm x 20 mm) prior to laser treatment. The lasers used in this work were a CO_2 laser (RS1000, Rofin-Sinar) emitting at 10.6 µm with a maximum output power of 1 kW and a HPDL (D-60, Diomed) emitting at 810±20 nm with a maximum output power of 60 W in continuous wave mode. The power density of each is set at 2.25 kW 〖cm〗^(-2).

The depth of melting resulting from CO_2 laser glazing, along with the depth of the HAZ, are found to be greater than those obtained with the HPDL . In addition the glaze generated after HPDL interaction was found is fully amorphous in nature, whilst the glaze generated after CO_2 laser interaction was seen to be of a semi-amorphous structure, with sizeable areas, randomly located within the glaze, displayed a somewhat regular columnar structure.

The researchers J. Lawrence and L. Li (2000) [12], are continue in their research to report on the comparative testing of the CO_2 and HPDL generated glazes in terms of their mechanical, chemical and physical properties, as well as a comparison with the untreated OPC surface properties. Mechanical tests were conducted to determine such properties as pull-off (bond) strength, rupture strength, wear resistance and absorptivity to water. Additionally, chemical tests were carried out to examine the corrosion resistance of the laser glazed and untreated OPC with regard to acid (nitric acid) alkali (sodium hydroxide) and common industrial detergent. Life assessment testing of the laser glazed and untreated OPC was also carried out. The experimental which carried out find the following achievements:

(i) The required pull-off force after laser glazing was reduced from 636.8 N to 235.6 N after HPDL glazing and 40.3 N after CO_2 laser glazing as shown in figure 12. The general reduction in required pull-off force after laser glazing is believed to be due to the inherent generation of a heat affected zone (HAZ) comprising mainly of weaker CaO. Similarly, the marked difference between the pull-off strength of the CO_2 and HPDL glaze can be attributed to the fact that the HAZ after HPDL glazing was much smaller than that of the CO_2 laser glaze.

(ii) The average rupture strength of the CO_2 and HPDL generated OPC glazes were very similar, 0.82 and 0.8 J respectively, whilst the rupture strength of the untreated OPC surface was some 4.3 J. This is because laser glazing of the OPC surface has resulted in partial (CO_2 laser) and full (HPDL) verification, effectively generating a glass.

(iii) Laser glazing of the OPC surface afforded the concrete approximately twice as much resistance to water absorptivity than the untreated surface, 0.096 mm/ min compared with 0.047 mm /min and 0.043 mm/ min for the CO_2 and the HPDL glazes respectively as shown in figure 13. The slightly higher water absorptivity of the CO_2 laser glaze is likely to be due to the greater prevalence of porosities and cracks in the CO_2 laser glaze; which will inherently allow more water to permeate through the glaze and be absorbed by the concrete.

(iv) Life assessment testing revealed that surface glazing of the OPC with both the CO_2 and the HPDL effected an increase in wear life of 1.3 to 17.7 times over an untreated OPC surface, depending upon the corrosive environment. The wear life and the wear rate of the HPDL glaze was consistently higher than that of the CO_2 laser glaze as shown in figure 14.

(v) Both the CO_2 and HPDL glazed OPC surfaces displayed no discernible microstructural changes or signs of devitrification resulting from exposure to corrosive agents. In contrast, the corrosive agents were seen to immediately attack the untreated OPC surface.

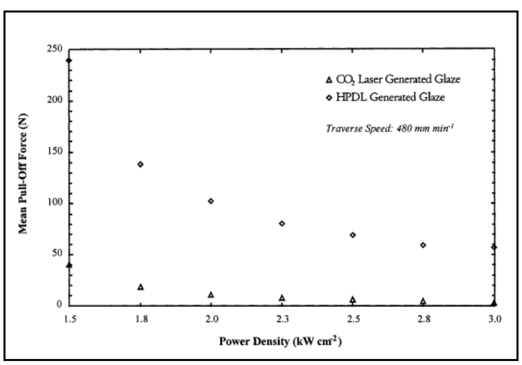


Fig. 12 Relationship between pull-off strength of laser glaze and laser operating parameters for the CO_2 and HPDL [12].

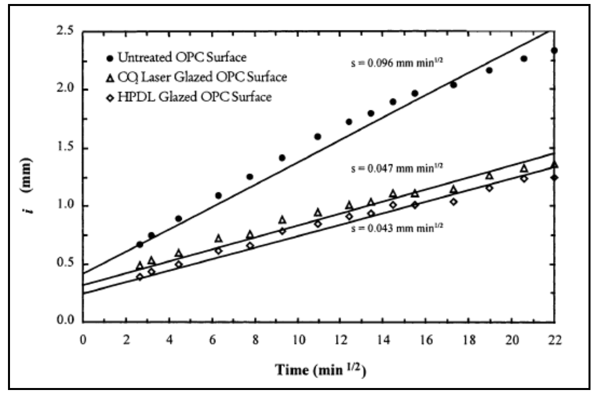


Fig. 13 Water absorption for the untreated and for the CO_2 and HPDL glazed OPC surfaces [12].

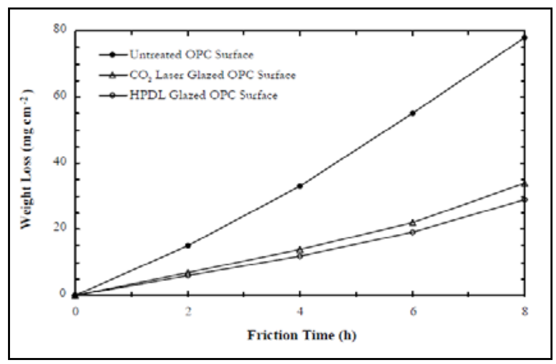


Fig. 14 Relationship between weight loss and friction time for the laser CO_2 and HPDL generated glazes and the untreated OPC [12].

The effects of using O_2, Ar and He process gasses during the treatment of the ordinary Portland cement (OPC) surface of concrete with a high power diode laser (HPDL) is studied and examined by J. Lawrence and L. Li researchers (2001) [13]. To study the effects of different shield gasses, coaxially blown gas jets of O_2, Ar and He were applied at a rate of 5 l 〖min〗^(-1).The use of O_2 as the shield gas is seen to result in glazes with far fewer micro cracks and porosities than those generated with either Ar or He shield gases. Such differences are found to be due to the smaller O_2 gas molecules dissolving molecularly into the open structure of the HPDL generated glaze on the OPC surface of concrete and react with the glass network to increase the fluidity of the melt. This is turn also seen to affect the cooling rate and therefore the tendency to generate micro cracks as shown in figure 15.

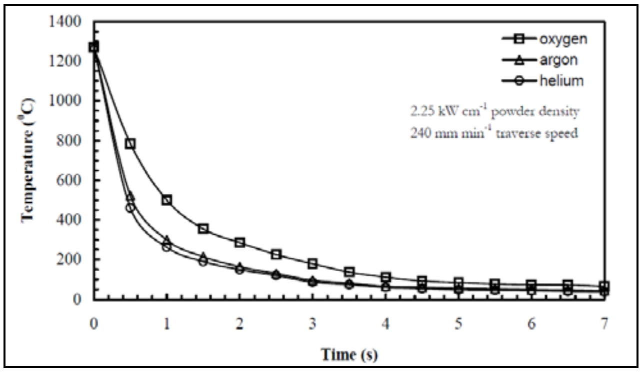


Fig. 15 Best-fit cooling rate curves for the laser glazed OPC surface of concrete when O_2, Ar and He shield gases are employed [13].

4. Conclusions

Glazing of the ordinary Portland cement (OPC) surface of concrete was successfully demonstrated by using CW CO_2, Nd:YAG and high power diode (HPDL) lasers. The characteristics of the glazes the treated concrete samples were examined using optical microscopy, scanning electron microscopy (SEM), energy disperse X-ray analysis (EDX) and X-ray diffraction (XRD) techniques, and the determination of laser beam absorption lengths of CO_2 and a high power diode laser (HPDL) radiation for the ordinary Portland cement (OPC) surface of concrete is also provided. The glazing layer characteristics of concrete is studied by several researchers in which they focus on advantages of glazing technique such as wear and corrosion of material laser processing. The researchers find out that the glazing depth is directly proportional with the laser power at specific traverse speed, and inversely proportional with the traverse speed at specific laser power.

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First Author Thikra Kadhim Ibrahim earned her B.Sc. in Laser & and Optoelectronics Engineering, from Al-Nahrain University, Baghdad, Iraq, in 2013.

Second Author Muhammed Sabri Salim earned his B.Sc. in Avionics and M.Sc. in Electrical & Electronic Engineering, from AL-Rasheed College for Engineering and Sciences, University of Technology, Baghdad, Iraq, in 1992 and 2005 respectively. He received his PhD in Mechatronics Engineering in 2013, from University Malaysia Perlis. Currently he is Senior lecturer in Engineering College, Al-Nahrain University, Iraq. His research interests are on automation, Optimal Control, Intelligent Control Systems, Parameter Identification and Medical Devices, and System Modeling.

Third Author Mr. Naseer Sabri received his B.Sc. and M.Sc. degree in Computer Engineering from Baghdad and technology universities, Republic of Iraq, in 1991, 1996, respectively. He is completed his PhD in November 2013 at Computer and Communication engineering School, University Malaysia Perlis, Malaysia. He is currently research associate at the Research and Innovation Centre at University Malaysia Perlis. Mr. Naseer Sabri, research interests are Intelligent wireless and mobile sensor network, mobile ad hoc network, ubiquitous and pervasive computing, communication protocol and algorithm, artificial intelligence, Fuzzy logic approach for control applications, Industrial Object Recognition and Classification.

Forth Author S. Fouad received her B.Sc. and MSc. degree in Laser & and Optoelectronics Engineering, from Al-Nahrain University, Baghdad, Iraq, in 2002 and 2005 respectively. currently she is PhD student at School of Microelectronics Engineering, University Malaysia. Her research interest are optical communication, laser application and optical sensor.