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RESEARCH OF DEGRADATION PROCESSES OF INSULATOR PORCELAIN C 130 TYPE

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This paper presents the results of acoustic emission (AE) measurements of samples under compressive stress. Additional research, concerning structure and parameters of the material, was performed using microscopic and ultrasonic methods. The object of the investigation were samples of porcelain material C 130 type of domestic long-rod insulator LP 75/31W. This kind of aluminous porcelain demonstrates high mechanical and electrical strength as well as resistance to aging degradation processes. It finds wide application in modern electrotechnical engineering. The aim of this study was to recognize stages of degradation processes of the porcelain structure. The present work constitutes a continuation of the study concerning the influence of technological faults, existing in porcelain material structure, on long-term mechanical strength. These results were presented at the OSA Conference in 2006. The analysis of mechanical-acoustic characteristics pointed out diversified strength and complicated mechanism of the material degradation. The effectiveness of the dispersive and fibrous reinforcement of aluminous porcelain C 130 type was ascertained. It was stated during the microscopic investigation that the structure of the material is different from that in the case of typical aluminosilicate ceramic materials. The main reason for this effect is due to densely dispersed corundum and mullite fine crystals in glassy matrix.

Keywords: porcelain material C 130 type, acoustic emission, compressive strength, structural degradation.

1. Introduction

The aluminous porcelain of C 130 type has at present a wide application in the production of very reliable electroinsulating elements of power systems. Line, station and apparatus insulators are produced using this kind of ceramic material. A reliability of power supply is determined primarily by the durability, closely connected with the long-term mechanical strength of insulators. So these properties are the most important in the case of these objects. An evaluation of operating time of the porcelain material is based mainly on the analysis of a formation and a growth of aging degradation effects in the structure. C 130 type material is widely applied in the domestic power industry only from 1990s, and there is not enough experience obtained during a longer period of operation.

In the papers [1, 2] the authors presented experimental results of study obtained on small, specially prepared samples of C 130 porcelain, containing structural defects of different intensity. That research was intended to determine the influence of structural faults on acoustic and mechanical properties of the samples. Presented study was carried out on specimens cut off from the domestic high voltage line insulator LP 75/31W from 2006. Samples under study did not contain any intentionally introduced defects in the structure. During microscopic and ultrasonic investigations it was stated that the material of insulator was characterized by a high homogeneity in macro and semi-macro scales. The application of a mechanical-acoustic method to evaluate parameters of power line insulator material has an innovative character and no similar approach was found in the literature.

The ultrasonic control of a homogeneity of material revealed the anisotropy typical for ceramic objects formed using the screw extrusion method in the vacuum deairing pug mills [3]. Velocities of the longitudinal c_L and the transverse c_T waves, measured along the lengthwise axis of insulator, were equal to 6980 m/s and 4130 m/s, respectively. The calculated value of Young's modulus E was equal to 111 GPa (density of the material $\rho = 2.64$ g/cm^3). In the crosswise direction of insulator, c_L had value 6620 m/s and c_T – 4100 m/s, respectively. The Young's elasticity modulus, determined from these data, was equal to 106 GPa. The uncertainty of measurements for c_L and c_T was $\pm$20 m/s, whereas for the calculated values of Young's modulus was about $\pm$1.0 GPa.

2. Acoustic-mechanical and microscopic examinations

The specimens cut off from the central part of the insulator rod were subjected to mechanical-acoustic measurements using the technique of acoustic emission (AE) on a special two-channel measuring system. Pieces of small dimensions ($7 \times 7 \times 10$ mm) were put to slowly increasing compressive stress with the velocity $v = 0.02$ mm/min, with a simultaneous registration of the force in one channel, and AE descriptors in the other one. The arrangement of the measurement system and the method of investigations were described in detail in the papers [2, 4]. The investigations enabled the recording and description of correlation between the increasing external load and processes of structure degradation, which are reflected in the AE activity. The important fact is that there exists a serious analogy between the effects of many years long exploitation under a working load and a material degradation during compressive stresses in a relatively short lasting laboratory test [4]. However, it is necessary to apply a quasi-static, very slow increase of stress and a precise registration of the AE descriptors. The equipment and software used in measurements of AE descriptors were modernized and in effect were considerably more sensitive than in the case of the previous research.

The compressive strength of nine samples loaded until a complete destruction showed relatively high dispersion. The mean value of strength was equal to 747 MPa, the lowest – 522 MPa and the highest was 933 MPa. The relative dispersion for these results corresponded to value 55.0%. Besides damaged samples, group of specimens was selected for the microscopic investigation. A compression process of these samples was stopped at different levels of stresses: 50, 100, 150, 200, 400, 550, 728, 741 and 839 MPa. The applied procedure enabled a detailed study of progress of degradation process in the porcelain material, subjected to increasing load. The obtained mechanical-acoustic characteristics of the particular samples showed considerable differentiation. Figure 1 shows the course of acoustic activity for the weakest sample – damaged at 522 MPa and the specimen, loading of which was stopped at 741 MPa.

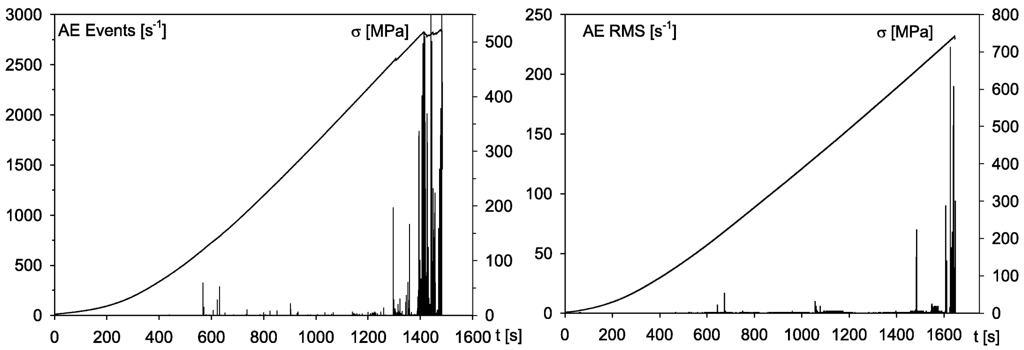

Fig. 1. Course of the rate of AE events versus compressive stress for the weakest sample damaged at 522 MPa – on the left, course of RMS AE rate versus stress for the specimen, loading of which was stopped at 741 MPa – on the right.

Comparison results of mechanical-acoustic and microscopic study revealed generally a presence of three stages of the structure degradation. The first stage of acoustic activity, defined as a preliminary one, takes place approximately from 50 to 300 MPa of compressive stress. This period corresponds to a destruction of particles of cullet, quartz grains and beginnings of mullite phase damage. The last effect takes place only in the central part of samples, where the highest concentration of stresses is present. In the stress range from 30 to 150 MPa, without an acoustic activity, particles of cullet undergo a fracture and a separation from the porcelain matrix. Majority of quartz grains go through a similar process in the approximate stress range 50–200 MPa, though in the case of few bigger quartz grains this process requires much higher stress. A degradation of quartz phase is followed by a weak AE activity. Relatively stronger AE effects follow only the cracks development in quartz grains of greater size (over 20 μm).

Next stage of structure degradation – subcritical one is closely connected with the homogeneity of the sample structure in micro and semi-macro scales. The subcritical stage begins at over 450 MPa stress for less homogenous samples and at above 600 MPa for stronger and homogenous ones. This phase of destruction is varied for particular samples and shows a moderate intensity of AE activity – Fig. 1. During the subcritical period cracks are created and propagated in mullite precipitates, which are numerously present in the material C 130 type. Moreover at the stresses exceeding about 400 MPa begins a degradation of centers of agglomerated corundum grains. Particular corundum grains undergo a separation from the structure of agglomerate – Fig. 2. Agglomerates of collected grains of corundum are not numerous in the material structure and the subcritical stage of degradation is connected especially with the internal fracture of mullite precipitates – Fig. 2. This process is the most intensive in the central part of the samples.

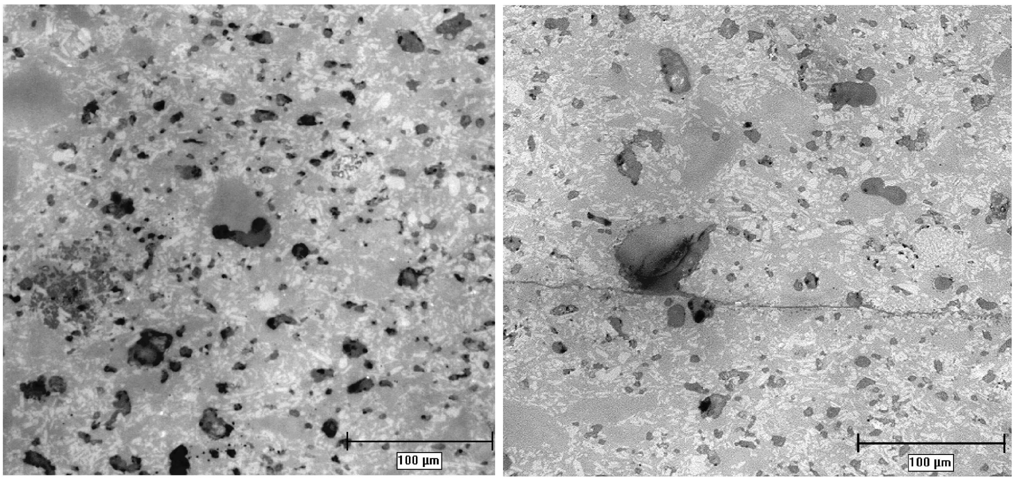

Fig. 2. Structure of sample loaded up to subcritical level – on the left. Crushed out parts of grey mullite precipitates, quartz grains, culet fragments and damaged agglomerate of corundum grains are visible. Structure on the right contains critical crack and damaged great precipitate of mullite.

The last interval, showing the highest level of acoustic activity, begins at a load by dozens of megapascals smaller than the destructive stress. It lasts up to the damage of the sample. This interval, defined as the critical one, is characterized by generally good repeatability of the level of AE signals. The extent of its occurrence, however, depends on the strength of the particular sample. Wide range of critical stresses, observed for some samples – Fig. 1, results from a fracture and a splitting off greater pieces of sample. During the critical stage of structure degradation further precipitates of mullite undergo the internal and peripheral fracture. The most important effect, followed by strong AE signals, is however a generation and a growth of elongated, not branched cracks – Fig. 2. The strong dispersive and fibrous reinforcement of the porcelain structure hampers their increase. At a sufficiently high stress the rapid growth of critical cracks in the glassy-mullite matrix takes place (Fig. 2). One of the samples, loaded up to the critical stress – 728 MPa showed also the characteristic branched cascade of cracks.

In Fig. 3 is presented a dependence of number of AE events versus an energy for three samples - damaged at compressive stress 522, 614 and 714 MPa. Weaker samples were characterized by a greater number of AE signals of low energy, which corresponded to the damage of quartz grains and the beginning of degradation of mullite phase. Stronger sample – P3, with smaller precipitates of mullite, not numerous centers of aggregated corundum grains and more homogeneously distributed crystallite phases in the matrix, showed a greater number of higher energy signals. The number of recorded AE signals is inversely proportional to the compressive strength: for P3 sample number of events was equal to 32400, for P1 – 53800 and for the weakest P2 equaled 86400.

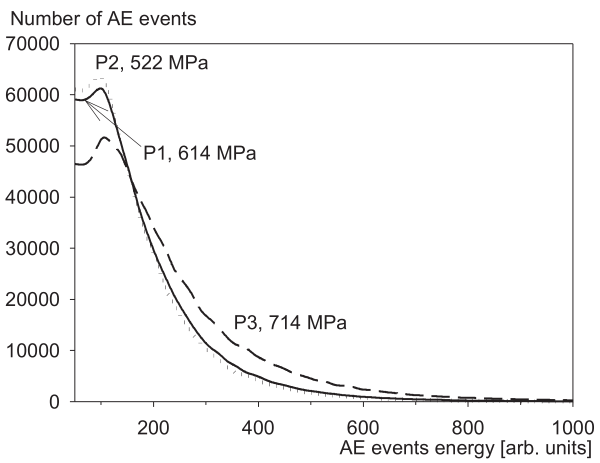

Fig. 3. Plots of a total number of AE events as a function of AE event energy for three porcelain samples of differentiated compressive strength (522, 614 and 714 MPa).

3. Summarizing remarks

Investigated samples were cut off from a carrying rod of big insulator of high voltage lines. It resulted in a dispersion of compressive strength and mechanical-acoustic characteristics of the specimens. Parameters of the porcelain are the consequence of its homogeneity, determined by a number, a size and a spatial distribution of mullite precipitates, quartz grains, centers of aggregated corundum grains and particles of cullet. Nondestructive ultrasonic control revealed the acceptable homogeneity of the insulator material and simultaneously the occurrence of anisotropy typical for ceramic products formed using screw extrusion method in a vacuum deairing pug mills.

The performed research confirmed the effectiveness of dispersive and fibrous reinforcement of the structure of aluminous porcelain C 130 type. The weakest mechanically element of the structure are particles of cullet, which undergo a destruction without acoustic effects. Next in turn, the process of peripheral and internal cracking of quartz grains takes place in stressed structure. The subcritical stage of destruction is connected with long lasting effects of mullite phase damage and a separation of particular corundum grains from a structure of agglomerates. These effects appear especially in the central part of the samples, where the highest concentration of mechanical stress occures. The last, critical stage of structure degradation is followed by a strong AE activity. It is mainly connected with the generation and growth of elongated, not branched cracks in the reinforced glassy-mullite matrix of porcelain material. In the opinion of authors the degradation processes, being the result of long-term exploitation of insulator on a power line, have a similar sequence and character as in the case of applied short lasting measurement [4]. As it was stated, total number of registered AE signals is inversely proportional to the mechanical strength of the sample, determined by the homogeneity of its structure.

Acknowledgment

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