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Electrostatic Properties and Characterization of Specific Polymeric Materials for Building Purposes

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This work analyzes the opportunities of wider characterization of the materials used in home or industrial constructions which may get electric charge. A non-contact way (method) for electrostatic properties measurement affecting these materials by ions with positive or negative charge is described. The method allows to measure the surface potential dependence on time and the surface potential dependence on deposited charge. From the measured dependencies the following set of parameters was calculated: the surface potential limiting value, the surface potential discharge rate, the maximum deposited charge, the layer capacitance, the energy of the accumulated charge, the volume resistance, the electric field strength and others. To verify the possibility of the proposed method for characterization of specific building materials a series of experiments were performed in order to establish the above-mentioned parameters of polymer, polyester, resin based varnishes, enamels, coatings and paints, polyethylene, polyurethane films, tapes and foams. The performed experiments demonstrate the possibilities of method application for comparison of different materials used for the same tasks or the same materials produced by different technological processes.

Keywords: static electricity, electrostatic discharge, surface potential measurement, charge measurement.

1. INTRODUCTION

Modern environment where human beings live and work is surrounded by the materials that may accumulate static electricity that affect a human body in one or another way. It is well known that static electricity accumulation processes in different materials differ. Accumulated static electricity can have not only a positive effect, as well as a negative one. For example, sudden external electric discharge via integrated circuits may damage electronic equipment or apparatus; electrostatic spark or discharge created by a strong electric field in the environment, which contains gases of easily inflammable materials may result in fire or explosion. Frequently electrostatic discharge through a human body may cause unpleasant senses and may become a reason of accidents dangerous for human health [1 – 3]. The advice about the materials often is limited by the statement that some of them accumulate static electric charges while others do not.

There are some ways when objects can be given a net charge. Static electricity can be generated on dielectric (insulating) materials (layers) surface by the following ways: charging by electrostatic induction, charging by friction, charging by ionizing radiation, charging affecting the material by electric corona discharge [4 – 6].

The accumulated surface charge determines a related surface electrostatic potential, which at the end of charging holds it for a short or long time, or slowly (or rapidly) falls down. Commonly, in order to eliminate a negative influence of static electricity an additional technical means based on reducing or eliminating electrostatic-generating processes or by providing ground paths to reduce charge accumulation are employed [7]. The means for electrostatic discharge become an integral part of a product, manufactory, building and others. More important is to choose or create new materials for building purposes to be immune from charge accumulating effect.

Generally, a designer and a user have to be acquainted with the properties and characteristics of employed materials and to have a way to legitimately evaluate and compare competing brands and types of products. A manufacturer has to notify a designer and a user about the products on the base of standards.

There are two groups of international standards that provide requirements for dielectric materials [8 – 11]. The first group covers requirements for specific products or procedures for electrostatic protection, discharge control, grounding and shielding. The second group covers the standardized test methods used to evaluate products and materials. The documents propose methods for surface and volume resistance or resistivity measurement of insulating and static dissipative planar materials. All of them are based on direct contact measurement or like a capacitor measurements. In this case, the tested material on both sides is covered by conducting electrodes and compressed with them.

The objective of the present article is to analyze the opportunities of a wider characterization of the materials used in home or industrial constructions, which may get electric charge in parameters that can be measured in a non-contact way (method) affecting these materials by ions with positive or negative charges.

2. EXPERIMENTAL

2.1. Measurement technique

We apply an original contactless technique [12] for electrical parameters measurement, which can be used for electrostatic properties measurement and characterization of specific insulating planar materials used for building or similar purposes.

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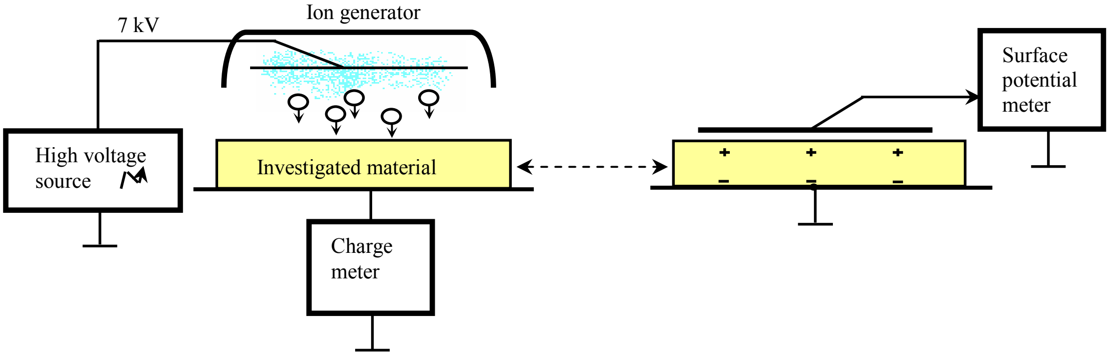


Fig. 1. Deposited charge and the surface potential measuring scheme

In the proposed technique the insulating material is exposed to a charge carrier flow and the transient processes of charge deposition on the surface and the surface potential of the tested insulating material are measured. Electrostatic charging using ionization is one of the most efficient ways of accomplishing many physical tasks for studying plastic films and sheets [13, 14].

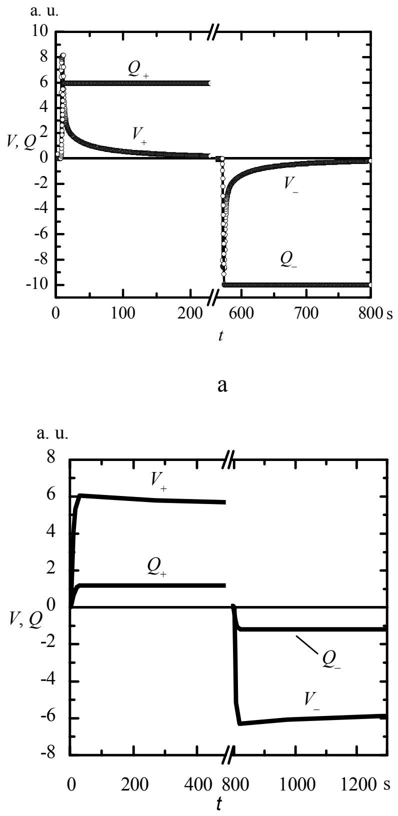
The measurement technique used to measure the electrical parameters and characteristics of insulating planar materials is based on a periodical deposition of a dose amount of charge and on a measurement of a moment values of deposited charge and the surface potential. The measurement technique consists of a source of ions to charge the tested material; a charge and the surface potential converter and a voltage source for calibration during measurements of the surface potential (Fig. 1). All data is sent to the computer. The computer synchronizes the system action, specifies the exposure time and duration of the measurement process collects and stores the data and calculates the parameters and the characteristics of an investigated material.

The entire measurement process is divided into four stages: at stage 1 the positive charge is deposited and this deposited positive charge and positive surface potential are measured; at stage 2 the positive surface potential is measured at free discharge; at stage 3 the negative charge is deposited and this deposited negative charge and negative surface potential is measured; and at stage 4 the negative surface potential is measured at free discharge.

The measurement technique specified in [12] allows to evaluate various insulating planar materials or layers the thickness of which is from 5 µm up to 5 mm. The measuring device can make up to five measurements per second of the surface potential and deposited charge. The charging of the insulating material can last from several milliseconds to several tens of seconds and the discharging can last from several seconds to tens of hours. The charge deposition and the free discharge process depend on the insulating material under study. Figure 2 shows two typical sequences of measuring the surface potential V and deposited charge Q.

The example shown in Figure 2 demonstrates that the surface potential V of one insulating material changes more rapidly (Fig. 2, a) in comparison with another insulating material type where the surface potential changes very slowly (Fig. 2, b).

The determination of the characteristics and the parameters of the charge deposition and the free discharge process are important for the description of many kinds of materials, also for the description of specific materials for building purposes.



a

b

Fig. 2. Two typical sequences of the surface potential V and deposited charge Q measurement process: a – fast discharge, b – slow discharge

2.2. Measured characteristics and calculation of parameters

For the evaluation of one or more characteristics or properties of a material, product, or technological process a definitive procedure that yields a reproducible test must be created. We propose to apply a procedure, which is based on the above described measurement technique based on a deposition of a dose amount. Giving extra charge the investigated object by periodic dosed charging with positive and negative ions and measuring the surface potential and the deposited (for a given value of the ions generator voltage) charge are obtained: the surface potential dependence on time ($V-t$); the surface potential dependence on deposited charge ($V-Q$); the electric capacitance dependence on the surface potential ($C-V$); the volume resistance dependence on the surface potential ($R-V$).

From the measured dependencies the following set of parameters are calculated: the surface potential limiting value, $V_{\max}$, (in V); the surface potential discharge rate or in other words the period of time, during which the surface potential is reduced by half t_{mid} (s, min); the maximum deposited charge, $Q_{\max}$, (C/cm^2); the layer capacitance C_l, (F/cm^2); the energy of the accumulated charge W_Q, (J/cm^2); the resistance-area product hereinafter referred to as volume resistance R, (Ω·cm^2); the electric field strength E, (V/mm).

Note. The layer capacitance is calculated as a ratio of the surface potential and deposited charge variation in every period of deposition of a dose amount of charge.

The parameters placed in this list are defined in the following way.

The surface potential limiting value. A capacitance change depends on the charge carrier accumulation processes on the layer. Typically, when the surface potential rises up to the medium value of the calculated capacitance, the value is almost constant, but when the surface potential reaches a particular value, the calculated capacitance value quickly starts to grow. Further, if the surface potential becomes major, the layer will be damaged. Consequently, when the capacitance becomes twice higher its initial value, this value on the $C-V$ dependence for a given value of the ions generator voltage is fixed as a limiting value of the surface potential $V_{\max}$.

The surface potential discharge rate. When the surface discharging process starts on, the surface potential decreases. To evaluate the discharge rate of the tested material the period of time during which the surface potential is reduced by half t_{med} on the $V-t$ dependence is fixed.

The maximum deposited charge. The dependence of the surface potential of an ideal dielectric material of the charge deposited on its surface must be linear. In the real situation the $V-Q$ characteristic is not linear. The deviation from this linearity is one of the subjects touched upon in studying dielectric materials. There are two possibilities to fix the maximum deposited charge $Q_{\max}$, one when the surface potential reaches the limiting value and the other when the material under study is electrified so that the surface potential has a preestablished value.

The layer capacitance. The layer capacitance is obtained from the calculated capacitance dependence on the surface potential $C-V$. The capacitance value C_l is fixed when the surface potential is equal to about one fifth of a surface potential limiting value.

Accumulated charge energy. The energy W_Q of the accumulated charge is calculated from the limiting value of the surface potential $V_{\max}$ and from the layer capacitance value by the equation $W_Q = C_l\, V_{\max}^2 / 2$.

Volume resistance. In order to obtain the volume resistance variation range the volume resistance dependence on the surface potential ($R-V$), two volume resistance values are fixed: the first is fixed when the surface potential gets a limiting value $R_{V\max}$, the second – when the surface potential is reduced by half t_{med} of the surface potential limiting value $R_{V\text{med}}$.

3. EXPERIMENTAL RESULTS

3.1. Selected research materials

The specific materials for building purposes, which can be investigated, are painted substrates (made with polyurethane, acrylic, polyvinyl acetate, alkyd, epoxies and other kinds of varnishes or coatings), protective films (made on the base of organic materials), floor covering materials (as linoleum, polyvinyl chloride), latex, polyester, or epoxy compounds) and many others. Below we present an example of the experiments carried out with painted substrates. The sample was painted over an aluminum plate polyurethane varnish and dried out in normal conditions for one week. The thickness of a painted substrate was (110 ±10) μm. The experiment was performed in laboratory conditions at the temperature 23 ºC and relative air humidity 30 %. The given value of the ions generator voltage was +7 kV and –7 kV. We exposed the sample to positive and negative ions and simultaneously the four above mentioned dependencies: the surface potential on time, the surface potential on deposited charge, electric capacitance on the surface potential, volume resistance on the surface potential dependencies were measured (Fig. 3 – 6).

The following parameters were calculated for this sample: the surface potential limiting value – 2250 V, the discharge rate – 73.0 s, the maximum deposited charge – 0.20 μC/cm^2, the layer capacitance – 83 pF/cm^2, the accumulated charge energy – 0.21 mJ/cm^2, the volume resistance was 0.91 GΩ·cm^2 and 0.58 GΩ·cm^2.

To verify the possibility of the proposed method to characterize of specific materials for building purposes a series of experiments were performed to establish the above-mentioned parameters of this kind of materials.

Polyurethane varnish is a polymer consisting of a chain of organic units joined by urethane links. There are an extremely wide range of mechanical properties and are commonly used to protect wood as floor varnish.

Alkyd enamel is the polyester modified by the addition of fatty acids which is employed as high gloss coatings and wood finishes.

Anticorrosive coating is a quick drying underseal based on rubber-synthetic resin with zinc powder, used to improve rust protection.

Anticorrosive coating Zinc is a combination of pure zinc powder and 5 % artificial resin for metal surface cathodic rust protection.

Polyurethane anti-slip floor paint is a kind of paint with incorporated rubber granules to give to a floor a flexible non-slip finish that will not flake, chip or peel.

Polyvinyl chloride (PVC) floor cover is one of the widely used biologically and chemically resistant thermoplastic polymers as a material for building purposes.

Polyethylene is a polymer consisting of long chains of the monomer ethylene and is a class of thermoplastics practically ubiquitous in consumer products and widely used as a film for building purposes.

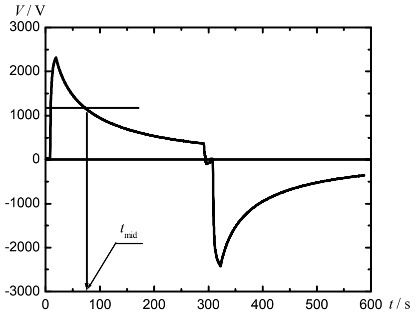


Fig. 3. Surface potential *V* dependence on time *t*

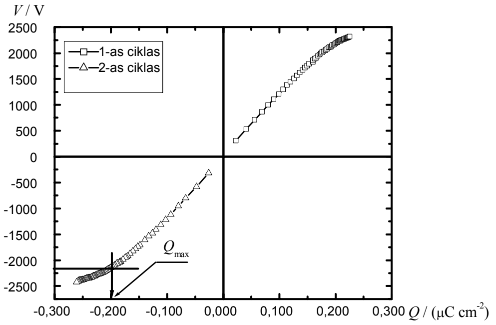


Fig. 4. Surface potential *V* dependence on deposited charge *Q*

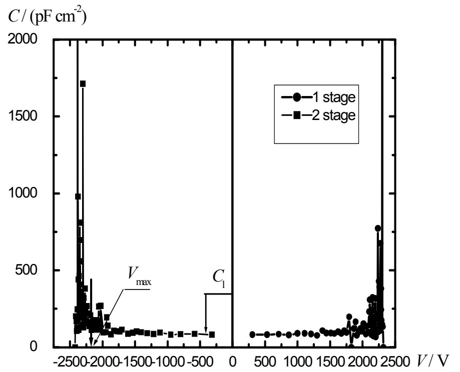


Fig. 5. Calculated capacitance *C* dependence on the surface potential *V*

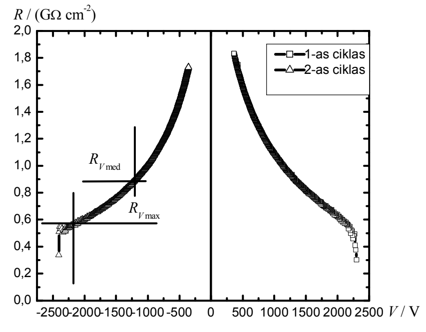


Fig. 6. Volume resistance R_b dependence on the surface potential *V*

Polyethylene foam is a foam form polyethylene which is used for packaging, surface protection, vibration dampening and insulation and many other building purposes.

Polyethylene terephthalate (PET) film is a linear thermoplastic resin that is created by the condensation of terephthalic acid and ethylene glycol. The main advantage in using PET is that it does not break easily and acts as a good barrier for separated elements.

Polyurethane protective adhesive tape is a self adhering tape that can be quickly and easily applied to form a long lasting protective surface.

Waterproof membrane tape is composed of a breathable membrane of polyester and polypropylene fleeces laminated with a copolymer and is designed for the use as a concealed flashing in window and door frames.

These materials have significantly different physical and technical characteristics. It is evident that the production technology even for the same material can be very different. Therefore, this experiment is performed only to demonstrate the possibilities of application of the method which is designed to investigate the electrostatic properties of dielectric materials.

3.2. Comparative analysis of selected research materials

The measurement results are shown in Table 1. All measurements were carried out at the same conditions, i. e. when the given value of a potential difference between the exploring material substratum and the ions generator corona discharge electrode was 7.5 kV. The test material was affected by positive and negative ions. The results presented in Table 1 show that the surface potential limiting value (column $V_{\max}$) may acquire different values from very high (4620 V) to very small (35.0 V) ones. The column $Q_{\max}$ shows the quantity of charge load required to provide a layer to a surface limiting value.

The presented results in column t_{med} also show that the surface potential changes particularly very slowly for polyethylene terephthalate and for polyurethane film and very rapidly for polyvinyl chloride floor cover (the surface potential discharge rate value was about 0.5 s). The volume resistance at the period of time during which the surface potential is reduced by half (column $R_{V\text{med}}$) shows that the values can be acquired from 2.0 TΩ·cm^2 to 1.2 GΩ·cm^2. The volume resistance for polyethylene terephthalate and for polyurethane film was fixed at a certain voltage value, which is recorded in the Table near the volume resistance value because the surface potential was changing slowly and was no possible to fix the period of time, during which the surface potential is reduced by half. The volume resistance for polyethylene terephthalate can reach 98.3 TΩ·cm^2, when the surface potential is 4400 V. For the surface potential limiting value it is possible to calculate the threshold value of the volume resistance (column $R_{V\max}$). The volume resistance value is much lower than the volume resistance value at the period of time, during which the surface potential is reduced by half: when the surface potential is approaching the surface potential limiting value, the influence of the leakage current is increasing.

Another way for comparative analysis of different materials can be applied so that the initial surface potential of all investigated materials can have the same initial value. The measurements of the investigated materials were carried out when the initial value of the surface potential was 700 (1 ±3 %) V. The measurement results are presented in Table 2. The test material was affected by positive and negative ions.

Table 1. Calculated parameters of selected research materials when the electrifying potential is 7.5 kV

Materials		$V_{\max}$ / V	t_{med} / s	$Q_{\max}$ / μC/cm^{-2}	$R_{V\text{med}}$ / GΩ·cm^{2}	$R_{V\max}$ / GΩ·cm^{2}
Polyethylene terephthalate film	+	4540	∞	0.12	98300 (+4400 V)	–
	–	–4620	∞	–0.22	63900 (–4470 V)	–
Polyurethane protective adhesive tape	+	4370	∞	0.32	58700 (+4160 V)	–
	–	–4510	∞	–0.15	54400 (–4230 V)	–
Polyurethane varnish	+	4060	99.9	0.42	2060	268.0
	–	–4300	84.6	0.41	1740	403.3
Waterproof membrane tape	+	4290	43.5	0.010	29160	6780
	–	–4350	44.9	–0.010	28800	14600
Polyethylene film, black		4010	93.4	0.29	2300	363
		–3860	106.0	–0.38	2660	470
Polyethylene foam		2760	0.9	0.013	289	224
		–3090	1.1	–0.015	330	218
Alkyd enamel	+	2790	15.8	1.43	143	52.3
	–	–2710	9.8	–0.76	87.4	34.1
Anticorrosive coating	+	2200	2.4	0.89	54.6	35.8
	–	–2100	2.1	–0.60	49.0	28.0
Polyvinyl chloride floor cover		1260	0.5	0.23	110	15.5
		–1480	0.6	–0.24	110	17.1
Polyurethane anti-slip floor paint	+	1160	1.1	1.01	10.7	7.44
	–	–1320	1,1	–0,97	10,4	7,33
Anticorrosive coating Zinc	+	35,0	11,1	0,59	1,34	0,69
	–	–38,0	9,9	–1,02	1,20	0,70

Table 2. Calculated parameters of a selected research materials when the surface of the test samples were electrified up to 700 (1 ±3 %) V

Materials		$V_{\max}$ / V	t_{med} / s	$Q_{\max}$ / μC/cm^{-2}	$R_{V\text{med}}$ / GΩ·cm^{-2}	$R_{V\max}$ / GΩ·cm^{-2}
Polyurethane protective adhesive tape	+	722	∞	0.059	78300 (+707 V)	150
	–	–709	∞	–0.057	149000 (–698)	1420
Polyethylene terephthalate film	+	710	∞	0.020	15000 (+672 V)	934
	–	–709	∞	–0.021	16800 (–670)	948
Polyethylene film, black	+	721	∞	0.039	18700 (+538 V)	624
	–	–715	∞	–0.031	42100 (–610 V)	735
Polyurethane warnish	+	703	224.7	0.057	4630	853
	–	–711	207.2	–0.062	4270	399
Waterproof membrane tape	+	718	86.2	0.001	56500	10400
	–	714	68.7	–0.001	45000	40400
Alkyd enamel	+	695	25.5	0.188	230	120
	–	–696	19.3	–0.146	177	60.8
Anticorrosive coating	+	700	3.2	0.191	79.40	43.6
	–	–707	3.3	–0.133	79.7	41.9
Polyurethane anti-slip floor paint	+	700	1.5	0.885	13.5	9.82
	–	–712	1.5	–0.418	13.8	10.2
Polyethylene foam	+	712	0.91	0.002	269	205
	–	717	1.1	–0.001	314	242
Polyvinyl chloride floor cover	+	696	0.5	0.114	110 (+122 V)	15.8
	–	–708	0.6	–0.086	110 (–88 V)	17.6

In Table 2 the surface potential discharge rate of different materials can be compared under the same initial conditions. It appears that in some cases the surface potential discharge rate (column t_{med}) does not correlate with the volume resistance (column $R_{V\max}$; see waterproof membrane and polyethylene foam). It can also be seen that when the test material is affected by positive and negative ions the value of the volume resistance can be different (see Polyurethane protective adhesive tape, Alkyd enamel, Waterproof membrane).

The thickness and the layer capacitance of the examined test samples are presented in Table 3. In this table the accumulated charge energy W_Q is calculated from the limiting value of the surface potential $V_{\max}$ and from the layer capacitance value C_1. In Table 3 all the investigated materials in accordance with the accumulated amount of energy can be compared. The evaluation of the accumulated energy W_Q along with the discharge rate t_{med} (Table 2) shows that some of the investigated materials are able to maintain the accumulated energy for a long period of time. At the same time there are other materials that lose the accumulated energy very quickly and are not able to accumulate it. These materials which lose the accumulated energy in a very short period of time (in a few seconds), can be considered to be antistatic material.

Table 3. Accumulated charge energy calculation of a selected research materials

Materials	Thickness, μm	C_1, nF·cm^{-2}	W_Q, mJ·cm^{-2}
Polyurethane protective adhesive tape	35	0.074	706.0
Alkyd enamel	120	0.16	623.0
Polyurethane varnish	60	0.07	577.0
Polyethylene film, black	30	0.06	482.0
Polyethylene terephthalate film	100	0.035	360.0
Anticorrosive coating	40	0.06	145.0
Polyurethane anti-slip floor paint	30 ... 600	0.15	101.0
Waterproof membrane tape	400	0.003	27.6
Polyvinyl chloride floor cover	2500	0.026	20.6
Polyethylene foam	2500	0.005	19.0
Anticorrosive coating Zinc	30	12.0	7.4

The results of the carried out experiments and calculations can be used for a deeper analysis of the investigated materials. Many factors, for example the composition of the material, the atmospheric conditions (temperature, pressure and humidity), and the process of hardening, the state of stress, the surface defects and many others affect the measured data. Thus, to evaluate the electrostatic properties of any material and the influence of a production mode requires more detailed study. Unambiguous characterization can be applied only for a finally produced product.

4. CONCLUSIONS

The results of the carried out experiments lead to the following conclusions. A contactless technique for electrostatic properties measurement and characterization of specific insulating planar materials for building purposes were proposed. The essential advantage of the method consists in one measurement process, which enables to determine a group of parameters of the investigated materials. That group of parameters (a collection of technical data) facilitates the comparison of different materials used for the same purpose or the same material produced by the different technological process and helps to choose a product with appropriate parameters. The results appear to be useful for interpretation of experimental data and characterization of specific materials and allow manufacturers or designers to find a way to compare different materials as well as to use the method as a quality control test.

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