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IMPLEMENTATION OF IMAGE ANALYSISON SURFACE DEGRADATION DETERMINATION CAUSED BY CAVITATION EROSION

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Abstract. The purpose of this study was to investigate different types of measurements by image analysis technique using Image Pro Plus program for determination of surface degradation during cavitation erosion testing. As a refractory concrete, low cement castable was synthesized, cured, and then sintered at 1600 °C. Mass loss and surface degradation of investigated samples were monitored during three hours of exposure to the cavitation erosion testing. Two different approaches using image analysis for surface degradation determination were applied: manual and automatic. The results obtained by those different approaches were similar. Cavitation damage test is usually used for metallic materials. Due to the fact that development and design of modern materials moves in direction of replacement metallic components with composite and ceramic materials, the idea of this study was to investigate possible application of refractory concrete in the extreme conditions of exposure to the cavitation. Usual method for monitoring the material degradation during the cavitation is measuring the mass loss. Novelty of this study is implementation of image analysis for monitoring the level of surface degradation during the cavitation resistance testing. Both methods are non-destructive.

Keywords: cavitation erosion resistance, image analysis; refractory concrete

РЕАЛИЗАЦИЯ АНАЛИЗА ИЗОБРАЖЕНИЯ ПО ОПРЕДЕЛЕНИЮ ВНЕШНЕЙ ДЕГРАДАЦИИ, ВЫЗВАННОЙ КАВИТАЦИОННОЙ ЭРОЗИЕЙ

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Аннотация. Целью данного исследования является изучение измерений на основе техники анализа изображения с использованием программы Image Pro Plus, которая используется для определения внешней деградации испытания кавитационной эрозией. В качестве образца использовался бетон из огнеупорного строительного материала. Потеря массы и внешняя деградация образцов контролировалась в течение трех часов воздействия кавитационной эрозии. Для анализа изображения определения внешней деградации использовались два подхода: ручной и автоматический. Результаты, полученные в итоге, были подобными. Испытание кавитационного повреждения обычно используется для металлических материалов. В связи с развитием, дизайн материалов перемещается в сторону замены металлических компонентов композитными и керамическими материалами. В работе исследуется возможность использования бетона из огнеупорного строительного материала в условиях кавитационной эрозии. Обычно для контроля деградации в течение кавитации используется метод, основанный на измерении массовой потери. Предлагается новый метод, основанный на анализе изображения для контроля уровня внешней деградации в течение испытания кавитационного сопротивления. Оба метода относятся к неразрушающим.

Ключевые слова: сопротивление кавитационной эрозии, анализ изображения; бетон огнеупорного строительного материала

РЕАЛІЗАЦІЯ АНАЛІЗУ ЗОБРАЖЕННЯ ПО ВИЗНАЧЕННЮ ЗОВНІШНЬОЇ ДЕГРАДАЦІЇ, ВИКЛИКАНОЇ КАВІТАЦІЙНОЮ ЕРОЗІЄЮ

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Анотація. Метою даного дослідження є вивчення вимірів на основі техніки аналізу зображення з використанням програми Image Pro Plus, яка використовується для визначення зовнішньої деградації випробування кавітаційною ерозією. У якості зразка використовувався бетон з вогнетривкого будівельного матеріалу. Втрата маси й зовнішня деградація зразків контролювалася протягом трьох годин впливу кавітаційної ерозії. Для аналізу зображення визначення зовнішньої деградації використовувалися два підходи: ручний і автоматичний. Результати, отримані в підсумку, були подібними. Випробування кавітаційного ушкодження звичайно використовується для металевих матеріалів. У зв'язку з розвитком, дизайн матеріалів переміщується убік заміни металевих компонентів композитними й керамічними матеріалами. У роботі досліджується можливість використання бетону з вогнетривкого будівельного матеріалу в умовах кавітаційної ерозії. Звичайно для контролю деградації протягом кавітації використовується метод, заснований на вимірі масової втрати. Пропонується новий метод, заснований на аналізі зображення для контролю рівня зовнішньої деградації протягом випробування кавітаційного опору. Обидва методи відносяться до не руйнуючих.

Ключові слова: опір кавітаційної ерозії, аналіз зображення; бетон вогнетривкого будівельного матеріалу

Introduction

Image analysis 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 refractory concrete related to 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.

Image analysis is powerful tool for many applications including surface degradation determination. The Image Pro Plus is one of the programs which allow performing such type of measurements. This special program for treatment and analysis of image recognizes and enables work in all known formats of images (TIFF, JPEG, BMP, TGA). It automatically performs image analysis-measures, counts and classifies all data obtained by analyzing objects. The advantage of Image Pro Plus is its compatibility with Excel that provides transfer of the obtained results to excel, so further analysis and calculation can be performed[1-4].

Degradation of ceramic materials can be caused by many factors such are: thermal shock, cavitation erosion, chemical influence (by acids, bases, salts, slags, liquid metalls etc.). In this paper degradation caused by cavitation erosion was monitored.

Cavitation, i.e. the appearance of vapor cavities inside an initially homogeneous liquid medium, occurs in very different situations. Hence, the study of the cavitation and cavitation erosion mechanisms of technical ceramics is of importance for improving their performances in real applications. Cavitation erosion usually involves an attack on the surface by gas or vapor bubbles. This attack is creating a sudden collapse due to a change in pressure near the surface. Low pressure (below the saturated vapor pressure) is generated hydrodynamically, due to various flow parameters, such as liquid viscosity, temperature, pressure and nature of flow. This deterioration is initiated by a sudden surge of bubbles harming the surface, and resulting in deformation, as well as pitting [5-7].

Experimental

Materials

Samples of refractory composite material, low cement castable, were used to measure damage caused by the cavitation.

Low cement high alumina refractory concrete (LCC) was prepared by using the commercially available raw materials (*Almatis, Germany*). Tabular alumina (T-60) with maximum particle size of 5 mm was used as an aggregate, while the fine fractions of tabular alumina, 5 wt. % of high alumina cement (CA-270) as hydraulic binder, reactive alumina as a component of ultra-fine filler (CL-370) and 1 wt. % dispersing alumina as an additive (ADS-3 and ADW-1) were used as components of the matrix. All fractions of matrix components lesser than 45 μm constitute 35 % of concrete mixture.

Optimum particle packing, and therefore maximum density and sufficient porosity, that allows concrete flowing and placing with slight water addition are achieved by adjustment of the particle size distribution to the theoretical curve based on the modified Andreassen's packing model, with the distribution coefficient (q) of 0.25, maximum grain size of 5 mm, continuous particle size distributions and dry mixture density of 3.75 g/cm^3.

The concrete was mixed with 4.67 wt. % of water (dry basis) dispersed with 0.05 % solution of citric acid. Namely, citric acid acts both as dispersing agent and additive to slow down concrete hardening (retarder). Since contents of water and cement were 4.67 wt. % and 5 wt. %, respectively, it corresponded to a water/cement ratio (w/c) of 0.934. This value satisfies requirement of w/c ≈ 1, typically used for the low cement concrete preparation.

First, dry components were mixed and afterwards deffloculant containing water was added; stirring continued until the appropriate consistency was achieved. The wet concrete mixture was cast in steel moulds by vibration in order to support removement of trapped air bubbles out of the concrete and to ensure easier flowing of wet concrete mixture. The cubes of 4 mm edge length were prepared for testing. After 24 hours, samples were demoulded. The prepared specimens were cured for 24 hours in the moisture saturated environment at room temperature and subsequently dried at 105°C for another 24 hours. Finally, they were sintered at temperature of 1600°C with the dwell time of three hours and cooled down to the room temperature inside the furnace.

Methods

Cavitation erosion testing

Modified Vibratory Cavitation Test Method was used for conducting the laboratory testing of the cavitation resistance. The set up consists of: a high frequency generator of 360 W, an electro-strictive transducer, a transformer for mechanical vibrations and a water bath containing the test specimen. Cavitation erosion testing was accomplished by utilizing the recommended standard values:

- Frequency of mechanical vibration: 20±0.2 kHz;
- Amplitude of mechanical vibrations at the top of the transformer: 50±2 μm;
- Gap between the test specimen and the transformer: 0.5 mm;
- Temperature of water in the bath: 25±1 °C;
- Ordinary water flow: from 5 to 10 ml/s.

The same conditions developed for metallic materials testing were applied to the refractory concrete with high content of alumina investigated in this research. These parameters were controlled throughout the testing process [8-10]. The test specimen was placed under the transformer with a gap of 0.5 mm. The cavitation damage level was determined by monitoring the mass loss and the surface degradation during the experiment. The mass loss of the test specimens was determined by analytical balance with an accuracy of ± 0.1 mg. Before being weighted, the test specimens were dried in dryer at 110 °C until the constant mass. The measurements were performed after each 30 minutes of subjecting test specimens to the cavitation. Total duration of the cavitation tests was 3 hours.

Image analysis

Image analysis, as non-destructive method for macro and micro structural characterization, was added to the standard laboratory procedure in order to monitor surface erosion caused by the cavitation and to determine level of surface damage. The sample surfaces were colored by blue in order to obtain better resolution and to make difference between damaged and undamaged surface more distinctive. Photographs of the sample surfaces were analyzed by Image Pro Plus, special software program that enables work in all known formats of images (TIFF, JPEG, BMP, TGA...). It automatically measures, counts and classifies all obtained data about analyzed objects. Program communicates directly with Excel, thus enabling statistical and graphical treatment of data. Results were presented as surface erosion ratio during the testing time.

Results and discussion

Figure 1 presents images of the samples sintered at 1600 °C before and during the cavitation erosion testing. Theinitialdegradationofthesamplescanbeobserved.

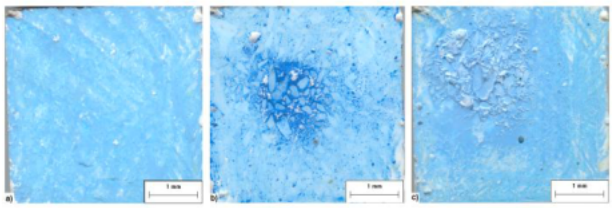

Fig. 1. Images of the samples sintered at 1600 °C during cavitation erosion testing:

a) before testing, b) after 60 min, and c) after 120 min

Mass loss

The total duration of the cavitation erosion testing was 150 minutes.

As the samples with high content of alumina were used, water absorption was expected and proved since it was about 4.5 % for all tested samples. After the first cycle of cavitation experiment, mass of the samples was increased, due to the water absorption. With the aim to quantify expected mass loss, samples were dried at 110 °C until the constant mass after every cycle of the cavitation experiment. In this way it was possible to follow behavior of the material and expected mass loss during the experiments is presented in Figure 2.

Masses of the testing samples were measured by analytical balance with an accuracy of ±0.1 mg. The measurements were performed after subjecting samples to cavitation erosion testing for each 30 minutes.

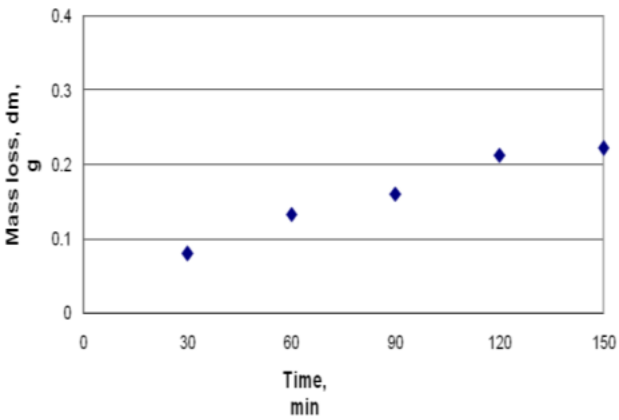

Fig. 2. Mass lossduring cavitation erosion testing

According to the results presented in Figure 2, small change in mass was observed for the samples sintered at 1600 °C. Also, linear trend of the curve that presents dependency of mass loss with duration of cavitation experiment was observed. Slope of the curve shows velocity of the cavitation erosion, while the intercept on the abscissa presents an indicator of the incubation period, which means time elapsed from the beginning of the testing to the beginning of the material destruction. Calculated values of cavitation erosion velocity is very small (0.013 mg/min), which indicate that the material is with good cavitation resistance. The incubation periods of 0.29 min is considered as short. Strong correlation between mass loss and time of the experiment can be observed.

Surface degradation

Optical microscopy technique was applied to analyze the effect of the erosion and to interpret the results of cavitation erosion testing. Image Pro Plus Program was used for determination of the surface deterioration level. For better differentiation between damaged and non-damaged surface areas, observed surfaces of the samples were covered with chalk. Damaged area was blue and non-damaged area was white. Determination of the damaged area was performed manually.

Erosion ring diameter and erosion ring area

The samples exposed to cavitation erosion testing (Figure 1) were also monitored in order to measure the diameters and area of the erosion ring region. These measurements were performed using the following steps:

Step 1: Taking the appropriate micrographs which include erosion ring area.

Step 2: Measurements of ring diameter.

At this point two types of measurements were taken: the diameter d_1 and the diameter d_2 of the cavitation ring erosion measured using Image Pro Plus Program. The effective diameter of each ring is calculated according to the equation (1):

$$d = \frac{d_1 + d_2}{2} \qquad (1)$$

Step 3: The effective area of the erosion ring calculated using measured values of diameter explained by Step 2, equation (2):

$$P_{av} = \pi d_1 d_2 / 4 \qquad (2)$$

Step 4: Measurement using Image Pro Plus program to determine the average erosion surface area of the ring (P_{mean}).

Measurements for average diameter of erosion ring were taken into after 60 and 120 minutes of cavitation testing.

Average erosion surface area was determined using two approaches. First approach included previous ring diameter measurements, and second was to determine ring area surface automatically, as ring area.

The obtained results using three different approaches-manual, with ring diameter and with ring surface, are given in Figure 3.

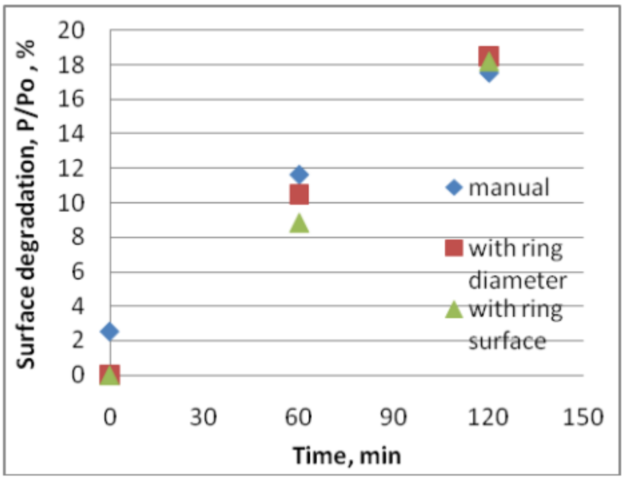

Fig. 3. Surface degradation during cavitation erosion testing using different measurements

Level of surface degradation, caused by cavitation erosion, was defined as portion of damaged (P) and undamaged surface area (P_0), and quantified by software program for image analysis.

Obtained results show good correlation of surface degradation level with time of exposure to the cavitation as well as linear trend. Surface degradation level was below 25 % after 150 minutes of exposure to the cavitation erosion testing. Changes in surface degradation level are in accordance with the presented mass loss. It is obvious that the samples sintered at 1600 °C exhibited small damage during the testing. Also, presented results suggested that these samples could be very good candidate for application where the cavitation resistance is required.

Conclusion

Implementation of image analysis for surface degradation determination during cavitation erosion testing was presented. Theobtainedresultsare as follows:

- Manual measurements can provide more accurate results, but the process is slower.

- Automatic approach is very fast. Using this approach ring diameter and ring surface can be measured.
  Differences between the results obtained by various approaches were grater at the beginning of the cavitation erosion testing, and automatic method did not include initial degradation of the sample. For longer experiment time, the differences between results obtained by various approaches were negligible.
- Future application of low cement castable sintered at 1600 °C can be expected in conditions where the cavitation resistance is needed.

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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 Res. – 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 Res,* 2003, 33, 1949.

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

Lemaire G., 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-Husovic T. Use of image analysis for durability testing of sulfur concrete and Portland cement concrete.*Materials and Design*, 2012, 34, 346.

5. TomlinsonW.J., MatthewsS.J. / TomlinsonW.J., MatthewsS.J. // Cavitation erosion of structural ceramics. Ceramics International. – 1994. – 20. – 201.

TomlinsonW.J., MatthewsS.J. / TomlinsonW.J., MatthewsS.J. // Cavitation erosion of structural ceramics. *Ceramics International,* 1994, 20, 201.

6. Litzow U., GahrK.-H.Z., Schneider J. / Litzow U., GahrK.-H.Z., Schneider J. // Cavitation erosion of advanced ceramics in water. International Journal of Materials Research ZeitschriftfuerMetallkunde. –2006. – 97. – 1372.

Litzow U., GahrK.-H.Z., Schneider J. Cavitation erosion of advanced ceramics in water.*International Journal of Materials Research ZeitschriftfuerMetallkunde,* 2006, 97, 1372.

7. Niebuhr D. / Niebuhr D. // Cavitation erosion behavior of ceramics in aqueous solutions. Wear. – 2007. – 263. – 295.

Niebuhr D. Cavitation erosion behavior of ceramics in aqueous solutions.*Wear,* 2007, 263, 295.

8. Martinovic S. Influence of sintering temperature on thermal stability of low cement high-alumina castable: PhD Thesis:2011 / Martinovic S.; Faculty of Technology and Metallurgy. – University of Belgrade.

Martinovic S. *Influence of sintering temperature on thermal stability of low cement high-alumina castable.PhD Thesis*.University of Belgrade, 2011.

9. Martinovic S.,Vlahovic M., DojcinovicVolkov-Husovic M. T.,Majstorovic J. / Martinovic S.,Vlahovic M., DojcinovicVolkov-Husovic M. T.,Majstorovic J. // Thermomechanical properties and cavitation resistance of a high-alumina low-cement castable.International Journal of Applied Ceramic Technology. – 2011. – 8. – 1115.

Martinovic S.,Vlahovic M., DojcinovicVolkov-Husovic M. T.,Majstorovic J.Thermomechanical properties and cavitation resistance of a high-alumina low-cement castable.*International Journal of Applied Ceramic Technology,* 2011, 8, 1115.

10. Martinovic S., Dojcinovic M., Majstorovic J., Devecerski A., Matovic B., Volkov Husovic T. Implementation of image analysis on thermal shock and cavitation resistance testing of refractory cocncrete. Journal of European Ceramic Society. – 2010. – 30. – 3303.

Martinovic S., Dojcinovic M.,Majstorovic J., Devecerski A., Matovic B., Volkov Husovic T. Implementation of image analysis on thermal shock and cavitation resistance testing of refractory cocncrete.*Journal of European Ceramic Society*, 2010, 30, 3303.