

New Technology of Polyamideimide Wire Enamels

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Abstract Polyamideimide coatings on magnet wire offer the best performance in chemical resistance and toughness. The thermal properties of polyamideimide coatings are also outstanding when compared to the cost of polyimide resins. Recent developments in polyamideimide resins are discussed and future trends-product offerings are also reviewed. Developments include corona resistance enamels, self-lubricated and high abrasion resistance coatings. The hybrid car industry offers opportunities for further innovations in magnet wire coatings.

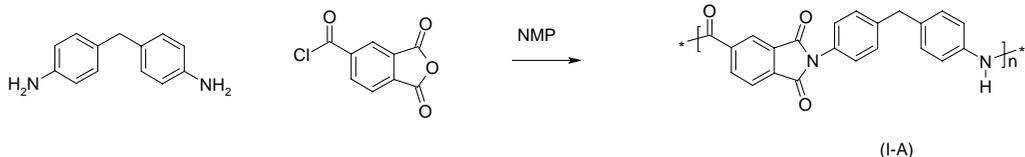
Key words polyamideimide, wire enamel, top coat, abrasion resistance

1 Background

Polyamideimide (PAI) resins were first discovered by Amoco chemists in the 1960's.^[1] The reaction between trimellitic acid chloride and an aromatic diamine such as methylenediphenylamine (MDA) yields a

polyamideimide resin (Scheme I). This product typically was thin film evaporated to yield a yellow powder with trace levels of chloride ion. The resin could then be re-dispersed in N-methylpyrrolidone (NMP) at roughly 20-40% solids with viscosities of 500-6,000 cps.

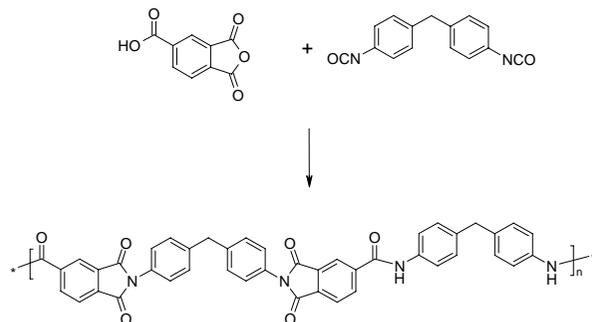
Scheme I



The high commercial costs of trimellitic acid chloride, removing the chloride ions and re-dispersing the resin was not acceptable to the electrical insulation market. A second route that was cost effective was pursued in synthesizing PAI resins.

Methylenediphenyldiisocyanate (MDI) and trimellitic anhydride (TMA) were observed to condense together to yield the PAI resin shown in Scheme II. Although the exact mechanism is not fully understood, many key steps are well characterized.^[2]

Scheme II



Patents by Nexans, Phelps Dodge and others include various permutations to the above formula.^[3] This includes the use of adipic acid, isophthalic acid and other diacids as a fractional molar replacement of TMA. Changes to the backbone also include substitution of some to all of the MDI with alternate diisocyanates.^[4]

2 Recent Innovations

Abrasion Resistance: Winding of motors and other electrical devices has been seeing a tremendous speed increase in recent years. In order to maintain low defect rates for the manufacturer, magnet wire coatings have had to improve their abrasion resistance to the winding process.

A new coating being offered by The P.D. George Company is AI Select™. This coating has shown significant improvements in abrasion resistance as detailed below. An additional benefit is the high solids content (35-37%) with low viscosity (800-1500 cps @ 25 C).

A patented process allows one to change the glass transition (Tg) through control of the cross-link density.^[5] In Chart 1 a control material (a conventional PAI) is compared to AI Select™ using differential scanning calorimetry (DSC). The glass transition of the conventional PAI observed to be around 280 C even after three heat/cool cycles. AI Select on the other hand increases in Tg on each heat/cool cycle, from 280 C to greater than 350 C.

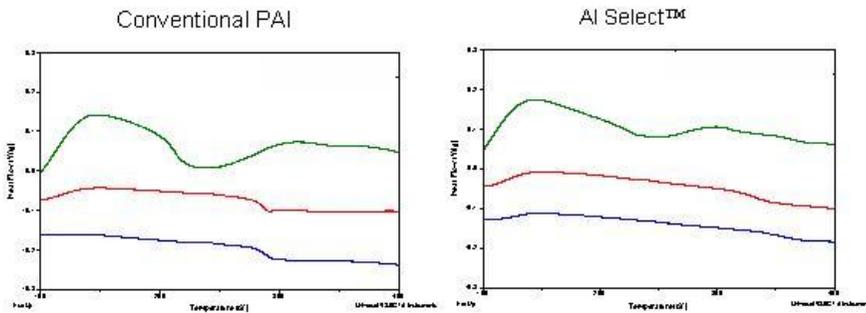


Chart 1: DSC curves (three heating cycles)

The repeated scrape test is a widely recognized and employed measure of abrasion resistance for wire coatings. The repeated scrape test consists of a test wire suspended adjacent a pendulum having a needle attached at the end thereof. The needle swings back and forth scraping the coating on the periphery of the wire. A defined loading is applied to the pendulum providing a controlled force to the needle against the wire. For the examples described herein, the control and test wires were tested under a 700-gram load pendulum scraper for an 18 gauge (1 mm diameter)

copper wire. The number of strokes (Rptd. S.) it took the scraper to wear through the coatings was recorded. A greater number of strokes before failure indicated a more abrasion resistant coating. AI Select™ is shown to roughly double the abrasion resistance compared to the control material.

Table I: Repeated Scrape

Resin	Strokes
AI Select™	200-400
Conventional PAI	100-200

Additionally, Al Select™ topcoat improved the unilateral scrape resistance. This test determines the scrape abrasion resistance of magnet wire insulation. The scrape head applies an increasing load to the magnet wire insulation until a fault occurs. The scrape head speed is set at 16 inches per minute. The wire sample is rotated through 0°, 120° and 240° after each test, allowing 3 scrape tests per sample.

Table II: Unilateral Scrape

Resin	Grams
Al Select™	1700-1800
Conventional PAI	1500-1600

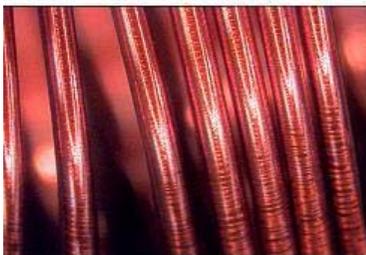
The thermoplastic flow test determines the capacity of the magnet wire insulation to resist thermoplastic flow (softening) under the influence of

temperature, load (pressure), and time. The specimen test voltage was set at 110 volts AC. The test temperature rate of rise was set at 5°C per minute with a load of 975g. Al Select™ wire coatings are observed to have a 10°C improvement in cut-through compared to the control sample.

Table III: Thermoplastic Flow

Resin	°C
Al Select™	390-400
Conventional PAI	380-390

A side benefit to Al Select™ coatings is the improved resistance to solvent crazing. This is important in the impregnation of motors with secondary insulating materials. Crazing of the coating can lead to dielectric failures in the finished product.



Typical Solvent Crazing



Al Select™

Chart 2: NMP craze resistance

Corona Resistance: Inverter duty motors are gaining popularity across the globe. Inverter duty motors are designed for optimized performance when run with variable frequency controllers. A wide range of products are available including energy efficient motors, RPM A-C motors offering superior constant horsepower ranges, and V*S Master motors offering full torque from 0 – 60 Hz. Inverter Drive Motors are wound with 200 C moisture resistant Corona resistant magnet wire

which dramatically extends the life of the motors compared to motors wound with non-corona resistant wire.

The Corona resistant magnet wire dissipates charge build up at the surface thereby minimizing the damaging effects of corona formation. The Corona Clear coatings offered by The P.D. George Company use semiconducting nanoparticles to achieve optimum charge dissipation while offering excellent coatability and dispersion

stability.^[5] Applications include conveyors, pumps, fans, metal processing, compressors, test stands, and material handling equipment.

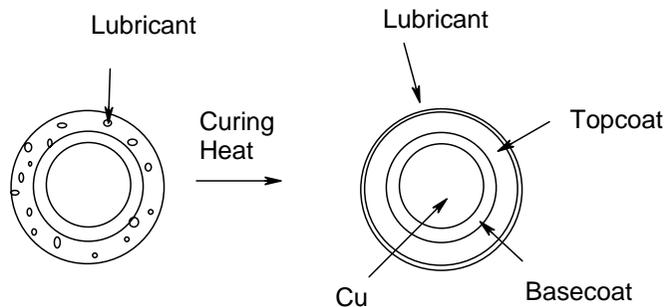
Internal-Lubrication: Lubricated wire has traditionally been an external process in which a lubricant solution is applied after enameling by a felt pad. A second approach is to utilize a nylon overcoat to improve lubrication, however, the nylon reduces the thermal characteristics of the underlying wire.

A third approach involves the use of an internal lubricant in the outer layer of the wire. The lubricant is typically incompatible with the base resin and is expelled to the surface upon curing of the coating.

Self-lubricated PAI has been approached by the third method detailed above. PAI is dissolved in a mixture of

aromatic hydrocarbon and NMP. An internal lubricant is mixed with the resin solution. The internal lubricant can be a PE wax, natural wax, fatty amide, fatty acid, PTFE, silicone, or other slip agent. Most of these materials are insoluble in the solvent mixture and are in fact dispersions. The topcoat has a dried thickness of approximately 10 microns and the coating process achieves a temperature of at least 205 °C on the wire. This means that lubricants with melting points lower than 205 °C will melt during the coating process. For example a polyethylene wax with a melting point of 100 °C will melt and most likely tend to phase separate from the PAI resin. As the wax migrates to the surface a thin film will develop which will perform as the lubricant for the wire sample (Scheme III). A thickness estimate of wax on the surface is between 10-200 nm.

Scheme III



A number of problems are associated with this technique. First, the wax dispersion in NMP tend to float to the surface. The wax blooming to the surface also creates a potential problem. Due to differences in index of refraction, an optical effect can be observed from the thin wax outer layer. This is noted as “sparkle” on the wire. While this has no physical impact on the wire performance, the appearance can be problematic to certain customers.

The P.D. George Company has recently been investigating a new dispersion

technique for wax particles in PAI resins.^[6] A variety of waxes have been successfully dispersed in current PAI products with little to no signs of settling with time. We expect to launch a new product line should all the long term aging studies continue to be positive. Excellent COF values are obtained (<0.06 static) with no surface issues.

3 Future Trends

Cost considerations are always critical in the development of coatings for the

magnet wire industry. There will be continued efforts to achieve PAI coatings in alternate solvent systems to NMP.

NMP is also on the environmental watch list in Europe and North America. Europe recently reclassified NMP as a toxic material and its use is foreseen to be dramatically reduced in the EU and possibly NAFTA. A replacement solvent N-ethylpyrrolidinone has been introduced although its long term use is in doubt with the same concerns as NMP.

The introduction of the hybrid car gives some opportunities for PAI resin in the

future as well. Improvements in cut-through and thermal properties for under the hood applications will be needed.

4 References

- [1] "Amoco AI Polymers for High Temperature Applications" Bulletin HT-1 1964, Amoco Chemicals Corp.
- [2] PDG internal report.
- [3] US Patent 436272.
- [4] US Patent 564322.
- [5] US Patent pending.
- [6] PDG internal report.