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IMPLEMENTATION OF IMAGE ANALYSIS ON LOW LEVEL LASER (LLL) DESTRUCTION OF LOW CEMENT HIGH ALUMINA REFRACTORY CONCRETE

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Abstract. Implementation of image analysis for monitoring the level of destruction during impact of low level laser (LLL) was goal of our investigation. The chosen material was low cement high alumina refractory concrete (LCC). Two series of samples were used in experiment: reference ones dried at 105 °C, and the others sintered at 1300°C. Based on the applied methodology, degradation of the refractory concrete samples subjected to the low-level laser beam during time interval from 5 to 25 minutes was monitored by measuring destruction level: damaged area – pits, as well as pits depth. Comparison of the results using automatic and manual approach will be given. This experiment was done in order to establish whether this material can be used in conditions that require resistance to the laser action and subjected to machine that uses laser techniques.

Keywords: low level laser (LLL), laser destruction, mechanical comparator, image analysis, damages size, refractory concrete

РЕАЛИЗАЦИЯ АНАЛИЗА ИЗОБРАЖЕНИЯ НА ОСНОВЕ НИЗКОЛАЗЕРНОГО РАЗРУШЕНИЯ БЕТОНА ИЗ ОГНЕУПОРНОГО СТРОИТЕЛЬНОГО МАТЕРИАЛА

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Аннотация. Целью исследования являлась реализация анализа изображения для контроля уровня разрушения в течение воздействия низкоуровневого лазера. В качестве исследуемого материала был избран бетон из глиноземного огнеупорного материала с максимальным содержанием цемента. В эксперименте использовались две серии образцов: первые подвергались сушке при температуре 105 °C, остальные – агломерации при температуре 1300 °C. Основываясь на прикладной методологии образец из огнеупорного строительного материала подвергся низкоуровневому лазерному воздействию в течение интервала времени от 5 до 25 минут, при этом контролировался уровень разрушения. Было произведено сравнение результатов, которые получены в ручном и автоматическом режиме. Эксперимент проводился для того, чтобы установить, может ли данный материал использоваться в условиях, требующих сопротивления лазерному воздействию.

Ключевые слова: низкоуровневый лазер; лазерное разрушение; механический компаратор; анализ изображения; размер разрушения; бетон огнеупорного строительного материала

РЕАЛІЗАЦІЯ АНАЛІЗУ ЗОБРАЖЕННЯ НА ОСНОВІ НИЗЬКОЛАЗЕРНОГО РУЙНУВАННЯ БЕТОНУ З ВОГНЕТРИВКОГО БУДІВЕЛЬНОГО МАТЕРІАЛУ

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Анотація. Метою дослідження була реалізація аналізу зображення для контролю рівня руйнування протягом впливу низькорівневого лазера. У якості досліджуваного матеріалу був вибраний бетон із глиноземного вогнетривкого матеріалу з максимальним вмістом цементу. В експерименті використовувалися дві серії зразків: перші зазнали сушіння при температурі 105 °С, інші – агломерації при температурі 1300 °С. Ґрунтуючись на прикладній методології зразок з вогнетривкого будівельного матеріалу піддався низькорівневому лазерному впливу протягом інтервалу часу від 5 до 25 хвилин, при цьому контролювався рівень руйнування. Було зроблене порівняння результатів, які отримані в ручному й автоматичному режимі. Експеримент проводився для того, щоб установити, чи може даний матеріал використовуватися в умовах, що вимагають опору лазерному впливу.

Ключові слова: низькорівневий лазер; лазерне руйнування; механічний компаратор; аналіз зображення; розмір руйнування; бетон вогнетривкого будівельного матеріалу

Introduction

Image analysis of the sample surface destruction is an important non-destructive method for assessing damage of the materials. Due to image analysis, more systematic and more accurate measurements have become possible. Therefore, more objective characterization of concrete from the aspect of material properties is provided. Evaluation of various concrete properties, as well as the effect of external influences on the microstructure of concrete, can be investigated using these non-destructive methodologies [1-4].

The Image Pro Plus is a special program for processing and analysis of image. It recognizes and enables work in all known image formats (TIFF, JPEG, BMP, TGA). This program automatically performs image analysis. It automatically measures, counts and classifies all data obtained by object analysis. The program communicates directly with Excel, which enables statistical and graphical data processing. In this study the image analysis was used for determination of surface destruction level before and during the testing.

The laser can be applied to different processing techniques such are drilling, cutting, and thermal treatment (thin film ablation and evaporation, hole drilling, piercing, perforation, point welding, thermal processing, cutting by gas laser, thermo-separation, and so on). There are two processing regimes of laser action: pulsed mode (PM) and continuous wave (CW). In CW lasers, continuous pumping of the laser emits instant light, while in a pulsed laser there is a laser power-off period between two successive pulses. PM laser irradiation was mostly used for thermal shock testing of ceramics, while CW laser was usually used for monitoring thermal properties and sensitivity of ceramics. The excitation energy provided by laser is rapidly converted into heat during laser-ceramic interaction. This is followed by various heat transfer processes such as conduction into the materials, convection, and radiation from the surface. As a consequence, various physical phenomena are created: heating, surface melting, surface vaporization, plasma formation, ablation [5].

Based on previously published results [6-8], related to behavior of refractory concrete under extreme conditions, thermal shock and cavitation erosion, attempt was made to investigate the resistance of this group of materials to effects of the laser beams. Other authors' studies were usually occupied with using high level of power laser (CO_2, NdYAGi, etc.) [9-12].The same effect can be obtained with the low level laser as with higher level laser but for the longer time. Therefore, this research is devoted to the behavior and sensitivity of this group of materials on low level laser action.

Experimental

Materials

Samples of refractory composite material, low cement castable, were used to measure damage caused by the low level laser beam action. Preparation of refractory concrete consisted of samples synthesis and their sintering. Prepared alumina based refractory concrete had 98.11 % of Al_2O_3 and 1.22 % of CaO. Since its chemical composition indicates that the content of components that can form low melting phases (CaO) is quite low, good mechanical characteristics and corrosion resistance were expected. It should be emphasized that chemical composition plays a major role for the characteristics of the aggregate-matrix bond interface which determines thermo-mechanical properties of refractory materials.

After the synthesis, sintering at 1300 °C with the dwell time of three hours was realized.

Methods

Low-level laser beam application

Prepared samples were subjected to the action of low-level laser beam.

The plan of investigation was related to the monitoring of materials behavior in extreme condition of laser action. In this experiment, CW laser beam with permanent effect was appliedfor monitoring resistance and sensitivity of ceramics.

Continuous non-polarized semiconductor laser with integrated collimator MGL-S-532 from *"CNI" Company* was used in experiments. Power in a stationary temperature regime was measured using Laser Check from *"Coherent" Company* and was 366 mW. The wavelength was 532 nm. Beam profile was oval with the axis ratio of 3:2, with a Gaussian distribution of power. Focus was placed on the sample surface using a built-in optics and achieved beam major axis length of 0.46 mm.

Different times, from 5 to 25 minutes, with interval of 5 minutes were selected to investigate the resistance of the samples to the LLL beam.

Image analysis and pit depth measurement

Destruction level of the samples during laser beam treatment were characterized by affected area and depth of pit. Image analysis was applied for damaged area measurements. Program Image Pro Plus was used, and destruction area was measured using both manual and automaticalmethods.Analyzed surfaces were colored by red color with the aim of obtaining better resolution and facilitating the difference between damaged and undamaged areas of material. Accordingly, undamaged area was red, and damaged area was white or lower intensity of red color. This approach was performed to achieve better image condition for image analysis application.

Pit depth measurements were based on the microphotographs and performed using comparator Orion added to the microscope.

Results and Discussion

Surface damaged area

Measurements of the surface damaged area using image analysis included detecting differences between damaged and undamaged areas of the material. The results were calculated and compared to the ideal surface and presented in percentages $(P/P_0)\cdot 100$ %.

Images of the samplesdried at 105 °C and sintered at 1300 °C for different intervals of the laser beams exposure are given in Fig. 1.

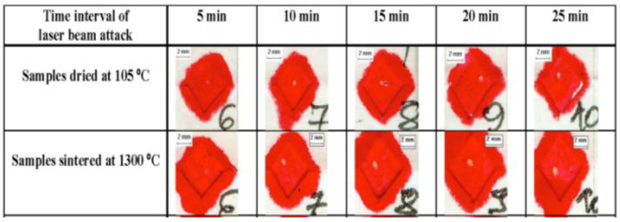
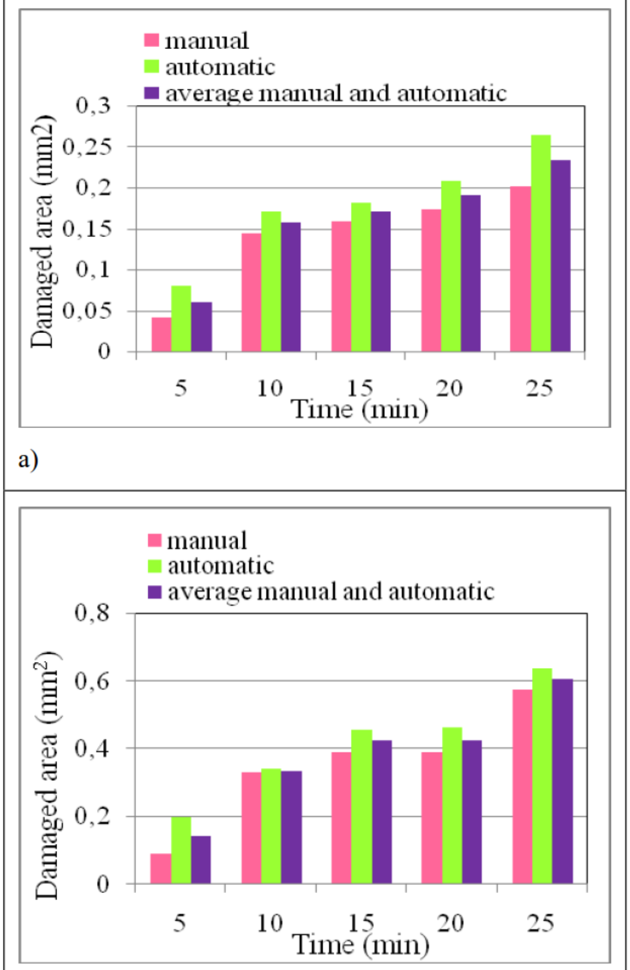


Fig.1. Images of the samples dried at 105 °C and sintered at 1300 °C for different time intervals of exposure to LLL [13]

Damaged areas for the samples treated at 105 and 1300 °C, measured manually and automatically, and the average values, presented in Figure2.

The obtained results showed close values of both methods (manual and automatic) for the tested samples after 5, 10, 15, 20 and 25 minutes of exposure to LLL. It can be observed that the maximum difference between the applied methods was for the samples treated at 105 °C after 25 minutes of exposure to LLL. Some differences in the obtained results and difference between manual and automatic data for damaged area are related to the possibilities of obtaining image with excellent resolution.

Comparison of the obtained data for damaged area measurements for different time intervals of the laser beams exposure is presented in Figure 3. For shorter time interval, 5 minutes, differences between damaged areas are smaller. For longer time of exposure to LLL, these differences are higher, and the highest difference is observed for the longest time period.



a)

b)

Fig. 2. Damaged area during LLL exposure for samples treated a)105 °C and b) 1300 °C

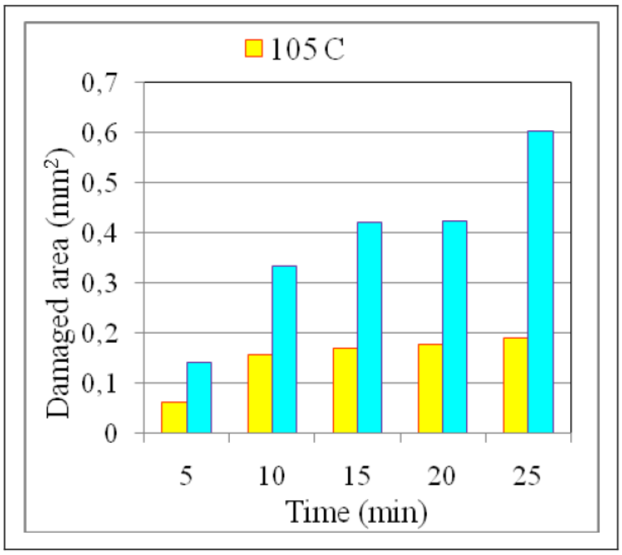
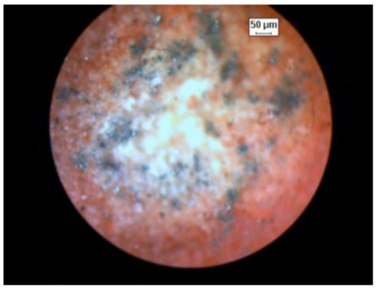


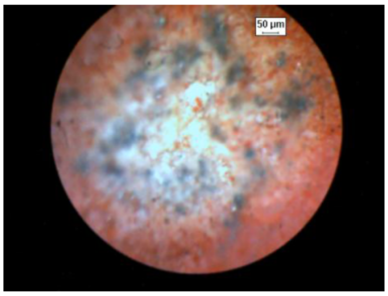
Fig. 3.Comparison of damaged area for different time intervals of exposure to LLL

Pit depth

The examples of microphotographs of the sample surface and pit are given at Fig. 4.



surface



pit

Fig. 4.Microphotographs of the surface and pit for the samplessintered at 1300 ºC and exposed to LLL for 25 min

The results of the pit depth values for the samples treated at 105 and 1300 °C during the laser beams exposure are presented in Fig. 5.

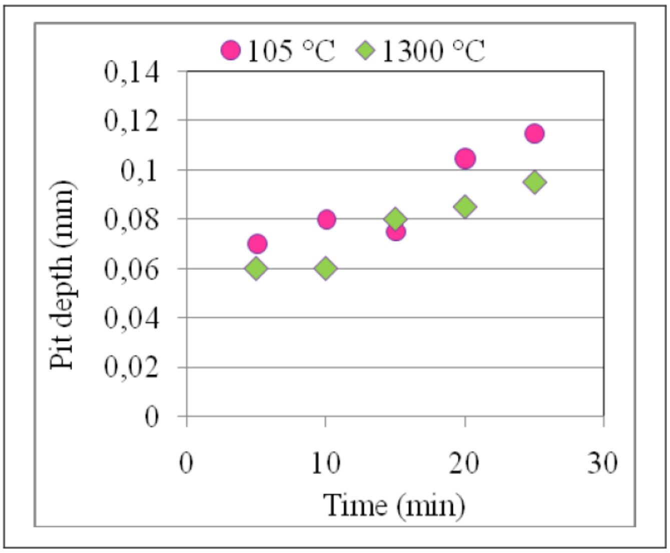


Fig. 5. Comparison of pith depth values fordifferent time intervals of exposure to LLL

It can be noticed that pit depth is increasing from 0.07-0.115 mm during the time interval from 5 to 25 minutes for the samples dried at 105 °C. This increasing trend is also observed for the samples sintered at 1300 °C, pit depth changed from 0.06-0.095 mm in the time interval from 5 to 25 minutes.

Having in mind the influence of the treatment temperature, it can be observed that after 5 minutes samples exhibited similar behavior, with pit depth of 0.06 mm for the samples sintered at 1300 °C and 0.07 mm for samples dried at 105 °C. As the time of impact of the LLL was increasing, higher differences for the pit depth were observed. The minimal value of 0.085 mm was measured After 25 minutes, for the samples sintered at 1300 °C smaller value (0.095 mm) was noticed compared to samples dried at 105 °C (0.115 mm).

Conclusion

According to the results obtained using two types of measuremets to establish level of degradaton of the samples- degradation area and pit depth, it can be concluded that:

- At the begining of the experiment, for LLL exposure time of 5 minutes, differences between samples treated at different temperatures exist, but they are small. These differences are increasing with time of LLL exposure. For 25 minutes, significant differences in the degradation area as well as pit depth can be observed.
- Pit depth measurements indicated that samples sintered at 1300 °C exhibited better resistance to the LLL impact compared with those dried at 105 °C.

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REFERENCES

1. Ammouche A., Riss J., Breysse D., Marchand J./Ammouche A., Riss J., Breysse D., Marchand J. // Image analysis for the automated study of microcracks in concrete.CemConcr Compos. – 2001. – 23. – 267.

Ammouche A., Riss J., Breysse D., Marchand J. Image analysis for the automated study of microcracks in concrete.*CemConcr Compos,* 2001, 23, 267.

2. Soroushian P., Elzafraney M., Nossoni A. / Soroushian P., Elzafraney M., Nossoni A. // Specimen preparation and image processing and analysis techniques for automated quantification of concrete microcracks and voids. CemConcr Resю. – 2003. – 33. – 1949.

Soroushian P., Elzafraney M., Nossoni A. Specimen preparation and image processing and analysis techniques for automated quantification of concrete microcracks and voids. *CemConcr Resю,* 2003, 33, 1949.

3. LemaireG.,Escadeillas G., Ringot E. / LemaireG.,Escadeillas G., Ringot E. // Evaluating concrete surfaces using an image analysis process. Constr Build Mater.– 2005. – 19. – 604.

LemaireG.,Escadeillas G., Ringot E. Evaluating concrete surfaces using an image analysis process. *Constr Build Mater*, 2005, 19, 604.

4. Vlahovic M., Savic M., Martinovic S.,Boljanac T., Volkov-Husovic T. / Vlahovic M., Savic M., Martinovic S.,Boljanac T., Volkov-Husovic T. // Use of image analysis for durability testing of sulfur concrete and Portland cement concrete.Materials and Design. – 2012. – 34. – 346.

Vlahovic M., Savic M., Martinovic S.,Boljanac T., Volkov-HusovicUse of image analysis for durability testing of sulfur concrete and Portland cement concrete.*Materials and Design*, 2012, 34, 346.

5. SamantA. N., DahotreN. B./ SamantA. N., DahotreN. B. // Laser machining of structural ceramics - A review.J Eur Ceram. – 2009. – Soc29. – 969.

SamantA. N., DahotreN. B. Laser machining of structural ceramics - A review.*J Eur Ceram*, 2009,Soc29, 969.

6. Martinovic S., Vlahovic M.,Dojcinovic M.,VolkoHusovic T.,Majstorovic J. / Martinovic S., Vlahovic M., Dojcinovic M.,VolkoHusovic T., Majstorovic J. // Thermomechanical properties and cavitation resistance of a high-alumina low cement castable. Int J Appl Ceram Techno. – 2011. – l8. – 1115.

Martinovic S., Vlahovic M., Dojcinovic M.,VolkoHusovic T., Majstorovic J. Thermomechanical properties and cavitation resistance of a high-alumina low cement castable. *Int J Appl Ceram Techno*, 2011, l8, 1115.

7.Martinovic S., Vlahovic M.,Dojcinovic M.,Boljanac T.,Volkov-Husovic T./ Martinovic S., Vlahovic M.,Dojcinovic M., Boljanac T.,Volkov-Husovic T. // Cavitation resistance of refractory concrete: Influence of sintering temperature.J Eur Ceram. – 2013. – Soc33. – 7.

Martinovic S., Vlahovic M.,Dojcinovic M., Boljanac T.,Volkov-Husovic T. Cavitation resistance of refractory concrete: Influence of sintering temperature.*J Eur Ceram*, 2013, Soc 33, 7.

8.Martinovic S., Vlahovic M., Boljanac T., Majstorovic J., Volkov-Husovic T./ Martinovic S., Vlahovic M., Boljanac T., Majstorovic J., Volkov-Husovic T. // Influence of sintering temperature on thermal shock behavior of low cement high alumina refractory concrete. Compos Part B-Eng. – 2014.– 60. – 400.

Martinovic S., Vlahovic M., Boljanac T., Majstorovic J., Volkov-Husovic T. Influence of sintering temperature on thermal shock behavior of low cement high alumina refractory concrete. *Compos Part B-Eng,* 2014, 60, 400.

9.Kirilov E., Mark M.J., Seg M., Nägerl H. Compact, robust, and spectrally pure diode-laser system with a filtered output and a tunable copy for absoulute referencing: ApplPhys B – Lasers O. / Kirilov E., Mark M.J., Seg M., Nägerl H. // Online first articles. – 2015. – Access Mode:DOI:10.1007/s00340-015-6049-5.

Kirilov E., Mark M.J., Seg M., Nägerl H. Compact, robust, and spectrally pure diode-laser system with a filtered output and a tunable copy for absoulute referencing: ApplPhys B – Lasers O. *Online first articles,* 2015.doi:10.1007/s00340-015-6049-5.

10. Sroka R.,Pongratz T., Scheib G., Khoder W., Stief C.,Herrmann T.,Nagele U.,Bader M. / Sroka R.,Pongratz T., Scheib G., Khoder W., Stief C.,Herrmann T.,Nagele U.,Bader M. // Impact of pulse duration on Ho:YAG laser lithotripsy: treatment aspects on the single-pulse level. World J Urol. – 2015. –33. –479.

Sroka R.,Pongratz T., Scheib G., Khoder W., Stief C.,Herrmann T.,Nagele U.,Bader M. Impact of pulse duration on Ho:YAG laser lithotripsy: treatment aspects on the single-pulse level. *World J Urol,* 2015, 33, 479.

11.Ding Y., Yao B.Q., JuY. L.,LiY. Y., DuanX. M., HeW. J. / Ding Y., Yao B.Q., JuY. L.,LiY. Y., DuanX. M., HeW. J. // High power Q-switched Ho:YVO4 laser resonantly pumped by a Tm-fiber-laser.Laser Phys. – 2014. – 25. – 1.

Ding Y., Yao B.Q., JuY. L.,LiY. Y., DuanX. M., HeW. J.High power Q-switched Ho:YVO4 laser resonantly pumped by a Tm-fiber-laser.*Laser Phys*, 2014, 25, 1.

12. Dostalova T., Jelinkova H., Kasparova M., Ginzelova K., Feberova J., Sulc J., Nemec M.,Fibrich M.,Bradna P. / Dostalova T., Jelinkova H., Kasparova M., Ginzelova K., Feberova J., Sulc J., Nemec M.,Fibrich M.,Bradna P. // Er:YAG laser radiation: Contact versus non-contact enamel ablation and sonic-activated bulk

composite placement: Microleakage evaluation. Laser Phys. – 2015. – 25. –1.

Dostalova T., Jelinkova H., Kasparova M., Ginzelova K., Feberova J., Sulc J., Nemec M.,Fibrich M.,Bradna P. Er:YAG laser radiation: Contact versus non-contact enamel ablation and sonic-activated bulk composite placement: Microleakage evaluation. *Laser Phys*, 2015, 25, 1.

13. Martinovic S., Vlahovic M., Stevic Z., Volkov-Husovic T. / Martinovic S., Vlahovic M., Stevic Z., Volkov-Husovic T. // Influence of sintering temperature on low level laser (LLL) destruction of low cement high alumina refractory concrete.Engineering structures. – 2015. – 99. – 462.

Martinovic S., Vlahovic M., Stevic Z., Volkov-Husovic T. Influence of sintering temperature on low level laser (LLL) destruction of low cement high alumina refractory concrete.*Engineering structures,* 2015, 99, 462.