UDK 621.3:(53+54+621+66), ISSN0352-9045

THE INFLUENCE OF ENVIRONMENTAL CONDITIONS ON THE ELECTRICAL INSULATION PROPERTIES OF POLYAMID PLASTIC PARTS

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Keywords: plastics, polyamid resins, environment conditions, ageing, climatic conditions, hygroscopy, ageing phenomena, surface phenomena, insulation resistance, phosphoric acid, insulating characteristics, electrical properties, air humidity, chemical reactions, plastic additives, failure analysis

Abstract: Insulating characteristics of plastic parts in electrical devices can be essentialy reduced due to ageing under the influence of combined climatic conditions (humidity, solar irradiation, dust, air polluting agents, etc.), therefore devices in normal operation often exibit failures or malfunctions. At specific ambient conditions the ageing phenomena could be very active for specific type of plastic material, as it is illustrated in the example of polyamid ageing and reducing its insulating resistance.

Vplivi lokalnih klimatskih razmer na električne izolacijske lastnosti poliamidnih plastičnih delov

Ključne besede: smole umetne, smole poliamidne, pogoji okolja, higroskopija, posledice staranja, pojavi površinski, upornost izolacijska, kislina fosforna, lastnosti izolirne, lastnosti električne, vlaga zraka, reakcije kemične, dodatki smolam umetnim, analize odpovedi

Povzetek: Električne izolacijske lastnosti sestavnih delov iz umetnih smol v električnih napravah in elementih pod vplivom lokalnih klimatskih razmer (vlaga, UV sevanje, prah, onesnaženost zraka in podobno) utrpijo posledice staranja, zato se pri njihovem delovanju lahko pojavljajo napake. Za določen tip umetnih smol je učinek nekaterih klimatskih dejavnikov še posebej izrazit, kot je prikazano v primeru staranja poliamidnih plastičnih delov in sprememb v njihovi izolacijski upornosti.

1. Introduction

Polyamid resins reinforced by glas fibres have almost entirely replaced phenolic-based resins in wide field of application in the production of electrical devices. Thus electric insulating parts carrying electric conductive parts, housings and covers of electric devices, formerly made of well-known bakelite are nowadays made mostly of polyamide resin, because of better resistivity to absorption of moist and consequently also better resistivity to creepage currents. For electric insulating parts in electric devices the 6,6-polyamides are applied, which exibit relative high hygroscopy, and 6,10-polyamides with lower hygroscopy /1/.

The problem of water absorption in polyamid-based plastics can be indicated after long-time exposure even in environments with moderate humidity, demonstrated in the reduction of insulating resistance, which can lead to failures in operation of electric devices. Special study was carried-out on telecommunication relays in telephone-exchange offices, having relay base with contact carrying parts made of 6,6-polyamid reinforced by glass fibres. Relays often operated in ambients with intentionaly higher air humidity, sometimes greater than 60% relative humidity, but below the dew point.

2. Surface phenomena on polyamid parts after long time exposure

Ageing of polyamid parts of telecommunication relays under the influence of humid air consequently caused failures in transmission of telecommunication signals due to high isolation currents flowing between separated contacts. Isolation currents are found to have the same order of magnitude as currents conducted through closed contact circuits of relays. Electric currents of such magnitude are able to flow between isolated electric conductive parts separated by plastic surface on the distance of some mm under the electric potential difference of a few 10 V.

In order to mantain low contact resistance of telecommunication relays the ambient air is often humidified by special air conditionning. At an inspection of failures on telephone exchange station, installed in the ambient with special air humidifier, the phenomena of reduced electric insulation characteristics caused general fault of the transmission. Plastic parts of relay connecting system were made of 6,6-polyamid. Their surfaces, when examined with bare eyes and fingers, can be considered as covered by ordinary house dust and sligtly wetted or oiled. Therefore the first supposition at the inspection was, that dust and condensed moist in consequence reduced the insulation resistance of plastic surface. But contrary to this idea on the other parts in the vicinity of the examined plastic parts there were no dusty- or oily-like surfaces. Plastic parts could be also covered by a layer of separation agent applied on casting tool when manufacturing plastic parts. To prove this supposition the inspection on plastic parts of the same kind was made immediatelly after casting. No indication of oiled surface can be observed on these parts. Dust deposit on parts remained in the workshop ambient for a few days or a week exibits different nature as observed at the inspection in telephone exchange station.

It was necessary to proceed further examination of surface phenomena with laboratory equipment and to carry out some simulations in order to reconstruct the processes leading to bad insulating characteristics.

3. Laboratory examinations of exposed polyamid parts

After performing *in situ* inspections of failed devices in applications, sample pieces were selected for further laboratory test purposes. Plastic parts with inserted parallel conductors, convenient due to simple geometry, were selected for measurement of insulation resistance under various ambient conditions, while other pieces with more complicated geometry were used for microscopy and chemical microanalysis.

Samples from failed telecommunication relay boards were tested in laboratory, performing at first measurements of insulation resistance between parallel electric conductor. Prior to testing selected samples were exposed for a few days to normal ambient conditions in testing laboratory (cca. 25 deg.C, 40-45% of relative air humidity). After conditionning to normal ambient conditions the insulation resistance was measured by Megaohmmeter HP 4329A (Hewlett-Packard) at measuring voltage 500 V. Measured values were under the lowest range of instrument (less than 1 MΩ), therefore exact evaluation was not possible. The surface conditions were recovered very slow in normal climatic conditions, so that even after exposition of a few weeks insulation resistance increased onto the range of 100 MΩ. Further tests were performed at more defined climatic conditions.

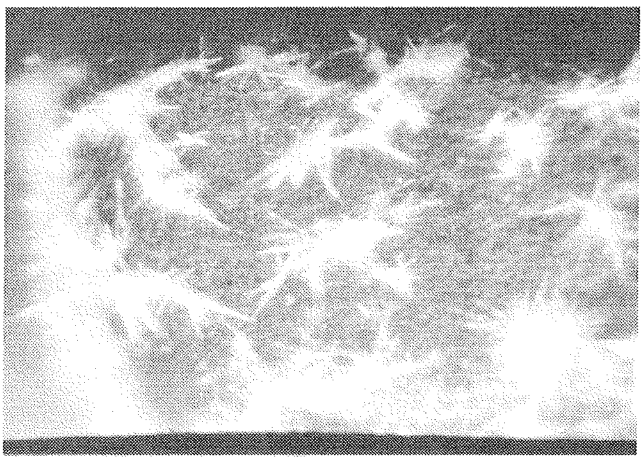

Fig. 1: White crystal flakes formed on the polyamid plastic connection holder (optical stereo-microscope, magn. approx. 100)

Observations of surface on samples, taken from failed device, were performed at first by optical stereomicroscope at magnification 100. Surface conditions observed on polyamid parts differ essentially from conditions on the adjacent metalic and PCB surface. Almost the whole polyamid surface was covered by small droplets of diameter range 0.1 mm and white "snow-flakes", identified by crystal clusters formed from water solution of chemical additive to polyamid material. Clusters of long thin needle cristal forms were growing from distinct centers distributed uniformly over the entire surface (Fig.1), or spred over the surface in the form of stripes, where crystal needles were oriented uniformly in the same direction (Fig. 2).

Fig. 2: Crystal clusters on polyamid plastic surface forming strip-like structure (SEM, magn. 300)

In order to define morphology of observed crystals, the scaning electron microscopy (SEM) was performed. The chemical composition of particular cristal units were defined by energy dispersion X-ray microanalysis (EDAX).

3.1. SE microscopy and EDAX microanalysis of crystals

Larger magnification of crystal formations indicates needle-shaped crystals of various lenght. Short, quickly developed crystals, were in the form of double pyramide with sharp peak (Fig. 3), longer crystals had the peak of pyramide additionaly cutted in the prismatic form (Fig.4). Long crystal "hairs" growed presummably more than a year in the forme of long bars with rectangular cross-section (Fig.5). Crystal morfology can be more distinctive on the pictures of monocrystals (see Fig.6, Fig.7, Fig.8).

EDAX microanalysis is applied for the detection of semiquantitative chemical composition of small particles or surface area. This method of microanalysis indicates chemical elements present in the observed area. The results of analysis are often represented as X-ray spectral plot of detected chemical elements. The microanalysis performed on monocrystals observed on polyamid samples, detects only the presence of phosphorus (P), which is recognised from spectral plot, containing only one large and distinct peak, coresponding to chemical element P. It cannot be expected to find elementary phosphorus on the surface of samples under examination. The expected additional elements are hydrogen H and oxygen O, which cannot be detected by EDAX due to principal limitations of analyse methode /2/. Additional indication, which can lead to the conclusion about chemical composition of observed crystal formations is their low melting temperature: during microanalysis by electron beam the termal effect of electron impact on crystal caused melting of analysed spot. Considering all results and indications it can be concluded, that white crystal flakes on the surface of polyamid parts are presummably crystalised ortophosphoric acid, which exibits low melting temperature (43 deg.C) /3/. Due to their high hygroscopy the water dissolution of acid is formed at greater air humidity, which is electrically conductive, therefore electrical insulation resistance can be extremely low in this case.

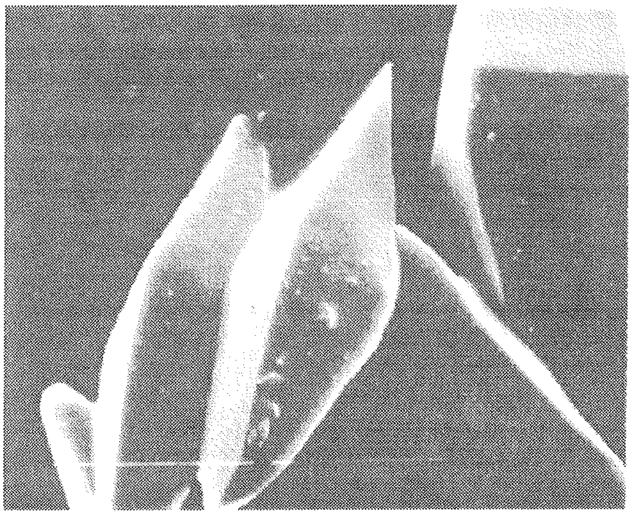

Fig. 3: Individual crystals in the earlier stage of formation (SEM, magn. 2500)

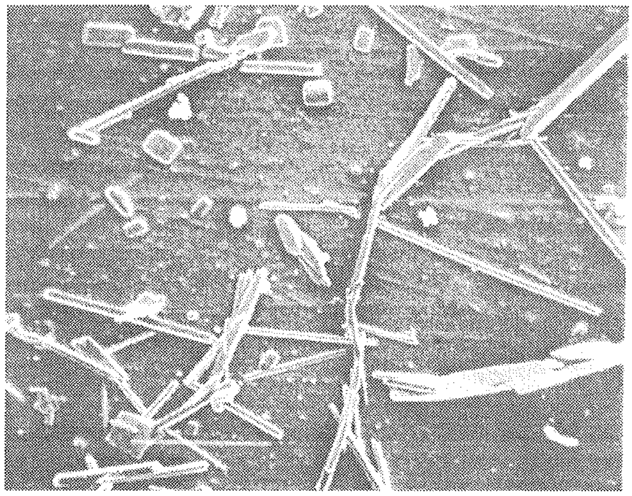

Fig.5: Formation of crystal clusters with long bar-like units (SEM, magn. 85)

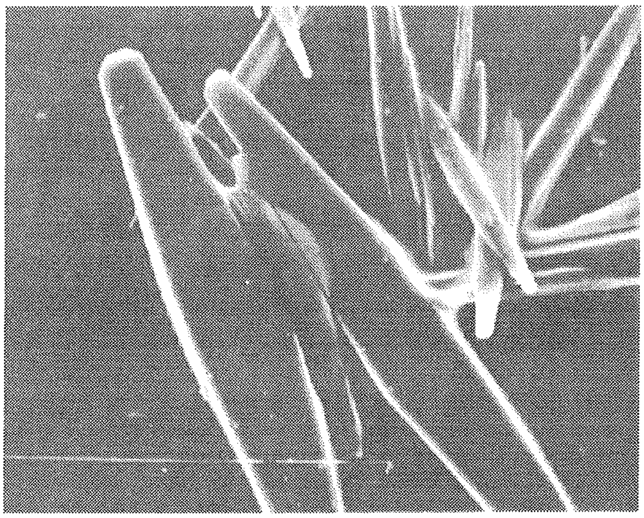

Fig.4: Morphology of entirely developed crystal (SEM, magn. 1000)

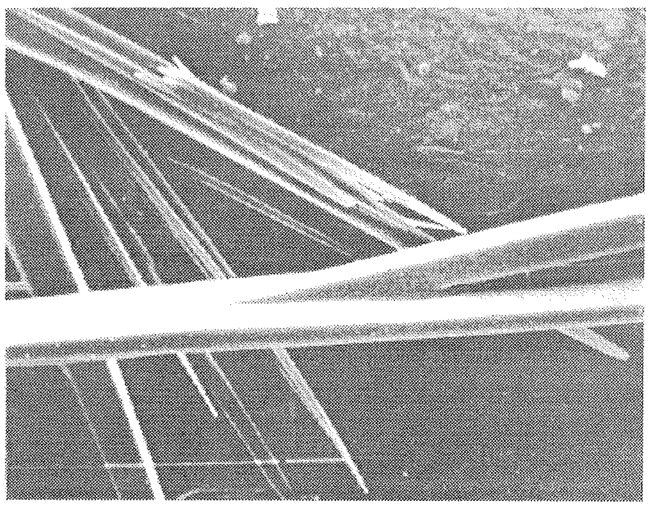

Fig.6: Structure of extremely long individual crystals (SEM, magn. 630)

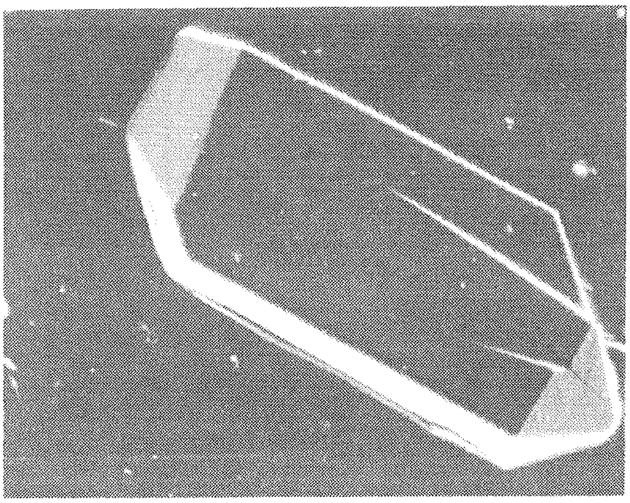

Fig.7: Characteristical form of individual crystal (SEM, magn. 850)

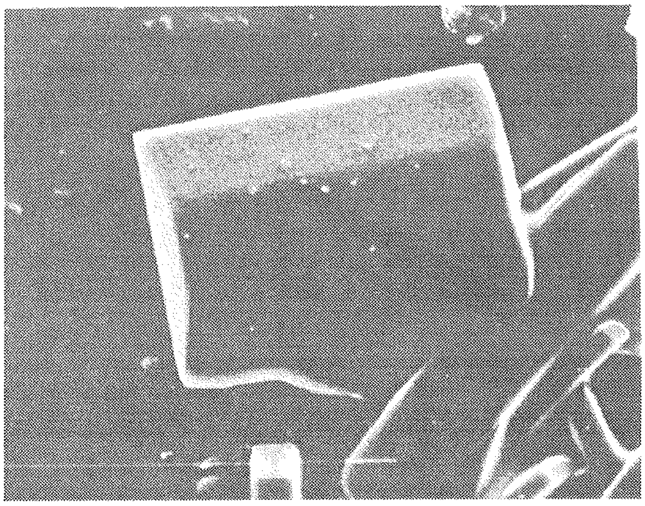

Fig.8: Characteristical form of individual crystal (SEM, magn. 1600)

3.2. Laboratory simulation of phenomena observed on samples

In order to indicate the processes leading to bad insulating characteristics of polyamid surface under the influence of humid air, in the first experiment it was confirmed, that the origin of phosphoric acid is polyamid material itself, in the second experiment the time dependent variation of insulating resistance was observed under the influence of humid air.

For the purpose of first experiment a piece of polyamid reinforced by glass fibres was cut into small particles, which were cooked in the water in order to extract water-soluble additives. After drying at slightly elevated temperature particles of dry residue were examined by SE microscopy. The formation of crystals of the similar form can be recognized on dried particles of polyamid, as shown on Fig.9. Formation of large fully developed crystals take more time for crystal growth, therefore drying time was too short for formation of larger crystals.

Comparative experiments and measurement were performed in order to find the difference between characteristics of new and aged polyamid parts. Representatives of both types of samples were exposed to the same preconditioning process and the same climatic conditions. Preconditionning took place in computer-controlled climatic chamber at 35 deg.C and 16% relative air humidity in overnight period. After precondition period the value of 70% relative humidity has been set by computer and after 30 min rel. humidity in the chamber in fact reached the preset value. During climatic test the insulation resistance was measured by Megaohmmeter and plotted by time, starting at the moment, when particular air humidity has been set by control computer.

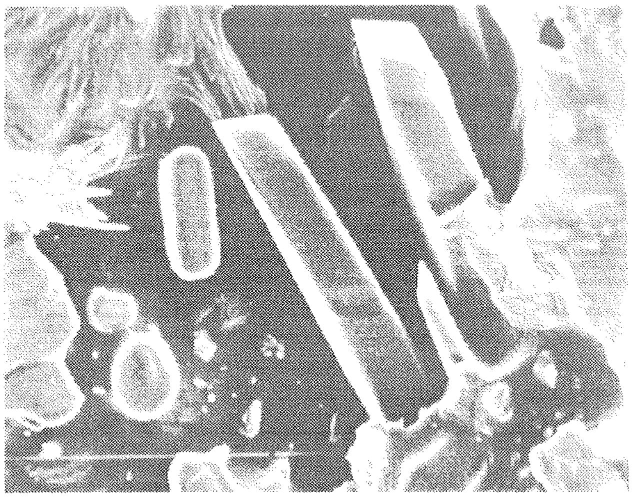

Fig.9: Formation of crystaline structure after cooking and drying of polyamid particles (SEM, magn. 800)

The variation of insulation resistance versus time of exposition in climatic chamber shows certain characteristic difference between new unused sample and aged sample, which exibited low insulation resistance during application. On the new sample insulation resistance began to decrease at approx. 60% rel. humidity. At 70% rel. humidity measured resistance tends to reach for a factor of 10 lower value than initial (see graphical presentation of measurement on Fig.10). For comparation purpose measured values on new sample at 80% rel.humidity are added on Fig.10. Measurements performed on naturally aged samples from failed device in application show different characteristics: insulation resistance began to decrease by increasing rel. humidity at 30%, at 70% rel. hum. decrease into the minimal value, which is for factor

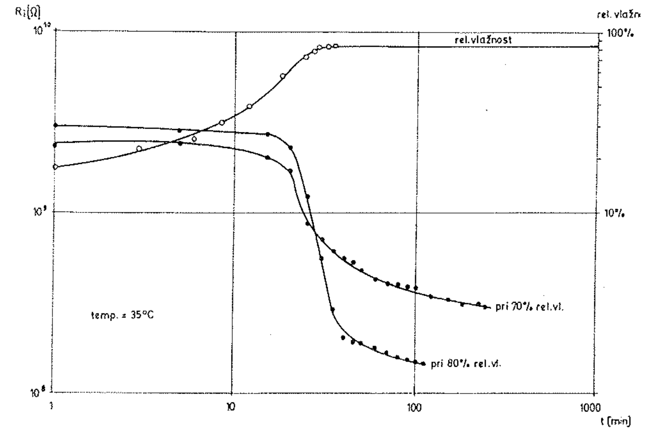

Fig.10: *Decreasing of insulation resistance on a new and unused polyamid part during exposition in climatic chamber*

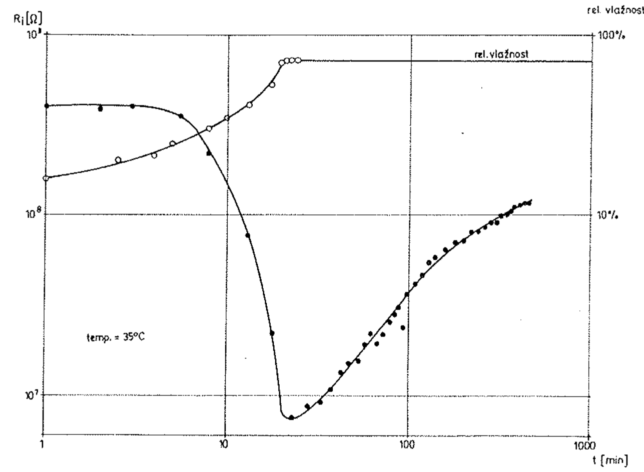

Fig.11: *Results of the same test as shown in Fig.10 obtained on sample, aged in application*

100 lower than initial resistivity, but after reaching minimum it tends to increase, following certain recovery phenomena (graphically presented on Fig.11).

At the discussion of measured results it should be considered, that at variation of control parameter for climatic chamber certain transition period is required in the chamber, in which climatic condition are not uniform and stable, therefore on Fig.11 a minimum is obtained and certain recovery phenomena is indicated, presummably due to nondefined conditions in the climatic chamber during transition period. The same phenomena can appear in application, where operation of air-condition devices are intermitent due to control response in order to maintain appropriate humidity of ambient air.

4. Conclusions

Humid air influences the ageing process of plastics, particulary on surfaces of hygroscope plastics, such as polyamid resins. Water wapor is absorbed on the surface of plastics and penetrates into bulk material by various modes of diffusion. During penetration procedure water presummably reacts chemically with additives in plastics. Products of reaction are collected on the surface. In the case of polyamid used for telecommunication relays, having commercial name Ultramid, the product of reaction was phosphoric acid, vhich was responsible for failed electrical insulation. Due to its electrolitic characteristics and hygroscopy the sensitivity of insulation characteristics of Ultramid surface on ambient air humidity is considerably high. Harmfull influence of air-conditionning on insulation was indicated especially in the cases, where air-condition system blows humid air intermitently directly onto telecommunication eqipment. Similar effect has been simulated at testing in laboratory climatic chamber as described in the preceeding chapter by graph on Fig.11.

In most types of plastics additives are used to improve resistance to flammability, creapage currents and other required characteristics. One of theese aditives in commercial polyamid (Ultramid A3XG5, A3XG7, ...) is presummably certain phosphorus-based material. Presummably similar problems in applications of polyamid materials as described in this paper are known by other users and company BASF, the producer of Ultramid plastics. The improved types of Ultramid, which followed types A3XGn are labelled by A3X2Gn, having increased resistivity to creapage currents and effects of ageing.

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Prispelo (Arrived): 30.3.1995 **Sprejeto (Accepted):11.7.1995**