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Enhanced Performance Epoxy Materials for High Temperature Applications

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Abstract– Electrical insulating component design has become increasingly challenging due to rapidly changing requirements in power industry applications. Cost reduction and increased performance requirements present new challenges for traditional insulation solutions. Modern insulating component designs must push the limits of dielectric performance while maximizing mechanical strength characteristics in a host of environments. In particular, the recent advancements in the use, size and scale of renewable energies such as solar and wind power necessitate enhanced performance epoxy insulating materials capable of delivering high dielectric and mechanical strength in high temperature environments. This paper summarizes a brief history and current state of epoxy component insulation with commentary on advancements made for applications requiring enhanced material performance for high temperature applications.

Index Terms–Epoxy, High Temperature, Insulator, Bushing, Power Transformer, Switchgear.

I. INTRODUCTION

Epoxy materials have been used in electrical insulation applications in North America since the 1960's. Advancements in materials leading to improved performance have led to steady growth of epoxy use in insulating component design since that time. The design flexibility facilitated by the use of a cast resin system has provided many advantages over traditional insulating materials. Initial applications using Bisphenol-A (Bis-A) materials in basic enclosed applications evolved to outdoor, UV-exposed applications with the development of cycloaliphatic epoxy materials. Epoxy materials are now found in a wide range of electrical insulation applications in varied environments including outdoor, UV-exposed; high contamination environments; high ambient temperature environment; and, gas insulated systems such as SF6. Typical epoxy materials and environments are:

- Bisphenol A – indoor applications or fully-enclosed, outdoor applications without UV exposure.
- Cycloaliphatic – outdoor applications with UV exposure.
- SF6 compatible – gas insulated systems.

Some examples of typical applications and materials used are:

COMPONENT TYPE	TYPICAL APPLICATIONS	MATERIAL / ENVIRONMENT
Switch & Bus (Standoff) Insulator	Switchgear Bus Duct	Bis-A Epoxy – Enclosed Applications. Cycloaliphatic Epoxy – Outdoor Applications
Roof Entrance or Cover Mounted Bushings	Switchgear, Distribution Breakers	Cycloaliphatic Epoxy – Outdoor applications
Transformer Bushings	Distribution transformers Power Transformers	Bis-A Epoxy – Enclosed applications. Cycloaliphatic Epoxy – Outdoor Applications
Separable Connector (Deadbreak Bushing)	Distribution transformers Switchgear	Cycloaliphatic Epoxy SF6 compatible Epoxy

II. TRENDS

Continued advancements in equipment design and the evolution of new applications have created a need for epoxy materials that exhibit enhanced properties with respect to electrical, thermal and mechanical performance. Most recently, a trend towards higher operating temperatures exceeding most common industry temperature classes of 105°C and 120°C has necessitated the development of epoxies capable of operating at significantly higher Tg (glass transition temperatures) and HDT (heat deflection temperatures). Tg and HDT properties are more clearly defined as follows:

A. Glass Transition Temperature (Tg)

Is the temperature range in which a material alters state – going from a glass-like rigid solid to a more flexible, rubbery compound

B. Heat deflection temperatures (HDT)

Commonly referred to as heat deflection temperature or heat distortion temperature is the temperature at which a polymer deforms under a specified load." The HDT, is a useful indicator of the temperature limit above which the material cannot be used for structural applications…" [1] The primary drivers for this trend of higher operating temperatures are:

- Equipment design – cost reduction efforts and space limitations have led to smaller equipment footprints with reduced cooling capability; and, requirements for more efficient component designs with current carrying components operating at higher current densities. Hence, higher ambient temperatures and component operating temperatures are more commonplace.

- Evolving technologies and applications – The significant rise in solar and wind generation activity has brought about new equipment design challenges in both transformer and switchgear design. Transformer applications have challenged designs to become compact with operation at high currents, often in overload conditions.

Extremely high ambient temperatures in excess of 40°C are common, and in some cases up to 75°C in continuous operation in enclosures where traditional cooling methods are not possible.

In all cases, these operating conditions are in stark contrast to typical component design criteria.

The H-J Family of Companies chemical engineers have developed and implemented epoxy formulation solutions to meet these more demanding requirements. The basic challenge was to design a formulation capable of withstanding high ambient and high continuous operating temperature for component designs. This led to the development of an epoxy system capable of operation in these extraordinary conditions, while maintaining the required electrical and mechanical performance. Developed as an enhanced Bisphenol-A epoxy system, the material provides Tg and HDT performance above 155°C class operating requirements. Achieving these higher material ratings allows component operation at or above 155°C with no detrimental effect on the structural performance of the material. Suitability for operating above the 155°C rating may be application and component geometry specific.

III. MATERIAL DATA AND TEST SUMMARY

A series of material tests were performed to verify suitability of the enhanced Bis-A epoxy system in these applications. The tests summarized below verify the technical characteristics of the material and confirm its suitability for application in insulating component design in these operating environments. The results meet or exceed requirements for the environments outlined in this document.
Tests performed include:

	STANDARD	UNITIS	VALUES
DIELECTRIC PROPERTIES			
Volume Resistivity	ASTM D257	Ω-cm@ 25 ° C	5.7x1015
Dielectric Strength	ASTM D149-09	V/ MIL 0.125" THICK	680
Dielectric Constant	ASTM D150-11	@ 23 ° C, 600 Hz	> 4.0
Dissipation Factor	ASTM D150-11	@ 23 ° C, 600 Hz	0.01
Incline Plane Tracking	ASTM D 2303	MINUTES @ 2.5 KV	>500
MECHANICAL PROPERTIES			
Flexural Strength	ASTM D 790-10 proc A	psi	13000
Compressive Strength	ASTM D695-10	psi	>22,000
Tensile Strength	ASTM D638	psi	7,600
IZOD Impact Resistance	ASTM D256-10 method A	ft-lb/in2	0.32
Continues operation temperature, Class		° C	>155
Flammability Test	ASTM D 3801, IEC 707, ISO 1210	1/4" Thickness	V0
Water Absorption	ASTM D570	% wt.	0.1%

IV. DESIGNS AND APPLICATIONS TO DATE – HIGH OPERATING AND AMBIENT TEMPERATURES

As previously outlined, a prime driver for the evolution of higher operating temperature requirements has been newer technologies including wind and solar generation. Component development specific to these sectors includes:

- Transformer bushings – typically high current carrying capability or high voltage application, coupled with high ambient temperature environments.
- High overload applications – customers require frequent overload capability with limited loss of life which conventional epoxies cannot meet.
- Separable connectors such as deadbreak bushings used in wind farm transformers and solar applications.
- Cable termination bushings used in solar inverter applications.

V. SUMMARY AND CONCLUSIONS

Trends toward more optimized equipment design and new technology applications continues to drive research activities to ensure that insulating materials used in component design meet these challenges. The design flexibility offered by epoxies, coupled with the availability of material rated for high operating and ambient temperatures, continues to make epoxy insulating solutions a preferred choice for insulating component designs now and in the future.

REFERENCES

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