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The Study of High-voltage Insulation Space-components Applying Resin Composites Modeling Technology

HONG Robin[1, a], WANG Hongmei[2,b]

[1]Tianjin University, Tianjin 300072, China

[2]Tianbo Science & Technology Co. Ltd., Tianjin 300072, China

[a]tianbohb@126.com, [b]whm0827@qq.com

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Abstract. High-voltage insulation space-components are critical to the reliability of traveling wave tube amplifiers on satellite. Unlike in atmosphere, high-voltage components working in space can easily discharge due to insulation molding defects, which will lead to failure of amplifiers. We can solve these problems through adopting epoxy resin matrix composites as filler and applying vacuum-pressure injection molding technology for insulated molding process.

Introduction

High-voltage insulation space-components are critical to the reliability of traveling wave tube amplifiers on satellite. Unlike in atmosphere, high-voltage components working in space can easily discharge due to resin molding defects, which will lead to failure of the amplifier. Therefore, foreign manufacturers, such as Thales, Tesat and ASP, regard their unique formula and special process as their core technology and strictly secure. In order to ensure the reliability of the critical pressure and the long-term space service, high-voltage insulation space-components manufactured by these manufacturers must undergo a rigorous process of producing, testing and experiment before used in practical applications.

In China, according to the statistical analysis**,** in development process of traveling wave tube amplifiers on satellite, eighty percent of breakdowns occur in the thermal vacuum tests, and more than seventy percent of them are due to deficiencies of casting materials and injection molding. Casting materials and molding technology of High-voltage Insulation Space-components are the core technology, and else are the main bottlenecks to limit the reliability of traveling wave tube amplifiers on satellite.

Existing Faultinesses and Shortages

If casting materials and molding technology have disadvantages, it may lead to the following problems:

1) The improper selection of molding material will lead to all kinds of disadvantages, such as poor electric property, poor insulating property and bad invasive ability. Sometimes, to pursuit of a single performance cannot help losing other performances, namely whole performance. For example, in order to improve insulation properties while we select materials, we can't help increasing viscosity that could make injection molding more difficult.

2) If molding body is not homogeneously filled when injecting/molding, there are defects such as dead spaces or cracks inside it[1][2]. These situations may not lead to some problems in ground applications. But in space applications, the pressure difference inside and outside dead spaces will cause deflation or lead to high-voltage discharge.

3) If there are micro-bubbles inside molding bodies, it probably brings partial discharge under high-voltage electric field. Long-term corona will gradually damage the insulation property of molding bodies and eventually lead to insulation failure.

4) If the thermal expansion coefficient of molding materials is inconsistencies with components, that will increase internal stress easily causing molding body cracking or damaging internal components while temperature changes.

The Selection of Resin Material

Based on the above four points, we must select molding materials firstly. In general, the requirements of injection molding material are high voltage resistance, low viscosity, high thermal conductivity, good invasive ability, low shrinkage rate and high/low temperature impact resistance, and so on.

Currently, there are mainly three kinds of molding materials used in high-voltage electrical insulation packaging, namely epoxy resin, polyurethane resin and silicone. The comparison of their main performances is shown in Table 1.

Table 1. The comparison of their main performances

Item	Unit/Condition	Epoxy Resin	Polyurethane Resin	Silicone
Hardness	Shore-A	90～100	50～70	25～50
Volume Resistivity	25℃, Ω·cm	1.0×10^{13}	1.0×10^{13}	$\geq1.0\times10^{13}$
Dielectric Strength	25℃, kV/mm	≥25	22.4	26
Water Absorption	24hrs, 23℃, %	0.13	0.3	0.017
Flame Retardancy	UL-94	V-0	V-1	V-0

As can be seen from table 1, polyurethane resin and silicone have certain flexibility after curing, and so will not crack due to the small internal stress. But water absorption of Polyurethane Resin is maximal and its insulation intensity is lower, it is not suitable to inject for insulation. The biggest drawback of silicon material is too high viscosity, and this makes it not easily conducive to infiltration, and could easily lead to inaccurate injecting and bad invasive ability**.** Therefore, taking pursuit of the best whole performance into account, we mainly select molding material from epoxy resin for insulation space-components. Such composite material is widely used in the insulation industry because of its high/low temperature impact resistance, anti-vibration, weather resistance, dielectric properties, flame retardancy, low water absorption, and so on. Usually, part A and part B are separately stored in two tanks. They don't react when separately stored. But they will generate exothermic reaction and mold under a certain temperature if they are mixed in proportion. Thus, the selection of molding material must take the special process of insulation space-components into account.

Epoxy resin matrix has a good comprehensive mechanical property, high adhesion, low shrinkage rate, good stability and excellent electrical insulation property. However, there are disadvantages of crisp, poor fatigue resistance, low heat resistance and poor impact toughness due to high density and high internal stress. So it is difficult to meet the engineering requirements and its application is restricted. For this reason, experts at home and abroad do a great deal of modification studies, of which the most important is to improve its toughness and high/low temperature resistance. At present, the modification of epoxy resin is mainly achieved through the blending structure.

There are mainly three types to increase toughen of epoxy resin: (a)Adding rigid inorganic filler, rubber, thermoplastic polymers and so on. Form two-phase structure while reacting. (b)Form semi-interpenetrating polymer networks interpenetrate thermoplastic into epoxy resin networks. (c) Changing the chemical structure of cross-linked networks (for example, introducing "flexible sections" into cross-linked networks). And improve its high/low temperature impact resistance also has three types, namely introducing containing fused-ring units into epoxy resin molecules, compounding epoxy resin molecules containing fluorine and using molding agent instead of the traditional DDS[2].

We select epoxy resin composites as molding materials for insulation space-components, separately loaded in A and B tanks. The mixture mixed in proportion is low viscosity, good invasive ability, high anti-breakdown ability and low water absorption under thermal state, and high mechanical strength after molding.

Characters.

1) Good invasive ability and longer duration.

2) Excellent electrical insulation property, good physical performance, good heat resistance property.

3) Excellent high/low temperature impact resistance, excellent durability property.

Mixing Ratio and Molding Condition.

1) Ratio (P.W.B): 100:28

2) Molding Condition: 85℃/2.5 h + transition time/1h + 140℃/2.5 h

Characteristic parameters of liquid before curing

Table 1. Characteristic parameters of liquid before curing

Order	Item		Unit/Condition	Parameters
1	Appearance	A		Black viscous liquid
		B		Light-yellow transparent liquid
2	Viscosity	A	cps, 60℃	6500±1000
		B	Cps, 40℃	21±3
		A+B	Cps, 60℃	300±50
3	Density	A	g/cm^3, 25℃	1.79±0.03
		B	g/cm3, 25℃	1.20±0.02
4	Gelling Time		s, 150℃/g	270±40
5	Available Time		h, 60℃	〉 3.5

Characteristics of molded resin

Table 2. Characteristics of molded resin

Order	Item	Unit	Index
1	Volume Resistivity	Ω·cm	$>10^{15}$
2	Dielectric Constant		<4.0
3	Dielectric Dissipation Factor	%	<1.1
4	Dielectric Strength	KV/mm	>25
5	Thermal Deformation Temperature	℃	137±5
6	Bending Strength	MPa	120±10
7	Hardness	H_D	95±5

Molding Technology

Resin vacuum casting technology is a traditional and effective method to improve voltage-withstand level, moisture-proof and shock-prevention and revolve the partial breakdown of electrical components[3-5]. Its principle as following: do separately vacuum-evacuating treatments before mixed firstly, and pre-dry packaged electrical components in a vacuum casting chamber. And then package in a vacuum casting chamber. At last, the encapsulated space-components mold at a certain temperature and pressure. This molding process does not eliminate the micro-bubbles between insulation space-components and has the phenomenon of no-fully filled molding. Pressure Gelation Process technology can effectively eliminate micro-bubbles between insulation space-components. Pre-treated mixture is pressurized into moulds pre-heated to 140℃ by the booster pump. And bubbles are evacuated from suitable reserved outlet in parting surface of gelling mould. At the end of injecting, the mixture is injected into the outlet and molds under pressure. Mould becomes sealed and the structure of products becomes dense. However, such molding techniques are usually applied to large molding parts, such as solid-sealed pole, switches and transformers. Speaking from the operating processes, it can't meet the requests to cast small insulation space-components.

Combining the universality of vacuum encapsulation technology in electrical component molding process and the effectiveness of pressure-gel technology for resolving the micro-bubble problem, we put forward vacuum-pressure molding technology applied into insulation space-components encapsulation. This technology evacuates the micro-bubbles through doing separately vacuum-evacuating treatments before mixed. In process of this technology we do separately vacuum-evacuating treatments before mixed firstly. Pre-dry packaged electrical components in a vacuum casting chamber. And then package in a vacuum casting chamber. At last, the encapsulated space-components mold at a certain temperature and pressure. The flowchart of this molding is shown in chart I. According to test experiments, it can be seen that it can effectively solve the false molding and the micro-bubble problem inside the molding body.

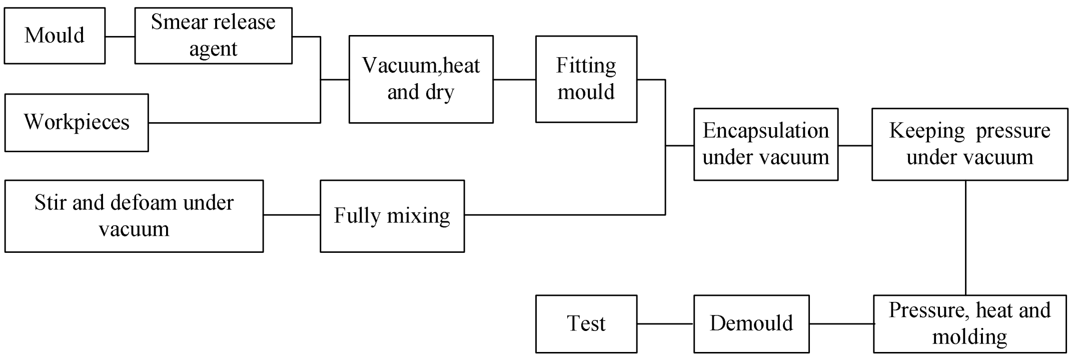

Fig.1. The flowchart of this molding

Molding Technology

Mould Design. Generally, the following points must be noticed when mold designing: Injecting port should be located at the site to conveniently inject; The injecting port should be large; easily assembly, demount and demould; the mould must tightly combine with the body to prevent leakage of resin material; Bottom surface should be leveling to ensure that the thickness of lamellas are basically the same to easily control the injecting height [5].

Pre-treatment of Workpieces and Moulds. Generally, we can use ethanol, gasoline, acetone or xylene cleaning workpieces and moulds 2 ~ 3 times. In particular, where there are solder joints must be cleaned. Put cleaned moulds aside for a moment, and then evenly coat them with release agent. And then pre-bake moulds to remove water vapor.

Evacuating bubbles. Resin mixed with bubbles not only affects the appearance of products and more importantly affects electrical performance and mechanical property of products. In general, the main reasons producing bubbles as following: produce low molecular substances and volatile components while reacting; bubble while mechanical agitation; moisture because of no-thoroughly dried material; narrow slit and dead corner are not fully filled between the components[6], that is air bubble. In order to eliminate bubbles, please preheat the raw materials and remove containing water and other volatile substances firstly. Secondly, materials must be fully stirred before mixing. In order to fully mix filler and material and avoid doping bubbles while mixing, we can adopt vacuum stirring technology. After mixing, the mixture is carried into a vacuum drying oven for evacuating bubbles. In evacuating process, the mixture gradually expands and rises under internal pressure. If continuing pumping vacuum, bubbles inside mixture breakout the overflow. At this time, valve should be opened, bubbles boost to burst, and mixture sinks. And then repeat decompression and deflated until bubbles completely disappear. Finally, evacuated mixture is slowly injected along the inner wall of the mold followed by top-down from right to left. If the injection port is very small, the mixture droplets are pulled into slender water columnar and injected from the side of port. Other side is used as outlet for bubbles until filled.

Patchment[8]. Check bubbles inside transparent lamella. If having air bubbles, please use the needle to puncture bubbles and deflate the air inside the bubble. And then draw resin mixture to repair bubbles. The position after repaired should level with others.

Molding under high pressure condition. When molding under pressure condition, please low the pre-molding temperature and extend the pre-molding time[7,8]. If molding at higher initial temperature, there will be more obvious that internal stress concentrates. Because the cross-linking reaction of epoxy resin all occur at molding temperature, it is likely to cause the reactive heat concentrate. It goes against reducing the internal stress of epoxy resin. In order to avoid problem, we have taken step-step molding process, that is, the pre-molding temperature is 80℃ and pre-molding time is 5h. In this method, most of epoxy resin matrixes produce cross-linked. A small number of unreacted groups will result in further cross-linking in the pass-molding stage. The molding rate of this technology achieves more than ninety-eight percent. It’s more important that the step-step molding process can greatly reduce the heat and further reduce the thermal stress.

Summary

Molding materials and molding process directly affect the quality of insulation space-components. Using epoxy resin matrix composites as filler and vacuum-pressure injection molding technology play more and more important roles and overcome the problems of bad whole performance, fault injecting and stress concentration.

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