

INTERACTION DYNAMICS
Between
WIRE ENAMEL AND IMPREGNATING RESINS

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Abstract:

The ability to modify the resin backbones of wire enamels and impregnating resins is a powerful tool in studying the possible synergistic effects of these two insulations. The possibility to develop a unified system of the primary and secondary insulation resins yields the potential to develop the next generation of insulation families.

Adhesive versus cohesive forces at work during the coating of substrates and the subsequent effect on insulation performance and durability is an area of great discussion within the industry.

Key words: wire enamels, impregnating resins, unsaturated polyesters, synergistic effects, bond strength

the predicted result(s). This work will focus on the chemistry portion of these resin systems to understand the interaction of specific functionalities that could be used to strengthen the durability of these systems in practice.

The concept focuses on improved finished coating system performance by eliminating any failure mechanism that could be caused by a lack of adhesion that would be replaced by a cohesive model of primary and secondary coating interaction. A “lock and key” principle of an insulation system would hold great benefit to manufacturers of electromagnetic devices if it can be shown that performance and durability are increased without significant changes to current application processes. A simple variation or tailoring of materials to applications could lead to a distinct competitive advantage in a market segment.

I. Introduction

A deeper understanding of the dynamics of the bonding forces between primary and secondary insulation coatings has been a desire in the industry for many years. The synthesis of the resins used in these systems has been somewhat isolated with respect to the interactions with the other portion of the insulation system. Some possibility exists that the combination of properties necessary to make a good insulation system could be enhanced by an approach that would cohesively join these two layers.

While other studies have been done to measure some of these interactions, this study will attempt to expand beyond a basic analysis to a synthetic modification of these coatings to measure the possible synergistic effects versus

A. Chemistry

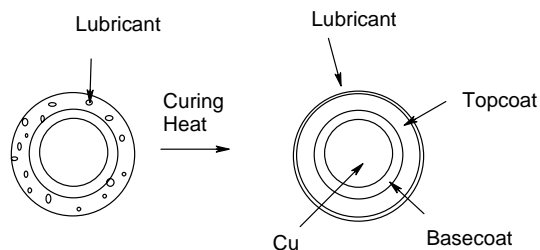
Primary electrical insulating coatings, commonly referred to as magnet wire coatings, are comprised of three main types: THEIC Polyester/polyesterimide, Polyurethane and Polyamideimide. Each type has thermal and physical property advantages and disadvantages including thermal index, flexibility, chemical resistance, adhesion and abrasion resistance. The industry standard for small and large motor applications and other electromagnetic devices is typically an MW35 wire construction.

MW35 magnet wire construction is THEIC polyester basecoat with Polyamideimide topcoat with an optional internal lubricant. The basecoat thickness is typically 80% of the total build to minimize cost. The topcoat at 20% of

the total build improves the chemical and abrasion resistance as well as the thermal properties of the system. Europe and Asia tend to favor a similar construction, however, THEIC polyesterimide is used in place of THEIC polyester.

The internal lubricant is either dispersed or dissolved in the polyamideimide resin solution. Upon curing of the resin during the coating process, the internal lubricant will typically migrate to the surface forming a thin film (Scheme I). This thin film is formed due to the compatibility issues between the polar resin and the non-polar hydrocarbon lubricant.

Scheme I



Upon coating the magnet wire, an external lubricant is applied at take-up to improve windability. The external lubricant along with the internal lubricant minimize damage to the wire by reducing drag (low coefficient of friction) during the winding step. The external lubricant is typically a paraffin wax or ester wax delivered in a hydrocarbon vehicle.

The chemistries of secondary coatings (also known as impregnating resins) are very diverse. Unsaturated polyesters were chosen as the chemistry family to focus on for this study. Further work will be done to expand this work into other chemical families that are used, or could be used, in the industry.

Unsaturated polyester chemistry involves the reaction of carboxylic acids with glycols to form ester linkages. The raw material choices, ratios of materials and manufacturing processes can vary the structure and finished product performance. Viscosity reduction is usually accomplished by the addition of styrene or vinyl toluene as a reactive monomer. The unsaturated polyester chemical family avails itself to many modification options that can result in potential sites for primary insulation interaction(s).

Adhesive and cohesive bonding between the primary and secondary insulating systems in this study exclusively focus on polyamideimide primary and unsaturated polyester secondary coatings.

B. Processes

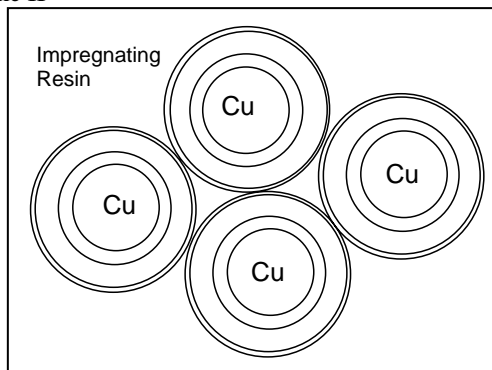
The synthesis/blending of modified resins was part of the project but testing protocols had to be defined initially. It was important to set a test methodology that would differentiate improved systems versus standards.

The protocols decided upon included the following:

- helical coil bond strength
- dielectric strength
- pulse endurance
- twist/peel testing
- surface microscopy

A cross section of a coil winding is shown in Scheme II. Interior voids and the external surface is coated with a secondary coating and cured. Bond failure can either be adhesive (between wire enamel and impregnating resin) or cohesive (within impregnating resin).

Scheme II



Testing of secondary insulation resins was designed to cover two monomer choices, styrene and vinyl toluene, as well as various dwell times of wire immersion in the unsaturated polyesters.

The tables below contain the results of combinations of various primary and secondary systems, standards and modified systems. The tables reflect combinations of wire lubrications and modification with nanomaterials.

Table 1 shows data that compares the effects of lubrication, internal and external, on bonding strength of an MW 35 wire construction with an unsaturated polyester secondary coating. These helical coil samples were cured 2 hours at 150° C and broken per ASTM bond strength test protocols.

It is not surprising that the larger gauge wire had better bond strength than the 18 AWG samples. Both wire sizes showed the same general trend of bond strength: No lube > Internal lube > Internal/External lube > External lube.

Table 1

| Sample | AWG | Lube | Bond, 25°C, lbs |
|--------|-----|----------------------|-----------------|
| A | 18 | None | 40 |
| B | 18 | External | 22 |
| C | 18 | Internal A | 30 |
| D | 18 | Internal A /External | 25 |
| | | | |
| A | 15 | None | 40 |
| B | 15 | External | 30 |
| C | 15 | Internal A | 42 |
| D | 15 | Internal A /External | 35 |

Table 2 show results using nanomaterial-modified wire enamel and unsaturated polyester compared to unmodified. The matrix below suggests that inorganic modified wire enamel or impregnating resin coatings do not significantly impact bond strength.

Table 2

| Wire | UPE | Bond, 25°C, lbs | Bond, 150°C, lbs |
|------|----------|-----------------|------------------|
| 1 | Std | 27 | 3 |
| 2 | Std | 24 | 3 |
| 3 | Std | 25 | 3 |
| | | | |
| 1 | Nano-mod | 27 | 3 |
| 2 | Nano-mod | 29 | 3 |
| 3 | Nano-mod | 26 | 3 |

Wire 1 is Internal Lube B (no external lube)
 Wire 2 is Internal Lube C (no external lube)
 Wire 3 is Internal Lube C nanomodified (no external lube)

Tables 3 and 4 contain helical bond strength data for three different commercially available magnet wires. All wires were 18 AWG with MW35 construction. All wire samples were also observed to contain an external lubricant. Table 3 compares the magnet wire vendors with a styrene based UPE while Table 4 compares the same wire samples with a vinyl toluene (VT) based UPE.

The styrene based UPE appears to be slightly better in bond strength compared to the VT UPE. No discernable difference was noted between bond strengths of the various samples at the 25° C or 150° C test temperatures. Dwell times also had little impact on overall bond strength between the primary and secondary insulation.

Of most interest is the relative difference in bond strength between the three magnet wire vendors. Vendor 1 magnet

wire had poor varnish adhesion to both styrene and VT based UPE resins. Vendors 2 and 3 demonstrated comparable helical coil bond strengths to both styrene and VT based UPE resins.

Table 3

| Wire Mfg. | Dwell time (minutes) | Bond, 25°C, lbs | Bond, 150°C, lbs |
|-----------|----------------------|-----------------|------------------|
| Vendor 1 | 1 | 7 | 3 |
| | 10 | 12 | 2 |
| | 30 | 11 | 2 |
| | 60 | 11 | 2 |
| | | | |
| Vendor 2 | 1 | 17 | 3 |
| | 10 | 18 | 3 |
| | 30 | 22 | 3 |
| | 60 | 21 | 3 |
| | | | |
| Vendor 3 | 1 | 17 | 3 |
| | 10 | 16 | 3 |
| | 30 | 19 | 3 |
| | 60 | 16 | 3 |

Table 3 results are focused on immersion dwell time and UPE (Styrene) type impacts on bond strength.

Table 4

| Wire Mfg. | Dwell time | Bond, 25°C, lbs | Bond, 150°C, lbs |
|-----------|------------|-----------------|------------------|
| Vendor 1 | 1 | 10 | 1 |
| | 10 | 11 | 1 |
| | 30 | 9 | 1 |
| | 60 | 9 | 1 |
| | | | |
| Vendor 2 | 1 | 15 | 2 |
| | 10 | 17 | 2 |
| | 30 | 15 | 2 |
| | 60 | 15 | 2 |
| | | | |
| Vendor 3 | 1 | 15 | 2 |
| | 10 | 15 | 2 |
| | 30 | 12 | 2 |
| | 60 | 12 | 2 |

Table 4 results are focused on immersion dwell time and UPE (Vinyl Toluene) type impacts on bond strength.

Another set of experiments involved the use of a long chain unsaturated material, lauryl acrylate. The idea was to allow the long chain portion of the molecule to interact with the paraffin waxes of the wire lubricants while the unsaturation would be crosslinked with the unsaturation of the polyester

in the secondary coating. These experiments involved the same vendors used in the work documented in Tables 3 and 4. The level of the lauryl acrylate was also varied to identify any trends based on loading levels. The lauryl acrylate was simply blended into the unsaturated polyester used as the secondary coating. The results are listed below in Table 5.

Table 5

| Wire Mfg. | Lauryl Acrylate Level, % | Bond, 25°C, lbs. |
|-----------|--------------------------|------------------|
| Vendor 1 | 1 | 12.8 |
| | 3 | 8.4 |
| | 5 | 7.2 |
| Vendor 2 | 1 | 19.4 |
| | 3 | 17.2 |
| | 5 | 13.5 |
| Vendor 3 | 1 | 16.7 |
| | 3 | 16.2 |
| | 5 | 11.4 |

C. Conclusions

The impact of wire lubrication, internal and external, is obvious showing a 25-35% reduction in bonding strength.. This effect is due to an inability for the secondary insulation to wet the wire surface as effectively as non-lubricated samples.

Nanomaterial modification within the context of this study shows no impact, positive or negative, on the bonding parameters. These were simple blends with no attempt to optimize the resin functionality or nanomaterial type to improve this performance characteristic.

Internal Lube A was observed to have improved helical coil bond strength compared to either Internal Lube B or C. This improvement is apparent even with an external lubricant. Both static and dynamic COF values for all three lubricants were equivalent.

The modification with a “di-functional” material, lauryl acrylate, did not have the desired impact. Actually the results indicate that increased loadings of this material decreased the bond strength. There may actually be a plasticization effect taking place where the crosslink density is being sufficiently reduced to lower the bonding at higher levels of long chain material.

Not all results from the test protocols for this study have been reported due to deadlines for publication. Additional

results and discussion will be shown during the presentation portion of the conference.

Further work will more fully explore the results using additional modifications to improve the system properties of the primary/secondary combinations. These directions will undoubtedly involve the modification of the polymer backbone as well as continued blending of multifunctional materials.

Thomas Murray received his Ph.D. in Organic Chemistry from the University of Illinois, Urbana-Champaign in 1994. Career achievements include innovative contributions in photothermography, evanescent wave biosensors and holography while at 3M. In his current position he is the Director of R&D for the Wire Enamel Group at The P.D. George Company in St Louis, MO; a company of ALTANA Chemie.

Ron Goetter received his BS in chemistry from Southern Illinois University at Edwardsville in December of 1987. He received his MS in organic chemistry from Southern Illinois University at Edwardsville in March of 1991. His professional career has included positions in product development and R&D with The P.D. George Company and Union Camp. In his current position he is the Director of R&D for the Impregnating Resin and Compounds Business Lines at The P.D. George Company in St Louis, MO; a company of ALTANA Chemie.