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ISPITIVANJE EROZIONE OTPORNOSTI KERAMIKE ZA PRIMENU U ELEKTROTEHNICI

EXAMINING EROSION RESISTANCE OF CERAMICS FOR ELECTRICAL ENGINEERING APPLICATIONS

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U ovom istraživanju, primenjene su dve nedestruktivne metode (NDT), termovizijska analiza i analiza slike, za praćenje površinskih promena- erozije uzoraka keramike na bazi mulita u uslovima kavitacije. Termovizijska analiza bila je fokusirana na određivanje profila temperaturske linije na kraju kavitacionog eksperimenta. Analiza slike je moćno sredstvo za kvatifikaciju nivoa degradacije izazvanog različitim uticajima i uslovima. Na osnovu rezultata analize slike, određen je nivo degradacije, odnosno erozije tokom testiranja, kao i broj nastalih oštećenja i njihove karakteristike (srednji prečnik i površina). Rezultati dobijeni pomoću obe metode diskutovani su sa ciljem ostvarivanja optimalne procedure kojom će se procenjivati degradacija, odnosno erozija izazvana kavitacijom.

***Ključne reči:** keramika; mulit; kavitaciona erozija; nedestruktivne metode; termovizijska analiza; analiza slike.*

In this research, two non-destructive testing (NDT) methods, thermal vision analysis and image analysis, were implemented for monitoring the surface changes- erosion of mullite based ceramic samples in conditions of cavitation exposure. Thermal imaging analysis was focused on determining temperature line profile at the end of the cavitation experiment. Image analysis is a powerful tool for quantification of degradation level caused by different impacts and conditions. Based on the results of image analysis, the degradation level during the testing was determined, as well as number of formed pits with their characteristics (average diameter and area). The results performed by both methods were discussed in order to obtain optimal procedure that should be followed for estimating degradation caused by cavitation erosion.

***Key words:** ceramics, mullite, cavitation erosion; degradation; non-destructive testing; thermal vision analysis; image analysis.*

1 Introduction

Ceramic materials for electrical applications must have high wear resistance, sparking resistance, strength, cracking resistance and chemical stability. They are applied for electric contacts, circuit-breakers, plug coatings, brushes, slide bearings etc. [1].

Mullite belongs to a group of a high-temperature ceramic material with good mechanical strength and excellent thermal shock resistance. Also, one of the advantages of mullite possible application is a lower cost alternative to dense alumina. Typical applications include, but are not limited to, thermal barrier coatings, thermocouple protection tubes, furnace muffle tubes, kiln rollers, target and sight tubes, rods and kiln furniture [2-4]. However, there are more extensive usages of mullite thanks to its exceptional characteristics. Since mullite has good mechanical and physical properties, great wear, corrosion, and thermal shock resistance, it can be assumed that it will be suitable for application in extreme conditions such as cavitation erosion. Cavitation erosion of engineering materials was investigated mainly for the metals, alloys, and composite materials such are

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stainless steels, grey cast irons with graphite phase, coated materials, Ni-P-SiC composite coatings. Since the development of advanced ceramic materials enables their new uses, especially towards replacing metallic components, the idea of this research was to investigate possible application of mullite ceramic material under exposure to the cavitation [5-9].

Cavitation erosion is a phenomenon which can be frequently observed in hydraulic machinery components like pumps, turbines, and propellers due to the interaction between the high velocity of fluid flow and the engineering material. Namely, the cavitation will occur if the static pressure at any location in the flow falls below the vapor pressure of the liquid at the given temperature. As a result of this situation, vapor bubbles are produced and transported by the flow and subsequently collapsed when the pressure recovers to a value above the vapor pressure. If the collapses of vapor bubbles interact with the adjacent solid surface, it can cause the formation of pits or the surface erosion and thus component suffers serious damage. The results of cavitation are fatigue wear. Detailed cavitation phenomena are well described in the literature [5-12].

Among the available techniques, infrared thermography (IRT) is the only diagnostic technology allowing the operator to instantly visualize and verify thermal performance of the investigated material. Active thermography represents a non-destructive technique based on observing temperature differences with an infrared camera after a thermal excitation and can be analyzed by various methods: lock-in thermography (LT), pulse thermography (PT), pulsed phase thermography (PPT) [13-16]. In the presented study, this approach was used for temperature line profile and histogram of temperature distribution at the end of the cavitation experiment.

Usually, level of cavitation damage is monitored by measuring the cumulative weight loss of the samples with the time of exposure to cavitation. However, using mass losses give information about eroded volume but cannot provide a clear and precise overview of surface changes, roughness, surface curvatures, pits formation and growth. Therefore, this study implements image analysis as the non-destructive testing in order to quantify the cavitation effect by determining the level of degradation as well as number and dimension of the pits [17,18].

2 Materials and Methods

Mullite powder was used for sample preparation [18]. Samples were pressed and sintered at 1200 °C for 3 hours.

Cavitation erosion testing was performed according to the procedure described by ASTM G32 standard. The ultrasonic vibratory cavitation set up with stationary specimen method was applied. The usual characteristics for the frequency and peak-to-peak displacement amplitude of the horn were used, as well as characteristics of liquid [10,11,16,17].

Mullite samples after 80 minutes of cavitation erosion testing were heated by two IR lamps of 200 W for 90 seconds and then cooled for 630 seconds. This regime was defined as in previous experiments [15]. IR thermograms were taken by camera FLIR E6 [20] and analyzed using software package FLIR Tools+ [21].

In order to apply Image analysis technique, sintered mullite samples were photographed before and during cavitation erosion testing. Image analysis was performed using Image Pro Plus software.

3 Results and Discussion

3.1 Thermal imaging analysis

Thermal changes of the sintered mullite samples exposed to cavitation erosion testing and afterwards IR- heating followed by 390 s of cooling are given at Figure 1 where a) presents thermographic image and b) temperature line profile.

a) b)

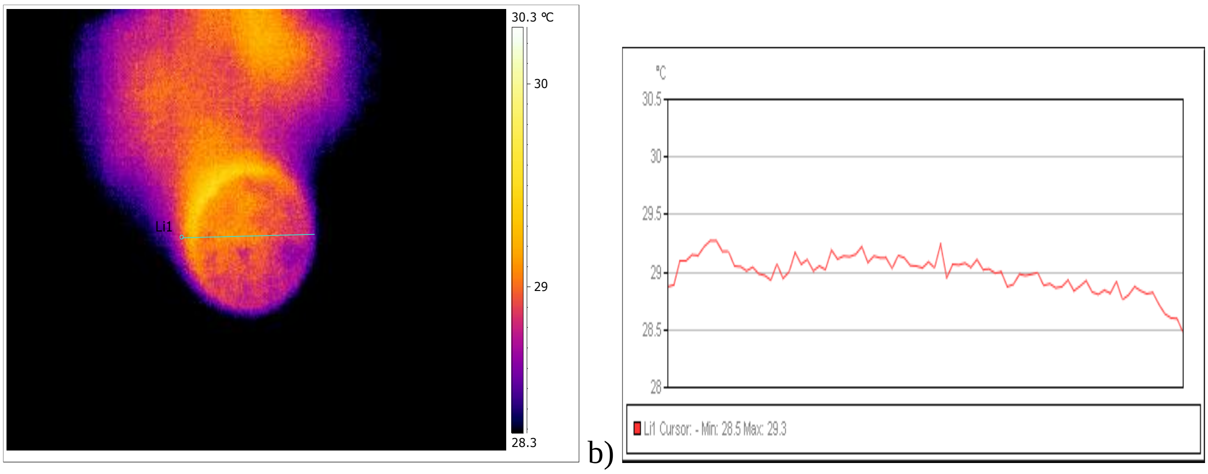

Figure 1. *Thermal imaging- mullite sample sintered at 1200 °C after cavitation, followed by IR-heating and 390 s of cooling: a) Thermographic image; b) Temperature line profile.*

After only 15 seconds of cooling, thermal changes, which provide discovering the influence zone, can be noticed at the mullite sample surfaces.

Temperature line profile is in this case cooling curve presenting changes of the maximum temperature with cooling time in the defect zone. The line, along which the temperature profile is determined, is marked on the thermal image at Figure 1 a). Based on the presented Figures 1 a) and b), temperature line profile of the sample signifies formation of degradation area.

These results are not exact since the number of pits, as well as their dimensions cannot be measured using temperature line profile but it can indicate damage with certainty. The most important advantage of this approach lies in the fact that the applied method is fast and can be useful for some examinations where using common digital camera is difficult. The mentioned weaknesses can be eliminated using the appropriate camera with higher resolution, which is related to the higher experimental cost.

According to the presented results, it can be concluded that the thermal vision approach, which implies considering temperature line profile and temperature distribution histogram, is very fast and useful for detecting the degradation on the samples. Therefore, this method should be combined with other techniques which provide deeper insight into material changes.

3.2 Iimage analysis

The obtained representative images for the mullite samples before and after 40 and 80 minutes of the cavitation erosion testing are given in Figure 2.

(a) (b) (c)

Figure 2. *Photographs of mullite samples during cavitation erosion testing:*
a) 0 min, b) 40 min, c) 80 min.

Visual observation of the mullite samples and viewing given images indicate that the surface of the referent sample, the sample before the cavitation erosion testing, is not ideal and has certain damages. The quantity and size of surface damages is increasing with the time of cavitation exposure. Furthermore, during cavitation erosion testing new pits are generating in the center of the sample, which corresponds to the diameter of the horn.

One of the applications of image analysis technique provided number and dimensions of formed pits. The results of number and average area of pits for mullite samples during cavitation erosion testing are given in Figure 3.

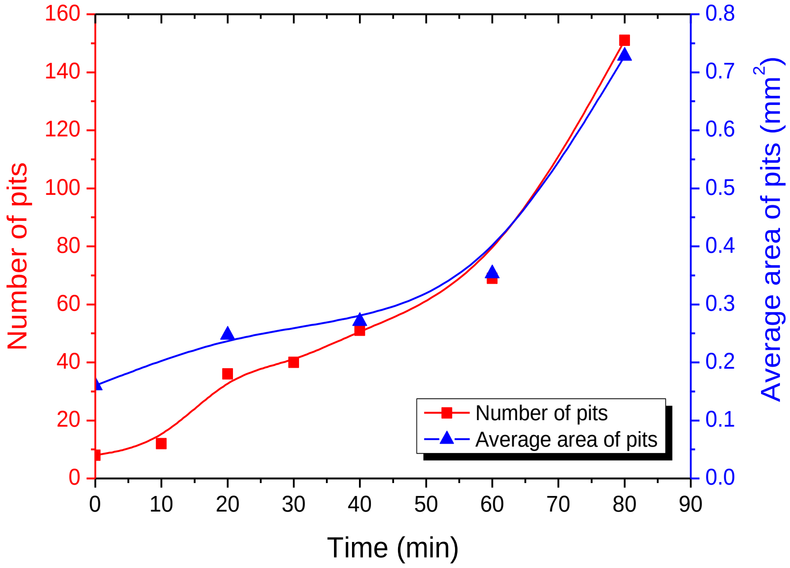

Figure 3. *Number and average area of pits during the cavitation erosion experiment of mullite samples.*

According to the results presented in Figure 3, it is clear that some defects are detected on the referent sample before the cavitation erosion testing. During the cavitation testing, a certain number of new pits was generating. Also, the formed pits are small and their dimensions, expressed as an average area, were increasing during the time of cavitation exposure. Monitoring of the dimensions confirmed the presence of bigger defects for the test period longer than 40 minutes. Bigger pits can be originally formed as a result of longer time of the cavitation erosion exposure, and also as a consequence of merging smaller pits that were previously formed. Furthermore, it can be observed that at the beginning of the cavitation experiment, till 40 minutes, the formation of new pits was slower, and after that time, it was rapidly increasing.

In addition, image analysis was used for line profile determination. Graphical representation of line profiles is given in Figure 4.

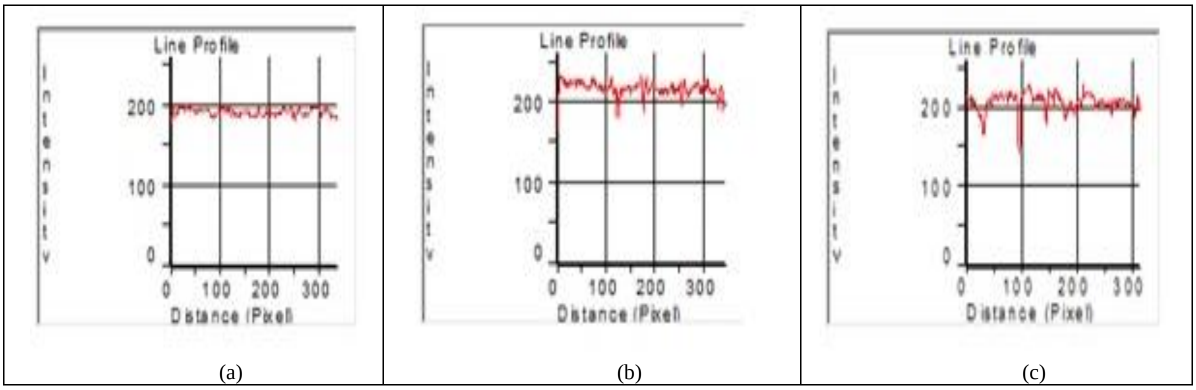

Figure 4. *Line profiles of mullite samples during cavitation erosion testing: a) 0 min, b) 40 min, c) 80 min.*

The shapes of the line profile curves are pointing out formation of new defects previously visually detected. Namely, obvious deviation from the straight line (which would indicate an ideal surface with no degradation or pits) is present here. Furthermore, width of the deviation corresponds to the diameter of the formed pit, and differences between intensity (y-dimension) to the depth of the pit.

According to the given discussion, the line profiles can be useful for the comparison of the surface analysis results for different testing periods. The real dimensions cannot be measured directly from the graph intensity- distance. Application of line profile analysis provides quantifications of changes along the observed line which is, in this case, chosen to present the diameter of the sample.

4 Conclusion

In this research the effect of cavitation exposure on sintered mullite samples was examined based on thermal imaging analysis application of image analysis.

Temperature line profile of the samples at the end of the testing period, based on thermal imaging analysis, as well as line profiles, based on image analysis are very useful for detecting degradation but they can only indicate formation of new defects without providing the exact results.

Unlike that, number and average area of the formed pits, provided by image analysis, represent the exact results which are mutually in accordance since they prove that degradation of the mullite samples occurred and progressed with the increasing cavitation experiment time.

Depending on the needs and available equipment, those methods, used separately or together, can be efficiently implemented for degradation monitoring caused by cavitation. Better and more reliable results can be provided using IR camera with higher resolution, which makes the experimental procedure much more expensive.

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