Journal of Thermal Analysis and Calorimetry, Vol. 60 (2000) 279–286

USE OF THERMOANALYTICAL METHODS IN PREDICTION OF THERMAL ENDURANCE OF INSULATING IMPREGNATING VARNISHES

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Abstract

The results of testing the thermal properties of insulating impregnated varnishes obtained by thermoanalytical methods and based on the IEC 216 standard are presented. It was found that the temperature index determined by means of thermoanalytical testing is quite close to that derived by a conventional standardized procedure. It was also established that thermoanalytical methods could be used in the recipe selection for the development of a new varnish.

The results obtained confirmed the possibility of using thermoanalytical methods for a quick, prognostic estimation of the thermal endurance of insulating impregnating varnishes.

Keywords: impregnating varnish, temperature index, thermal endurance, thermoanalytical methods

Introduction

At the present level of technology, a majority of the windings used in electrical machines and devices should be impregnated in consequence of various operational requirements. Impregnation is necessary for the additional protection of windings against the influence of internal and external operation-related and environmental factors. It also considerably influences the reliability and operating life of electrical devices.

Progress in the construction of electrical systems has involved the necessity of the optimum selection of substrates for the production of insulating impregnating varnishes with high thermal endurance.

Currently used insulating varnishes for the impregnation of electromagnetic devices belong in two groups (in conventional terms): solvent varnishes and solventless varnishes consisting of a resin base, reactive and non-reactive diluents, and also modifying, stabilizing and possibly cross-link initiating components. Another quality which differentiates these varnishes is the non-volatile matter content which ranges from 50 to about 85%.

Estimation of their thermal properties, including the determination of thermal endurance, may be accomplished through a long-lasting and energy-consuming thermal ageing method. The use of thermoanalysis [1, 2] effectively simplifies this esti-

1418–2874/2000/ $ 5.00

Akadémiai Kiadó, Budapest
Kluwer Academic Publishers, Dordrecht

mation although it does not afford a numerical equivalent of thermal endurance, i.e. the temperature index *TI*, determined by a conventional ageing test performed according to IEC 216 [3]. The level of *TI* mainly relates to the types of base resin and reactive diluent used to obtain the varnish.

The thermoanalytical methods of testing of varnishes and substrates to promote their preparation were inspired by a need for a quick estimation (especially of thermal properties) and preliminary assessment of samples of foreign varnishes applied in the national electrotechnical industry, as well as the necessity of using simplified estimation methods in work on new varnish recipes. The development of a new varnish with traditional methods requires the use of considerable amounts of components. The application of thermal analysis made it possible to operate on micro-samples of substrates with a decreased labour consumption.

Experimental

Apparatus and parameters of testing: Derivatograph OD 102
Measurement temperature range: 25–800°C
Rate of furnace temperature rise: 10°C min^{-1}
Mass: 100 mg
Furnace environment: air
Reference substance: Al_2O_3

a) Six selected solventless impregnating polyester or estroimide varnishes with a similar resin base containing reactive diluents of styrene or vinyltoluene type were tested (range of gelling temperature, loss of mass during gelling, temperature of total mass stabilization, initial decomposition temperature). The relative temperature index RTI_{TG} was also determined, calculated from the dynamic TG curve by the Di Cerbo method [2].

b) Recipe selection in the development of a new varnish is based on the simultaneous TG, DTG, DTA and T curves (loss in mass, RTI_{TG}). Such testing was preceded by estimation of the homogeneity and driability of the samples; after their selection the optimum composition was submitted to a bond strength test with the conventional method.

Results

a) Selected characteristic properties read from TG, DTG and DTA curves obtained under conditions of non-isothermal heating are presented in Table 1.

b) Recipe selection and RTI_{TG} values determined in the development of a new varnish are presented in Table 2 obtained via the simultaneous TG, DTG, DTA and T curves indicating loss in mass as a function of temperature (range of temperature 160–500°C.

Table 1 Results of thermoanalytical testing of insulating solventless varnishes

Varnish component base	Type of active cross-linking monomer	Range of gelling temperature/°C			Loss in mass during gelling/%	Temperature of total mass stabilization/°C	Initial decomposition temperature (5% loss in mass)/°C	RTI_{TG}	*TI* according to manufacturer
		initial	max.	final					
Polyester-imide resin	styrene	128	155	200	23	300	340	158	H(180) TI(155–166)
Polyester-imide resin	vinyltoluene	128	175	215	7	280	310	146	F(155) TI(146–165)
Polyester-imide resin	vinyltoluene	124	178	218	8	260	290	143	F(155) TI(142–156)
Polyester-imide resin	styrene	105	120	150	13	270	280	159	H(180) TI(156–167)
Polyester-imide resin	styrene	126	144	170	19	270	280	159	F(155) TI(153–159)
Polyester-imide resin	vinyltoluene	120	144	180	9	270	280	162	F(155) TI(149–156)
Polyester resin	styrene	110	139/151	220	17	240	280	137.6	B(130) missing
Polyester resin	vinyltoluene	105	130	175	10	240	280	147.6	F(115) missing

Table 2 Values of loss in mass in percent vs. temperature estimated from the dynamic TG curves and RTI_{TG} values determined from the dynamic TG curves by the Di Cerbo method for the eight samples of experimental composition

T/°C	Number of sample	1	2	3	4	5	6	7	8
	Parts by mass A:B:C	100:0.75	100:0.75	100:1.00	100:1.50	90:10:0.75	80:20:0.75	50:50:0.75	100:1.00
	Curing parameters	10'/120°C	20'/120°C	20'/120°C	20'/120°C	10'/120°C	10'/120°C	20'/120°C	30'/120°C
160		0.5	1	1	1.5	1	2	0.5	0
180		1	1	2	2.5	1.5	2.5	1	0.5
200		2	1.5	2.5	3	2	2.5	1.5	1
220		2.5	2	3.5	3.5	2.5	3	2	1
240		3	2.5	4	4.5	3	3	3	1
260		3.5	3	5	5	3.5	4	3.5	1.5
270		4	3.5	5	5.5	3.5	4.5	4	1.5
280		4	4	3.5	6	3.5	4.5	4	2
290		4	4	5.5	6.5	4	5	4	2
300		5	5	6.5	7	4.5	5.5	4.5	2.5
310		5.5	5.5	7	8	5.5	6	5	3
320		6	6	8	8	6.5	7	5.5	3.5
330		7	7.5	9	9	7	8	6	4
340		7.5	8.5	10	10	8	9.5	6.5	4.5
350		8.5	10	12	12	10	12	7.5	5.5
360		10.5	12.5	13.5	13.5	12	15	9	6.5
380		16	19	21	20	19	22	13	9
400		26	30	30	32	31	40	20	14
420		46	52	57	53	56	67	38	30
440		74	83	86	81	83	89	65	32
460		91	91	90	91	92	93	89	73
480		93	92	93	93	93	93	91	90
500		93	93	93	93	93	93	93	93
	RTITG	153.5	153.5	152.2	152.5	153.5	153.5	161.4	165.3

A=base resin; B=modifying resin; C=cross-link initiator

Discussion

a) The Di Cerbo method can be used for an approximate thermal endurance evaluation; it is based on the assumption that the decrease in mass is correlated with different degradation processes characterizing the varnish thermal endurance and its susceptibility to thermal ageing.

It has been proved that the level of RTI_{TG} lies within the *TI* index range found by conventional life tests according to IEC 216.

The relative temperature indicators, calculated from the dynamic TG curve by the Di Cerbo method, allowed an approximate estimation of the thermal endurance.

The possibility of a correct interpretation of the results permitted the labour-consuming candidate varnish testing with conventional methods to be abandoned in those cases where the results of thermoanalytical testing indicated that evaluation of the varnish usefulness would be negative.

As the decrease in mass could not always be treated as a measure of the thermal destruction process rate, the varnishes selected for the tests belonged in a common group of solventless varnishes, i.e. varnishes containing reactive solvent.

The results obtained confirmed the possibility of using thermoanalytical methods for the quick, prognostic estimation of the thermal endurance of insulating impregnating varnishes. This method is faster then the conventional methods and simpler than other analytical methods.

The thermal class of insulating varnishes given by the manufacturers should be estimated critically; in fact they do not comply with IEC 216 according to which the thermal class is determined by the lowest *TI* index. For example, the *TI* values given in Table 1 Pos. 1 and 4 evidently do not meet H class requirements.

RTI_{TG} yielded an approximately determined predicted thermal endurance of the varnishes, and enabled quick and objective estimation of the varnishes under test.

b) The test results compiled in Table 2 indicated that the best parameters i.e. high values of the initial decomposition temperature (5% loss in mass) – 310 and 340°C occur for compositions No. 7 and 8 containing 50:50:0.75 and 100:0:1 parts by mass of A:B:C (A=base resin; B=modifying resin: C=cross-link initiator).

The positive properties of the above compositions were confirmed in conventional (standardized) testing.

Because of the broad scope of the problem, a detailed description has been omitted.

Conclusions

Thermoanalytical tests used to estimate varnishes introduced into industry, and also a choice of criteria for selecting experimental material during work on new varnish recipes were preceded by the compilation of a comprehensive experimental material from the testing of varnishes by conventional and thermoanalytical methods. The thermoanalytical testing constituted a starting point before the undertaking of testing by conventional methods.

The numerous data proved that certain features read from the simultaneous TG, DTG, DTA and T curves significantly characterize the properties of the varnishes under test and the varnish substrates, especially their thermal properties.

References

1 G. C. Montanari and Z. Yingsuo, IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 1 No. 6 (December 1994) 1026.
2 P. M. Di Cerbo, Insulation/Circuits, No. 1 (1975) 21.
3 IEC 216: 1990 'Guide for the Determination of Thermal Endurance Properties of Electrical Insulating Materials'