DuPont Engineering Polymers

Electrical/Electronic Thermoplastic Encapsulation

Toroids from Standex Electronics
Solenoid by Dormeyer
Step Motor from Pacific Scientific

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with DuPont
Engineering Polymers

® DuPont registered trademark

Introduction

Electrical coils and components have for some time been encapsulated or potted with thermosets for protection from operating environments and to provide electrical insulation and thermal dissipation. With their good electrical properties, mould flow characteristics, and low cost, thermosets such as epoxies, phenolics, and thermoset polyesters were until recently virtually the only encapsulation resins used in coil / component encapsulation.

However, encapsulation materials are now shifting in the direction of thermoplastics. This is occurring for reasons of:

- productivity and component integration;
- better physical properties of thermoplastics in thin sections compared with thermosets;
- extensive IEC 85 and UL 1446 Electrical Insulation Systems recognitions for thermoplastics for encapsulated motors, solenoids, and transformers;
- the virtual elimination of volatile organic compounds (VOCs) generated in thermoset potting or encapsulation.

Environmental Considerations

Thermoplastic encapsulation processes use only solid materials that become a melt when heated. The volatile organic solvents used in varnish impregnation are not present, so environmentally harmful solvent emissions are eliminated. Also, parts encapsulated with thermoplastics come out of the moulds ready to assemble without requiring the inherently "dirty" deflashing or trimming operations so often associated with thermosets. The high-impact strengths of engineering thermoplastics in thin sections compared with thermosets also contribute to lower cost because there is significantly less part breakage.

When thermoplastic parts do break or for some reason are not usable, they can be ground up, remelted, and used again in the moulding process. Many of the DuPont engineering thermoplastic resins used in encapsulation have been approved by UL to be moulded using up to 50% regrind.

Global Availability

With technology and production increasingly becoming globally sourced, it is important to use encapsulation resins that are available worldwide and are recognized to internationally important standards, e.g., UL and IEC. The DuPont resins discussed here are generally available worldwide and meet the leading national and international standards.

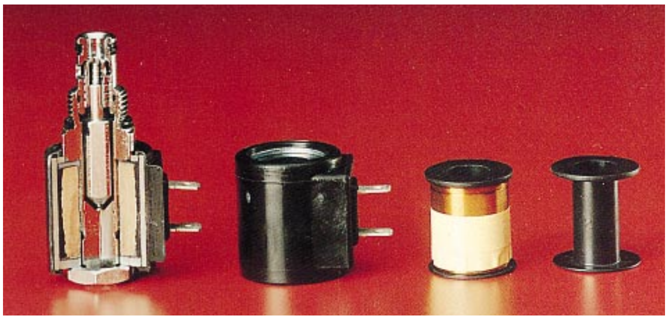


Fig. 1. **Hydraulic cartridge valve from HydraForce. Coil form in RYNITE® 530 (Foremost Plastic Products Co.). RYNITE® encapsulated solenoid produced by Warsaw Coil Co.**

Cost Comparisons with Thermosets

On a *weight basis,* thermosets can cost substantially less than thermoplastics. However, any cost comparison between the two material types must be done on the basis of "finished encapsulated part ready for shipment." Savings found in faster moulding cycles, higher product yields, and fewer secondary operations generally favor thermoplastic encapsulation over thermosets. This is particularly true in high-volume automotive component operations and in encapsulated coils and components where brackets and connectors can be moulded-in during the encapsulation step as value-added features.

The inherently *better toughness* of engineering thermoplastics used in encapsulation compared with thermosets allows use of thinner walls (**Table 1,** page 3).

Fig. 2. **Solenoid coil encapsulated with Zytel® glass-reinforced PA66 nylon resins (ATR).**

Fig. 3. **Antenna coil for automotive auto-theft system. Coil form and encapsulation in Zytel® 77G33 HS1L (Standex Electronics).**

Table 1 Comparative Impact Strengths of Selected Thermosets and Engineering Thermoplastics

	Phenolic Electrical	Alkyd	Thermoset Polyester (Electrical)	30% Glass-Reinforced FR PET Thermoplastic Polyester	33% Glass-Reinforced PA66 Thermoplastic Nylons
Izod Impact J/m ASTM D256	15,5	17,1	53,4	91,0	107 Dry as Moulded

The impact strength of thermoplastics is also a factor in the UL 1446/IEC 85 Insulation Systems recognitions now required in many encapsulated solenoid, motor, and transformer applications. Such recognitions are listed by *thickness of the encapsulation layer.* The required testing (see page 17) includes a vibration step that favours the stronger thermoplastics over thermosets in the thinner sections.

Thermoplastics also generally *mould faster* than thermosets. Cycle reductions of over 50% are frequently found in moving to thermoplastics. Thermoplastics are also more stable in contrast to thermosets, many of which have shelf lives of six months or less. Some thermoset grades must even be refrigerated during storage before moulding. Thermoplastics are also more easily coloured, either through cube blending with concentrates or through full compounding. Some thermosets do, however, offer two advantages compared with thermoplastics. Epoxies, for example, can be used to impregnate thin-wire, high-voltage coils before setting up, and some thermosets transfer heat better than conventional thermoplastics. Recently developed thermally conductive thermoplastics used in transformer encapsulation are even better in heat transfer. The thinner walls and encapsulation layers made possible using thermoplastics also help with heat transfer (see pages 13–15).

Moulding and Tooling Techniques

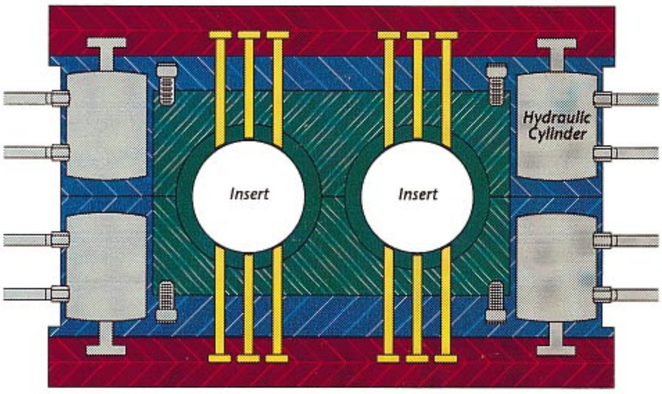
Thermoplastic encapsulation is basically an insert moulding operation. The wound coil or electrical component is inserted into the mould, and the thermoplastic material is injected while lead wires or terminals are clamped off from the resin flow. The object being encapsulated can be held either with stationary pins or hydraulic pins that are withdrawn before the melt freezes. This latter technique was developed by DuPont engineers to encapsulate golf balls with Surlyn® ionomer resins and is now used extensively in the encapsulation of sensors and transformers (see **Figures 4, 5** and **6**).

While some encapsulation is done using horizontal moulding equipment, the preferred encapsulation moulding process is based on vertical clamp machines, which use gravity to hold the coil or insert in place during the moulding process.

The use of shuttle or rotary table moulding presses with two or more lower mould halves leads to maximum productivity. While a device is being encapsulated at the moulding station, an operator or a robotic device can remove finished parts and insert coils at the loading / unloading station(s).

Moulding machines that are convertible from horizontal to vertical modes of operation are also available (see **Figure 5**). This allows, for example, solenoid coil bobbins to be moulded in the horizontal mode and solenoid encapsulation to be run in the same press in the vertical mode. In each case, care should be taken to size the barrel carefully to the shot size and the clamping pressure to part surface area.

Holding Pins Forward



Holding Pins Retracted

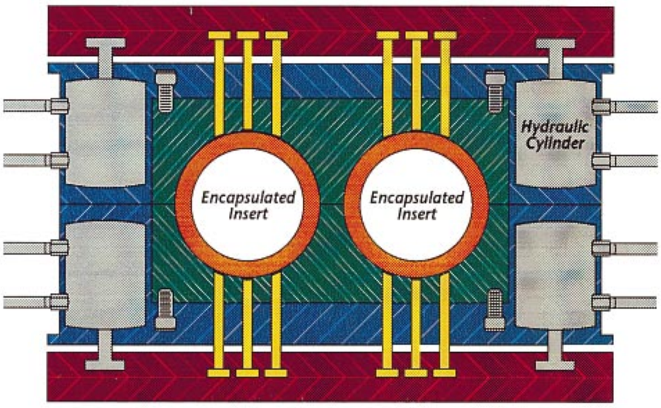


Fig. 4. **"Golf ball encapsulation" using hydraulic pins. As the molten polymer fills the cavity, the hydraulic pins are retracted, leaving behind a perfectly round, encapsulated golf ball. This same technique is used in the encapsulation of sensors and transformers.**

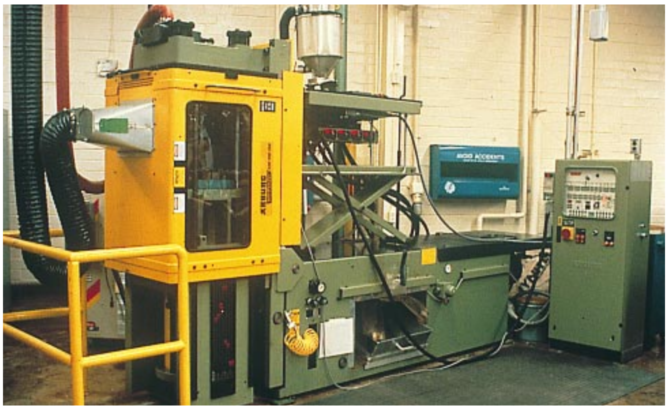


Fig. 5. **Vertical-clamp injection moulding machines are ideal for encapsulation. Unit shown is located at the DuPont Application Technologies Center, where it is used for development and testing of encapsulation materials, tooling, and methods. This unit is also convertible to horizontal operation.**

Fig. 6. **"Golf ball encapsulation" showing uniform wall sections achieved with the use of hydraulic pins (DuPont).**

Tooling

Tooling for encapsulated coils and components consists of two different types. The first is for the coil forms used in many encapsulated applications. The second is for the encapsulation process itself.

In designing and moulding coil forms, great care must be taken to produce fully crystallized products having uniform flanges that are tapered slightly for ease of part ejection. Uniform flanges are important to help safeguard against voids or distortion caused by the shrinkage of the coil form during the encapsulation process.

A modular type of mould can save time and expense in making and modifying prototype bobbins. DuPont engineers developed the design shown in **Figures 7** and **8** using a mould frame from Master Unit Die Products, Inc. It combines a standard frame, side-action mechanism and cooling system with provisions for interchangeable cavity inserts having their own cooling, side-action wedges and various other components that differ according to bobbin size and configuration.

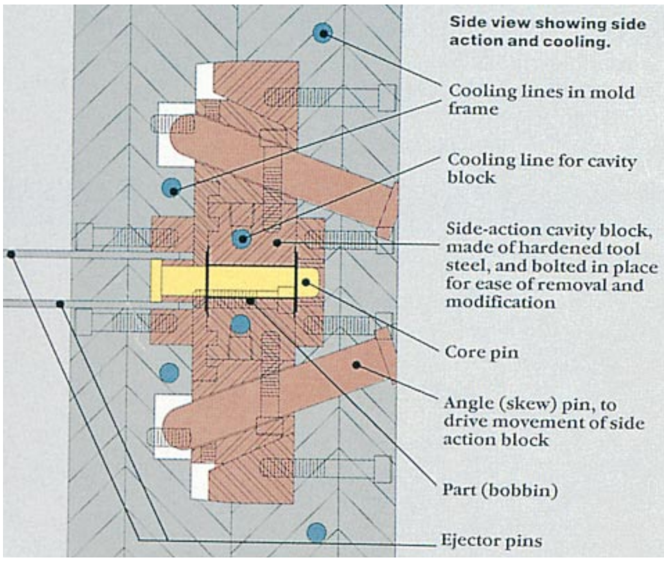


Fig. 7. **Modular mould for solenoid coil bobbins.**

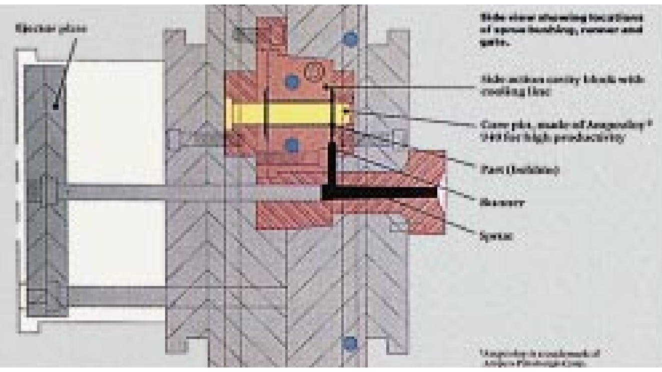


Fig. 8. **Modular mould for solenoid coil bobbins (continued).**

Productivity Tip

For faster cycling of bobbin moulds, we recommend core pins made of Ampcoloy* 940 copper alloy. The core pins generally do not have internal cooling; but because Ampcoloy 940 conducts heat six times faster than tool steel, the pins usually run only 1,6 to 2,2 °C hotter than the rest of the mould. This leads to shorter cycle time than with core pins made of tool steel.

Fig. 9. **Jim Patterson and Tom Boyer of DuPont Engineering Polymers setting up an encapsulated coil moulding trial.**

Gating

To minimize coil distortion, it is essential to ensure equal pressure on windings by filling the mould cavity through two or more gates (**Figure 13**).

Gate Design

The rounded-end design of tunnel gate (**Figure 15**) is a necessity for successful encapsulation. It prevents premature freezing of material at the gate, permits effective packing out to compensate for shrinkage in the relatively thick wall sections often used for encapsulated components, and ensures a good surface finish.

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* Registered trademark of Ampco Metal, Inc., U.S.A.

Venting

Good venting on the mould's parting line ensures maximum strength in weld line areas as well as preventing surface defects. It is also helpful to vent the runners to reduce mould deposit.

Fig. 10. **Automotive engine temperature sensor encapsulated with ZYTEL® glass-reinforced PA66.**

Fig. 11. **Danfoss magnet valve encapsulated in CRASTIN® PBT polyester.**

Fig. 12. **Electrovalve encapsulated with CRASTIN® T805 PBT polyester (CEME, Italy).**

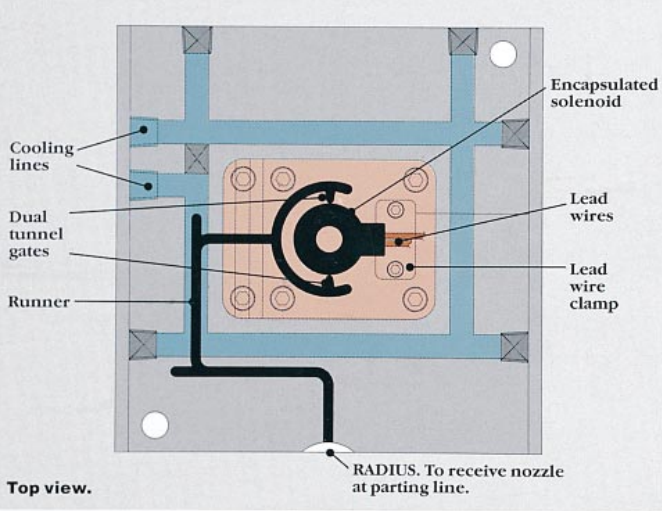

Fig. 13. **Modular mould for encapsulating a solenoid coil in a vertical-clamp press (top view).**

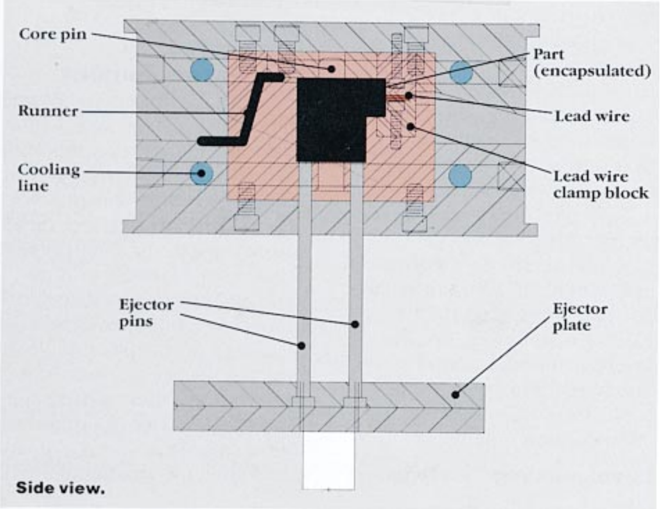

Fig. 14. **Modular mould for encapsulating a solenoid coil in a vertical-clamp press (side view).**

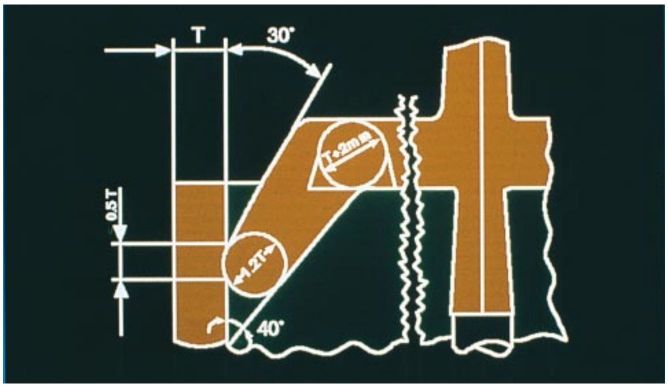

Fig. 15. **Gate design for encapsulation recommended by DuPont.**

Encapsulation Applications

Thermoplastic encapsulation is used in many applications that require some special manufacturing techniques and materials of encapsulation. These include solenoids, sensors, self-supporting coils, transformers, motors, and electronic components of various types.

Solenoids

Solenoids are generally made by encapsulating coils wound on coil bobbins (**Figure 16**). The number one requirement for coil bobbins used in solenoids is that they be fully crystallized, because the subsequent hot encapsulation process can cause additional coil bobbin shrinkage and distortion such as the “bubbles” shown in **Figure 17**. To achieve the full crystallisation needed, the typical minimum recommended mould temperatures for coil bobbin moulding are 100 °C for Rynite® PET thermoplastic polyester resins and 80 °C for Zytel® PA66 nylon resins.

Level or precision-wound solenoid coil winding is recommended whenever possible (**Figure 18**). This allows smooth flow of the encapsulation material over the surface of the windings. Random winding can cause flow problems and magnet wire bunching except in those coils using very fine wire.

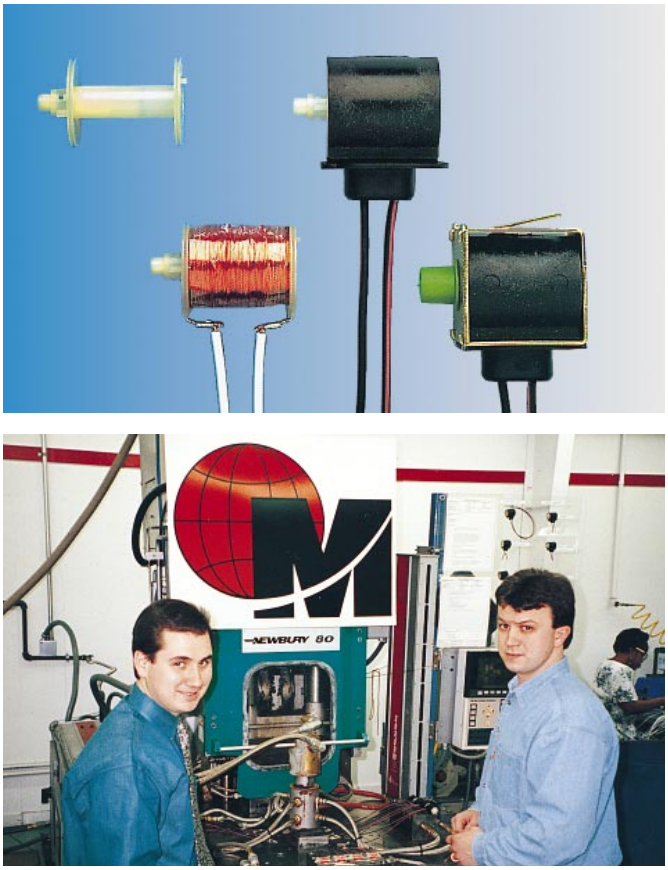

Fig. 16. **Cadillac load leveling system solenoid in Zytel® 70G33 HS1L (top) being produced by René Miller and Joey Champion of Multicraft Electronics (bottom).**

Fig. 17. **Result of encapsulating a wound coil bobbin that is not fully crystallized.**

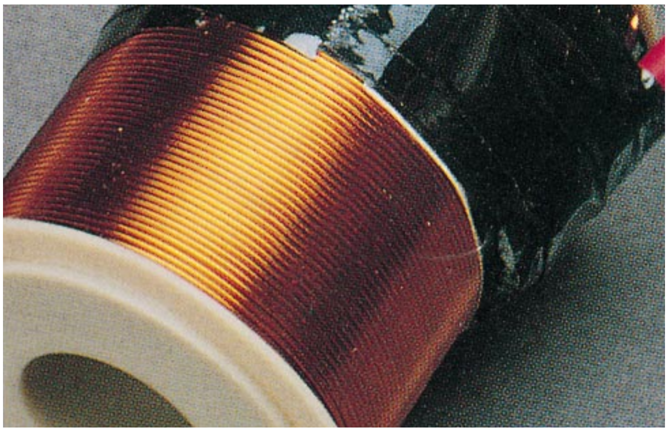

Fig. 18. **Smooth surface of level-wound coil eases flow during fill of encapsulation mould and avoids problems of bunching of magnet wire.**

Taping wound coils prior to encapsulation is not necessary and is not recommended. Also, it is important that good quality magnet wire be used in all encapsulated coils. Any defect in the coating of the magnet wire used will be magnified by the hot melt temperature, high pressure, and shearing action of the thermoplastic encapsulation process.

The metal cans used in many cases with solenoids for magnetic flux reasons are sometimes used as a “shell” into which the thermoplastic encapsulant is injected. Alternatively, the can may be included in the encapsulation layer.

Proper termination of the wound magnet wire on pins inserted into the bobbin flange is also important.
The encapsulation process can cause coil malfunctions if terminations are loose.

Fig. 19. **Appliance solenoid coil encapsulated with RYNITE® PET polyester (Dormeyer).**

Fig. 20. **Double solenoid for fuel pump flow-meter encapsulated in CRASTIN® T805 (Sirai).**

The types and thicknesses of magnet wire enamels are important for successful solenoid manufacturing. For example, thermoplastic-overcoated, polyurethane-enameled wire works far better in thermoplastic encapsulation than wire coated only with a single layer of polyurethane. Also, the thermoplastic encapsulation should be matched to the solenoid end-use environment. For example, in some automotive applications, polyamides function far better than polyesters. Solenoid terminals can be encapsulated in place using a pre-moulded insert. The high strength of the engineering plastics used in solenoid encapsulation help retain the terminals in place as well as permit compact solenoids to be made with encapsulation layers significantly thinner than is possible with thermosets.

Types of encapsulating resin used, moulding conditions, and coil bobbin flange design are all key to manufacturing quality solenoids. In extensive testing at our Yokohama, Japan, research facility, different solenoids having various resin combinations of coil bobbin and encapsulant are tested by first heating them at 80 °C for an hour, immersing them for an hour in a 0 °C, 5% NaCl solution, rinsing them off, and then measuring solenoid insulation resistance values. From this work, we are able to tailor encapsulation resins to meet specific application requirements (**Figure 21**).

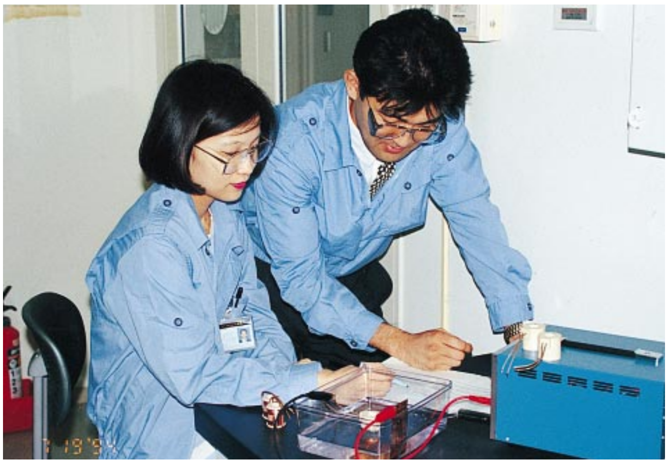

Fig. 21. **Yumiko Nakaniwa and Hajime Shiozawa of DuPont KK (Japan) testing the insulation resistance of encapsulated solenoids.**

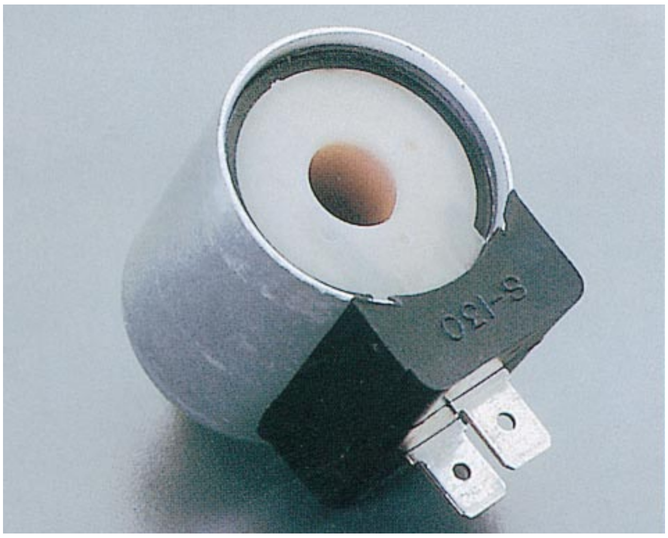

Fig. 22. **Deltrol Controls solenoid with a board mounted bridge rectifier chip encapsulated with RYNITE® 415HP.**

Our testing also shows that minor changes in the flange design of solenoid coil forms can improve solenoid performance dramatically. For example, switching from a flange design with straight ends to one with tapered edges leads to dramatically better adhesion between coil bobbin and thermoplastic encapsulant, because the tapered flange tip melts more easily during the hot encapsulation step than does a straight flange edge (**Figures 23** and **24**).

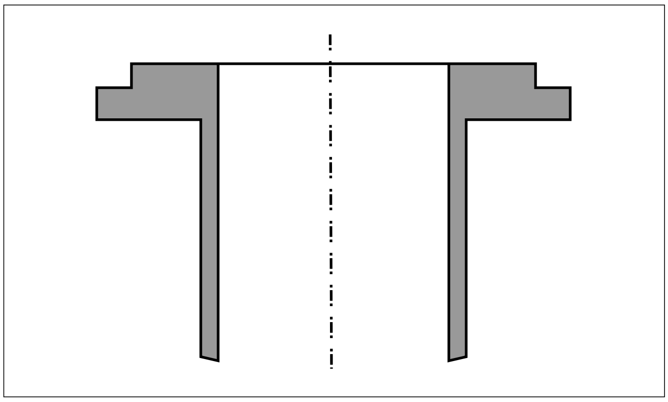

Fig. 23. **Vertical flange.**

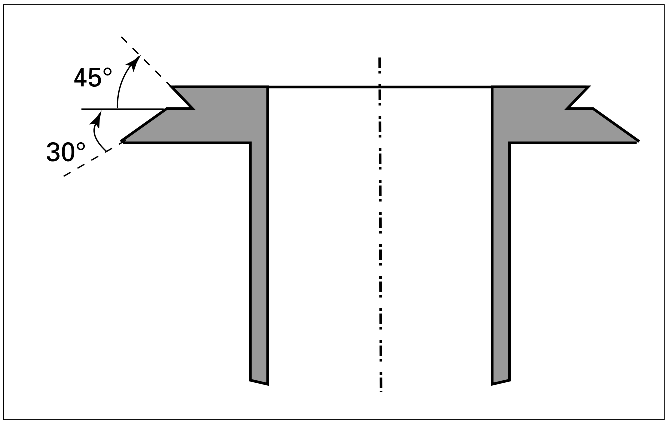

Fig. 24. **Tapered flange.**

Thinner, tapered coil bobbin flanges improve solenoid performance by melting more easily during encapsulation and forming a strong bond with the encapsulant upon cooling. The flange design shown in Fig. 24 is far superior to that in Figure 23.

Finally, solenoids used in appliances and some control systems may have to meet both UL94-V0 flammability and UL 1446 and IEC 85 Electrical Insulation Systems standards. It's important to recognize that both standards have thickness guidelines. Meeting these standards requires that both coil form thickness and encapsulation layer thickness be taken into account. (See **Table 3**, page 18.)

Sensors

The rapid proliferation of electrical and electrical-mechanical systems in automotive, appliance, and industrial applications has dramatically increased the demand for sensors. Sensors are used in such systems to measure variables such as speed, position, temperature, or fluid level. Many are encapsulated to provide insulation and to protect them against moisture, dirt, or mechanical damage. An example is the wheel speed sensor, shown in **Figure 25**, encapsulated with a glass-reinforced PA66, ZYTEL® 70G33 HS1L. Automotive sensors like this one used to require a two-step process: potting the coil in epoxy, followed by overmoulding. Today, the same part is encapsulated in a single step. Note that the metal inserts in the mounting flanges are moulded in. The cable is provided with a grommet and the encapsulation mould is designed to support the grommet and prevent flashing down the cable.

Fig. 25. **Wheel speed sensor encapsulated with glass-reinforced ZYTEL® PA66.**

Another major type of sensor being used in increasing numbers is the "Hall Effect" or electronic sensor. This type of sensor is used in ignition and transmission control applications as shown in **Figure 26**.

The primary challenge in encapsulating "Hall Effect" sensors is to avoid damage or displacement of their integrated circuit chips, other delicate components, and connections among them. In relatively simple sensor constructions, success has been achieved using conventional polyester resins and slow injection rates. The hydraulic pin configuration discussed (page 4) in golf ball encapsulation is also used in encapsulating electronic sensors.

Fig. 26. **Typical "Hall Effect Sensor."**

Glass-reinforced (GR) PA66 resins are widely used in sensor encapsulations. However, in more complex constructions involving multiple components, crimped connections, or other delicate assemblies, prototype work has shown that (GR) PA612 can produce even better encapsulated sensors than those encapsulated with either (GR) PA66 or PBT polyester. The reason is that the (GR) PA612 has a slower crystallisation speed than either of the other two resins. It also has higher flow and lower moisture absorption than (GR) PA66 and excellent elongation at low temperatures. The net result is an encapsulated sensor with much better adhesion between coil bobbin and encapsulation layer and better resistance to thermal shock cycles.

"Wire friendly nylons"

The abrasion of magnet wire enamel during winding or handling can open the way to electrolytic corrosion of the wire. Given the right conditions of moisture, temperature, time, and certain additives contained in many thermoplastic resins, electrolytic corrosion of any exposed conductor wire can occur, sometimes quite rapidly. However, as a practical matter, wire corrosion is rarely an issue for sensors that use 30 AWG or larger magnet wire because surface oxidation is insignificant compared to the volume of copper that must be corroded to cause failure. However, wires used in many sensors are much finer, typically AWG 39 to 50, and these can be affected more easily.

To prevent this destructive wire corrosion, new DuPont encapsulation resins called "Electrical / Sensor Resins" have been formulated for fine-wire encapsulations. They virtually eliminate the potential for electrolytic corrosion of magnet wire with punctured coatings. Both (GR) PA66 (Zytel® FE5389 BK-276) and (GR) PA612 (Zytel® FE5382 BK-276) resins of this type have been introduced for the encapsulation of sensors and other fine-wire electrical components (see pages 18 and 19).

For encapsulated sensors having to take very high temperature spikes, e.g., during soldering processes, both Zytel® HTN high temperature nylon and Zenite™ liquid crystal polymers (LCP) can be used. (Some additional sensors are shown below in **Figures 27, 28** and **29.**)

Fig. 27. **Motor "knock" sensor encapsulated in Zytel® 70G25.**

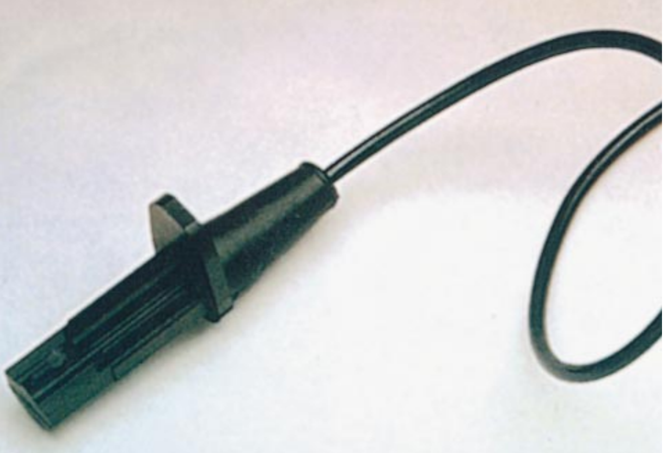

Fig. 28. **Wheel speed sensor for ABS system encapsulated in Rynite® 530 PET.**

Fig. 29. **Temperature sensor for outside of car, encapsulated in Delrin® 107 acetal resin.**

Self-Supporting or Bonded Coils

A particularly noteworthy type of coil now being used in thermoplastic coil encapsulation is the “self-supporting coil.” Self-supporting coils are just that: they do not depend on an independent coil form for support. Where feasible, assembly costs are lowered and manufacturability is enhanced (**Figures 30** and **31**).

The self-supporting or bonded coils are formed by winding a bondable magnet wire on a mandrel. The coils are then charged electrically to melt the adhesive coating, compressed, cooled, and ejected from the rotary head winder used in their manufacture. A major supplier of such coils is Alcoils located in Columbia City, Indiana, U.S.A.

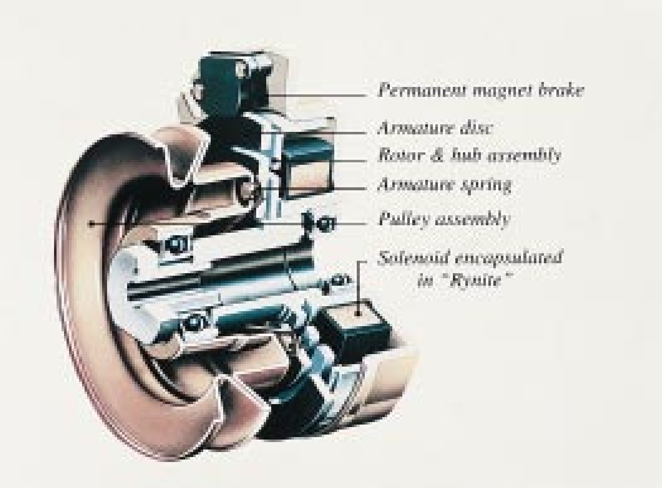

Fig. 30. **Warner Electric’s “Mag Stop” clutch and brake solenoid for riding lawn mowers encapsulated with Rynite® PET. The clutch solenoid is wound without coil bobbins, with the wire insulation being heat bonded to retain shape during encapsulation by Alcoils.**

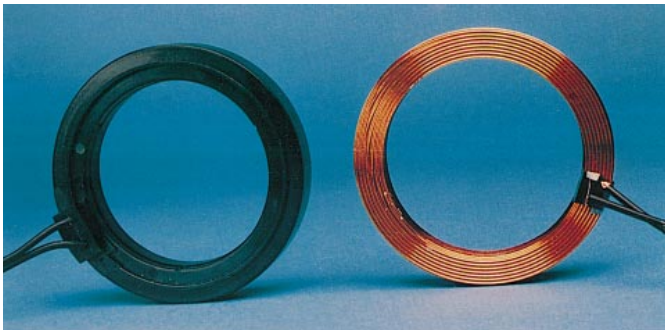

Fig. 31. **Warner Electric’s self-supporting clutch coil for automotive air conditioners encapsulated in Zytel® 70G33 L. Interchangeable mould permits use of the same tool to encapsulate coils terminated with either leads or connectors.**

Toroids

Toroids used for power filtering applications are another type of coil well suited to thermoplastic encapsulation. Conventionally potted with epoxies in either thermoset or thermoplastic cups, toroids encapsulated instead with engineering thermoplastic resins can generally be produced more quickly at significantly lower costs. In the case of the Standex encapsulated toroids (**Figure 32**), encapsulation with Zytel® glass-reinforced PA66 or PA612 nylon resins is done in multiple-cavity tooling in less than a minute; epoxy potting in a thermoset cup can take up to 24 hours of epoxy cure time.

Fig. 32. **Zytel® nylon resin encapsulated toroids for surface-mount applications (Standex Electronics).**

Motors

Motors are another area in which thermoplastic encapsulation is beginning to expand rapidly, particularly in stator insulation. Being replaced are the tapes, films, etc., used in conventional motor insulation. Complexity of encapsulation can vary from the small Hansen stator coils shown in **Figure 34** to the larger and more intricate Cadac (**Figure 35**) and Pacific Scientific (**Figure 36**) encapsulated stators. Using the steel laminate covers as an insert, the stator is made in a one-step overmoulding operation. Encapsulation provides slot and end insulation, termination holders, contour supports, and guide posts for windings – all in a single moulding step.

Fig. 33. **Steve Fecanin of DuPont Automotive working on another coil project.**

Fig. 34. **Encapsulated stator coil replaces a tape-insulated unit in a hysteresis synchronous motor that operates timing devices, vents, and valves in heating, ventilation, and air conditioning equipment. Both coil bobbins and encapsulation are in ZYTEL® PA66. Encapsulated coils withstand 3000 V versus a test limit of 2200 V for the taped coils being replaced (Hansen Corp.).**

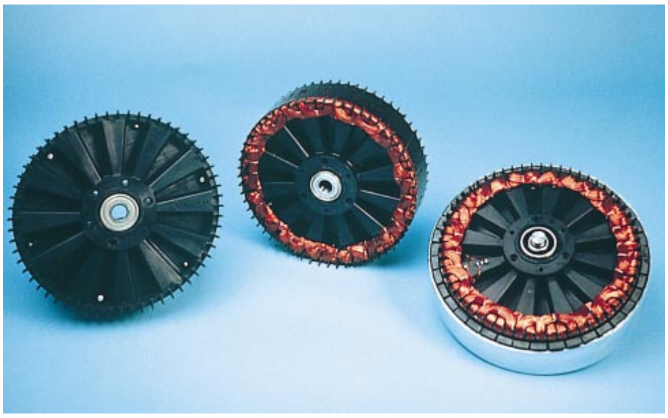

Fig. 35. **When used in a washing machine, this very energy-efficient Cadac 1,3-HP (1-kW) DC motor eliminates the need for a gearbox. Stator components in RYNITE® PET are part of an UL 1446 Class F (155°C) Electrical Insulation System.**

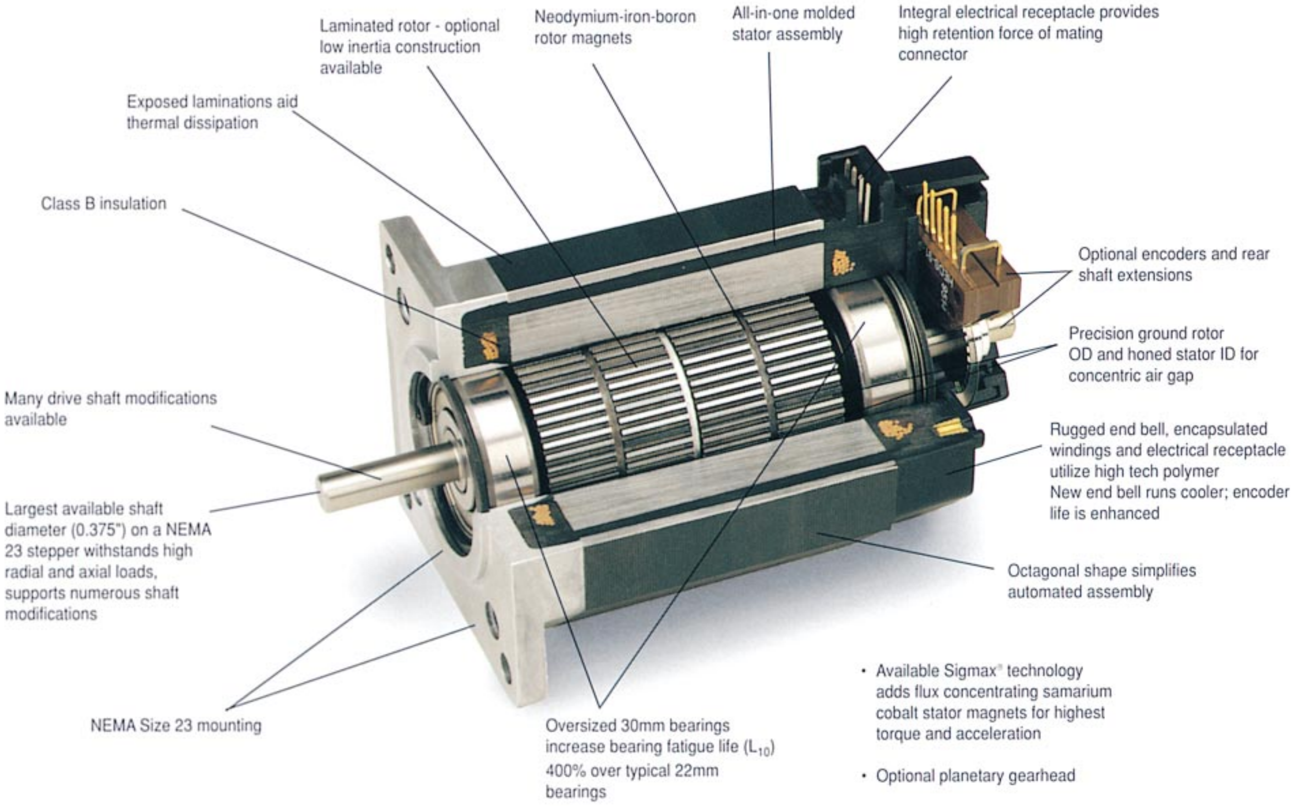

Fig. 36. **Key to the Pacific Scientific step motor encapsulation is the replacement of the aluminum rear end bell, an 8-pin connector and epoxy potting with RYNITE® 530 polyester in one moulding operation. This thermoplastic encapsulation also eliminates eight connectors and a circuit board, reduces production time from the 2 hours spent on epoxy potting to 45 seconds and forms an end bell that runs significantly cooler than the aluminum end bell used before.**

UL flammability and insulation system recognitions are also as important in motors as they are in transformers. DuPont qualifies all of its open UL 1446 insulation systems using motorettes so that the results are applicable to both motors and transformers. Encapsulated insulation systems are qualified using encapsulated coils for use in both solenoids and motors (see UL 1446 insulation systems, page 17).

Transformers and Lighting Chokes

Encapsulating transformers and lighting chokes with thermoplastics is basically the same as for solenoids and sensors and generally follows the same principles. As in the encapsulation of solenoids and sensors, transformer connectors or terminals can be moulded in. Coil forms with stepped configurations or the usual tapered flanges are used to ensure a secure bond with the encapsulation material, and coil windings are wound smooth to ease thermoplastic flow during encapsulation. Differences found in transformer encapsulation compared with the others include the large size of some of the encapsulated transformers, the use of conductive resins to remove heat from the coils / laminations, and the use of thermoplastic compression moulding compositions to encapsulate transformers larger than 3 kVA. Rynite® thermoplastic PET polyesters are generally used in transformer encapsulation because continuously operating transformers require encapsulation resins having higher relative thermal indices (RTI) than those of polyamides.

While transformers and lighting chokes have been encapsulated with potting thermosets for years, the same needs for higher productivity, cleaner environmental processing, and better product designs driving the thermoplastic encapsulation of sensors and solenoids are also applicable here. The growing importance of UL 1446 insulation system recognitions is also a driving force, because thermoplastics are able to achieve such recognitions at thinner encapsulation thicknesses than are possible using thermosets. Thermoplastic encapsulation also leads to a better locking of the lamination plates and less noise than can be achieved with thermosets.

We divide encapsulated transformers into three classes, based on size: 0 to 500 VA, 500 VA to 3 kVA, and 3 to >100 kVA.

0 to 500 VA

These are relatively small transformers that are encapsulated just like sensors and solenoids using conventional thermoplastics and moulding techniques. A good example is shown in **Figures 37** and **38** from DuPont U.S. Patent 5,236,779. In comparing small, epoxy-potted 20–50 VA transformers with the same transformer fully encapsulated with Rynite® FR530, we found that the operating temperatures for the encapsulated transformer were 10 °C lower than those for the potted transformer. By adding a layer of thermally conductive polyester resin containing carbon, we were able to reduce the transformer operating temperature yet another 14 °C.

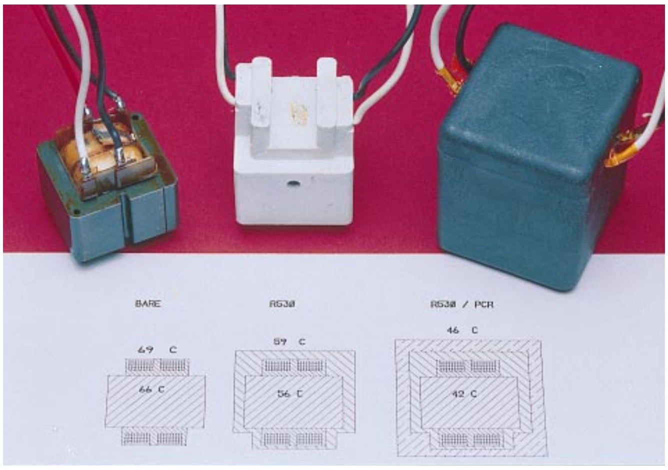

Fig. 37. **This example from U.S. Patent 5,236,779 to DuPont shows the effect on transformer operating temperature by first encapsulating with Rynite® PET polyester and then overmoulding that with a thermally conductive Rynite® containing carbon.**

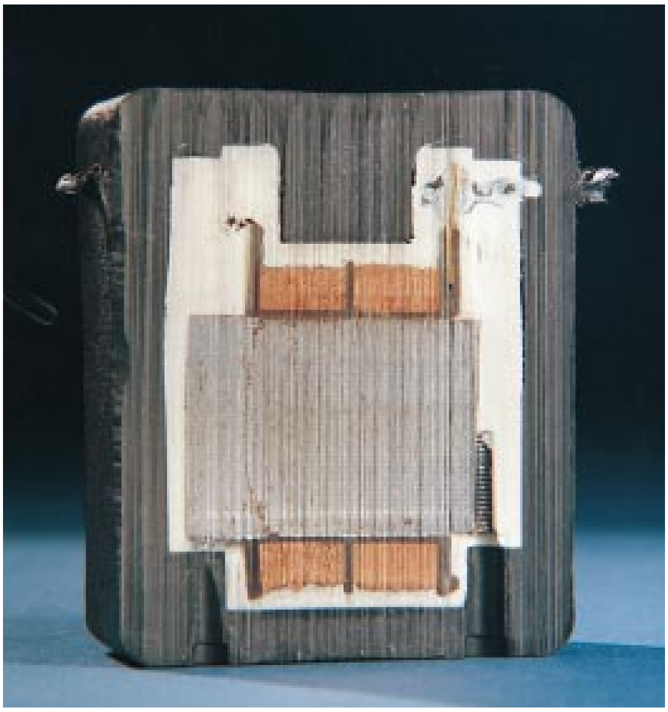

Fig. 38. **Cross section of the transformer above.**

While heat transfer through the RYNITE® PET polyesters is rather low at about 0,23 W/m-K, Philips found in 1988 that replacing the PA 66 encapsulating their 250 W and 400 W lighting chokes with RYNITE® 935 still resulted in a 2–3 °C lower heat rise (**Figure 41**). To minimize the unit heat rise further, Philips lighting chokes are encapsulated only on five faces. The exposed laminations on the base face are attached to the metal base plate to maximize heat transfer.

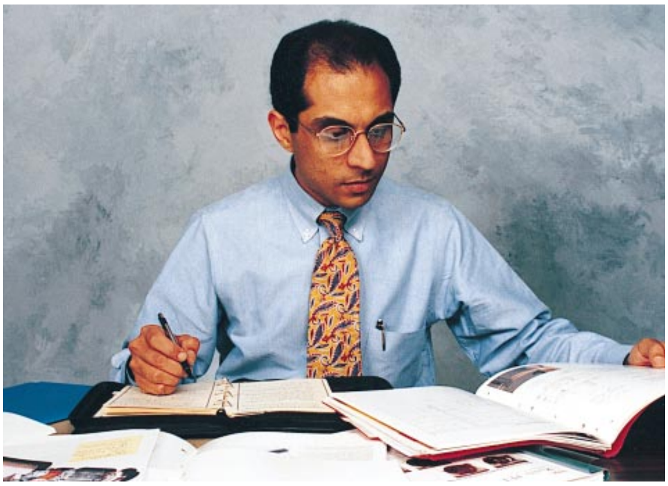

Fig. 39. **Rakesh Puri, DuPont Americas Encapsulation Leader, planning another project.**

500 VA to 3 kVA

Transformers of this size can be encapsulated through injection moulding; however, heat buildup begins to become a problem. One possible solution here is the use of conductive thermoplastics such as RYNITE® CR503 PET polyester which has a thermal conductivity of 1,5 W/m-K, some six times that of normal RYNITE®. Because the conductivity is enhanced through selected carbon additives, these compositions are electrically conductive as well. Therefore, a transformer encapsulated with this resin has to be insulated electrically in various areas before overmoulding with the conductive layer. This is illustrated in **Figure 38**. Note, too, the use of a three-flange coil bobbin with the tapered flanges used to get a good bond with the insulating encapsulation layer of RYNITE® FR530 PET polyester (white).

Resin selection for transformer encapsulation is particularly important because of product requirements involving heat transfer, thermal cycling, insulation systems recognitions, and long-term thermal stability. In addition, if both conductive and insulating resin layers are used, the interface between the layers must be void-free for optimum heat transfer. These requirements favor the polyesters over polyamides for transformer encapsulation.

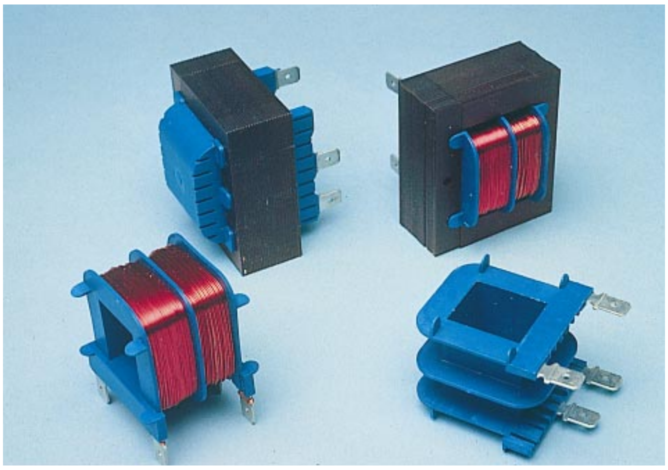

Fig. 40. **Valentine Technologies Class II transformer with coil bobbins and encapsulation in RYNITE® FR 530 polyester.**

Fig. 41. **Philips lighting choke transformers (250 and 400 W) for gas discharge lighting encapsulated in RYNITE® 935, a PET polyester with glass and mineral reinforcement.**

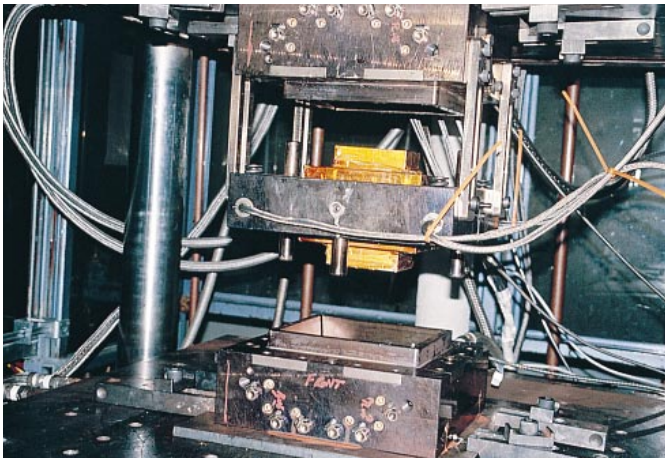

Fig. 42. **A 400-ton compression moulding press at DuPont's Application Technologies Center (ATC) holding a mould and a 3 kVA transformer being encapsulated with SC 125 mouldable composite sheet. (See U.S. Patents 5,236,779 and 5,338,602 to DuPont).**

3 to >100 kVA

The thermoplastic encapsulation of larger transformers (3 to >100 kVA) is particularly challenging for a variety of reasons. Incumbent dry-type transformers of this size go through heat cycles up to 200 °C. Therefore, any thermoplastic encapsulation layer of such a transformer has to be able to withstand significant thermal cycling without cracking and be able to dissipate heat.

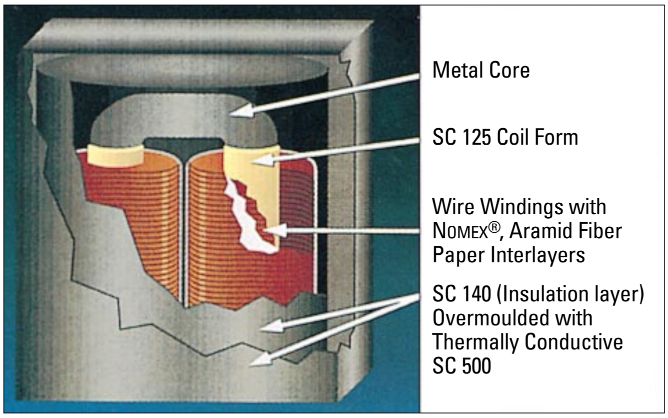

Fig. 43. **Concept drawing of a thermoplastic encapsulated distribution transformer. Such transformers in the 100 kVA range are now under development.**

Also, a 3 kVA transformer contains 20 kg of coils and laminates and requires 2 kg of thermoplastic encapsulation resin. Dealing with this size of shot in injection moulding requires prohibitive investments in both tooling and moulding equipment. In addition, experiments carried out at DuPont show that it is unlikely that, for this size transformer, injection moulded encapsulation layers can survive heat cycles to 200 °C without cracking.

In order to fulfill these requirements, DuPont has developed a proprietary thermoplastic, compression mouldable composite sheet (MCS) approach to the encapsulation of large transformers. In the thermoplastic encapsulated transformer concept shown in **Figure 43,** the transformer is overmoulded with a layer of electrically insulating, thermoplastic SC 140 and a layer of thermally / electrically conductive SC 500. Properties of the DuPont thermoplastic MCS materials are shown in **Table 2**.

Fig. 44. **DuPont Distribution Transformer Encapsulation Team of Bob Ward, Dr. Lana Sheer, and Gary Kozielski examine an SC 500 encapsulated transformer and the ZYTEL® HTN coil bobbin from Miles Platts that goes into it.**

Table 2 DuPont Mouldable Composite Sheet Preliminary Physical Properties (23°C)

Property	SC 125	SC 140	SC 500
Thermal Conductivity (W/m-K)	0,3	0,3	>3,4
Volume Resistivity (ohm-cm)	1×10^{16}	1×10^{16}	0,05
Tensile Strength (MPa), ASTM D638	180	226	64
Elongation (%), ASTM D638	2,3	2,0	1,4
Flexural Modulus (GPa), ASTM D790	8,3	11	9,4
Specific Gravity, ASTM D792	1,56	1,69	1,81

Electronic Component Encapsulation

Thermoplastic encapsulation of active electronic components such as integrated chips is extremely difficult and rarely done. The reason is that even at low pressures, thermoplastic encapsulation can easily result in fine wire distortions. Also, getting thermoplastics to penetrate tightly wound coils or very fine spaces is quite difficult. Components such as rectifier chips, resistors, etc., can be encapsulated.

Some small assembled circuit boards have also been encapsulated with thermoplastics. However, this can be done only with thermoplastics that have melting points low enough that solder on the circuit boards is not affected and the electronic components are not damaged. An example of an encapsulation resin used here is DELRIN® acetal resin (**Figure 45**). Other resins that can be used here include the low melting point HYTREL® polyester elastomers.

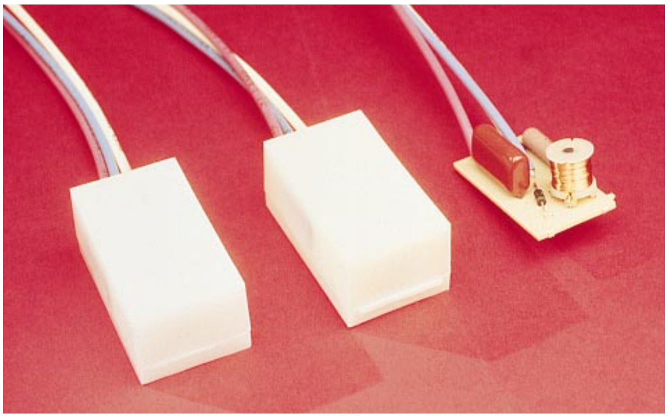

Fig. 45. **Circuit board encapsulated with DELRIN® acetal resin.**

Housings for Potted Coils and Components

For high-voltage coils used in such applications as automotive ignition systems and television flyback transformers, the wire used is too fine and too tightly wound to be encapsulated successfully with thermoplastics. Instead, such coils are vacuum impregnated with epoxies. Coil forms and housings used are typically moulded from CRASTIN® PBT or RYNITE® PET polyesters. Critical to success is the adhesion between the epoxy and thermoplastics used. Poor adhesion leads to minute air pockets being formed. This is an invitation to corona discharge degradation (**Figure 46**).

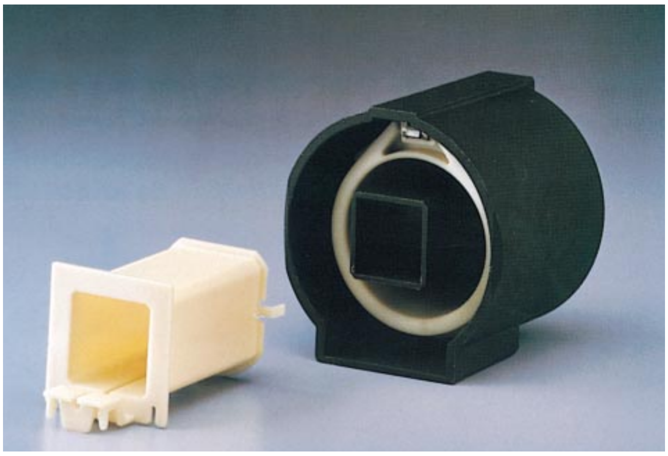

Fig. 46. **Automotive ignition coil and coil bobbins in RYNITE® PET chosen for its excellent dielectric properties, outstanding heat resistance, and ability to provide a good and lasting adhesion between the epoxy and the housing wall (Standard Motor Products, Inc.).**

UL 1446/IEC 85 EIS for Encapsulation

A fundamental requirement for many encapsulated solenoids, transformers, and some motors is that they meet either UL 1446 or IEC 85 EIS requirements (or both). To meet this need, we have gained UL 1446/IEC 85 recognitions for Rynite® PET encapsulation systems in Classes B (130 °C), F (155 °C), and H (180 °C). The successful systems are listed below and in the UL "Yellow Cards" under "Plastic Materials and Electrical Insulation Systems (OBEU2)" for UL 1446 and under "Insulation System Components, electrical, evaluated in accordance with IEC publications (OCTU2)" for IEC 85. We continue to expand our number of recognized encapsulated EIS; as additional systems receive recognitions, they will be listed.

UL standard 1446, paragraph 3.4 defines an electrical insulation system as follows: "An intimate combination of insulating materials used in electrical equipment. For example, the combination of a coil form, separators, magnet-wire coating, varnish, lead wire insulations, and outer wrapping of a relay coil." In the case of encapsulated coils, the combination includes as major components the coil form, the magnet wire, and the encapsulation layer. It is *extremely important* to note that in UL 1446 encapsulation system recognitions, *both* the coil form thickness and encapsulation layer thickness have to be measured.

To gain a UL 1446/IEC 85 EIS recognition is very difficult. At DuPont, UL testing is performed with bifilar wound solenoids that are encapsulated with thermoplastics in our laboratory. After the encapsulated solenoids are approved by a UL engineer, they are tested as follows:

- Heat Ageing
  High temperature: 3-day cycle
  Middle temperature: 7- or 14-day cycle
  Low temperature: 28-day cycle
- Cold Shock
  Hold until stabilized at –20 °C
- Mechanical Stress
  Vibration at 60 Hz for 3 min
- Moisture Exposure
  48 hr at 92–100% RH room temperature
- End of Life Test
  Check for shorted turns.
  Ground insulation dielectrically stressed to ground at two times the rated voltage plus 1000 V for 10 min.

Fig. 47. **The DuPont KK (Japan) Encapsulation Team: Mitsura Shimada, Hitoshi Shibata, Yoshiyuki Kuwazawa, and Tosio Abe.**

For a 600 V system, the test voltage is 2200 V. The test protocol requires that the low temperature have a geometric mean time to end-of-life of at least 5000 hr. The high temperature must have a geometric mean time to end-of-life of at least 100 hours. System evaluations are carried out according to UL 1446.

Using this test procedure, DuPont has obtained UL recognition of the following UL 1446 Listed Insulation Systems for Encapsulated Systems operating at a 600 V maximum (**Table 3**, page 18).

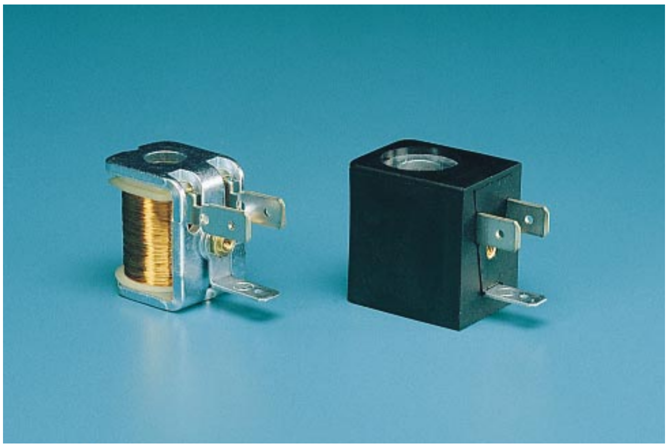

Fig. 48. **Solenoid from Amisco (Cinisello Balsamo, Italy) encapsulated with Zytel® 74G20.**

Table 3 DuPont Electrical Insulation Systems (EIS) for Encapsulation Recognized in UL 1446/IEC 85 Classes B, F and H

System Designation	Coil Bobbin	Magnet Wire	Encapsulant
Class B (130 °C)			
Z110E	ZYTEL® 70G33L, 0,75 mm	MW78	ZYTEL® 5429ER, 0,75 mm
E101N	RYNITE® FR530, 0,75 mm	MW28	RYNITE® FR830ER, 1,07 mm
E102N	RYNITE® 530, 0,75 mm	MW28	RYNITE® 815ER, 0,83 mm
Class F (155 °C)			
E200N	RYNITE® FR530, 0,75 mm	MW80	RYNITE® 815ER, 0,83 mm
Class H (180 °C)			
E300N	RYNITE® RE5220, 0,75 mm	MW35	RYNITE® 830ER: 0,83 mm

Notes:

1. All thicknesses are minimum thicknesses allowed.
2. Numerous minor ingredients (tapes, lead wire, sleeving) are available with these systems. Also, both NOMEX® and MYLAR® have been qualified in several of these systems as interwinding (major) insulation if needed.
3. The 600 V these systems are listed at refers to the input voltage. Output voltages can be considerably higher.
4. These systems are listed in UL File No. E-69939 and can be made available through DuPont.

DuPont Thermoplastic Encapsulation Resins

Most thermoplastic encapsulated coils and E/E components use one of the following DuPont resins: DELRIN® acetal resins, ZYTEL® nylon resins, CRASTIN® PBT and RYNITE® PET polyester resins, and ZENITE™ LCP resin.

Key factors in selecting encapsulation thermoplastic include end-use performance requirements and operating environment, moulding considerations, and costs. Costs are also affected by the availability and pricing of the required coil forms from the major coil form moulders.

DELRIN® Acetals

As noted earlier, DELRIN® acetal resins are used in some printed wiring board (PWB) encapsulations. The reasons include very low moisture absorption and a low 175 °C melting point that allows PWB encapsulation without melting solder traces. Low melting point HYTREL® polyester elastomers can also be used for PWB encapsulations.

ZYTEL® Polyamides (Nylons)

Heat-stabilized grades of the PA resins fulfill the service environment's requirements for chemical and solvent resistance, broad service temperature range, toughness, and strength. PA6, PA66, and PA612 all excel in thermal cycling performance, a key requirement in the automotive industry. Material costs are moderate, and processing economics are favorable owing to their ease of moulding.

Standard ZYTEL® PA66 resins, usually glass-reinforced, are firmly entrenched as workhorse encapsulation materials for solenoids. With proper mould design and moulding process controls, they give excellent results for most part configurations.

For sensors, ZYTEL® PA612 resins have recently emerged as the best choice in many cases. Owing to its crystallisation characteristics, this polymer is inherently well suited to relatively slow, low-pressure injection. Such process conditions are a key factor in the prevention of bunching of the very fine magnet wire (AWG 39 to 50) used in variable-reluctance sensors or damage or displacement of delicate assemblies of electronic circuitry and components employed in "Hall Effect" sensors.

ZYTEL® PA612 has advantages in end-use performance as well. Its thermal cycling performance and resistance to road salt are even better than that of PA 66. Moisture absorption is also significantly lower, providing better dimensional stability.

RYNITE® PET and CRASTIN® PBT Polyesters

Thermoplastic polyesters are also being used in encapsulated solenoids, sensors, and transformers. The primary reasons include very low moisture absorption and better heat-aging performance than the polyamides (nylons). Both PET and PBT polyesters are used. In general, the RYNITE® PET resins offer higher temperature resistance in service and slower crystallisation during moulding than CRASTIN® PBT polyesters. The latter is an advantage in the relatively long injection cycles typical of encapsulation moulding. A toughened RYNITE® PET formulation with 15% glass reinforcement has proven particularly well-suited for slow, low-pressure injection cycles. Also, as noted above, the RYNITE® PET polyesters have been used successfully in gaining UL 1446 insulation system recognitions for encapsulation in Classes B (130 °C), F (155 °C), and H (180 °C).

High Temperature Polymers: ZENITE™ LCP and ZYTEL® HTN Resins

Polyamides (nylons) and polyesters function well at service temperatures up to 130 °C and 155 °C , respectively. Above that, thermoplastic encapsulation is done with either LCP or HTN. The high temperature resistance and outstanding dimensional stability of LCP, for example, makes it ideal for sensors that must withstand temperatures greater than 175 °C. Furthermore, its low melt viscosity (approximately half that of polyamides and polyesters) makes it possible to fill thin wall sections and to avoid damaging the fragile sensor components. However, attention must be given to the low knit-line strengths of LCP when designing the part. ZENITE™ LCP also has exceptional dielectric strength at high temperature.

The newest candidates for thermoplastic encapsulation are the "high-temperature nylons." These resins are partially aromatic polyamides featuring melting points around 300 °C compared with the 262 °C melting point of PA66. It is expected that they will be used in sensor, solenoid, and some transformer applications where short-term exposures to high temperatures occur and better chemical resistance is required than is possible with the polyesters. ZYTEL® HTN resin also has significantly higher dielectric strength than PA66 at elevated temperatures.

Table 4 Specific Product Information on Selected DuPont Thermoplastic Encapsulation Resins

	Generic	% Glass	UL94 Flammability at 0,8 mm	UL 1446/IEC 85 Encapsulation Recognition
ZYTEL® Polyamides				
101	PA66	—	V2	–
70G30 L	PA66	33	HB	–
FR70G25 V0	PA66	25	V0	–
5429ER	PA66	33	HB	Class B
ZYTEL® "Electrical/Sensor Resins"				
FE5382 BK-276	PA612	33	–	–
FE5389 BK-276	PA66	33	–	–
ZYTEL® HTN				
HTN51G35 HSL NC-010	HTN	35	HB	–
HTNFR51G35 L NC-010	HTN	35	V0	–
CRASTIN® PBT Polyesters				
T803	PBT	20	HB	–
T805	PBT	30	HB	–
T841 FR	PBT	10	V0	–
T843 FR	PBT	20	V0	–
T845 FR	PBT	30	V0	–
RYNITE® PET Polyesters				
415HP	PET	15	HB	–
FR515	PET	15	V0	–
530	PET	30	HB	–
FR530	PET	30	V0	–
RYNITE® "Electrical Specialty Resins"				
815ER	PET	15	HB	Classes B, F
830ER	PET	30	HB	Class H
FR815ER	PET	15	V0	–
FR830ER	PET	30	V0	Class B
ZENITE™ LCP				
6130 WT010	LCP	30	V0	–
Potted Coil Housings				
CRASTIN®				
LW9020	PBT/ASA	20	HB	–
LW9030	PBT/ASA	30	HB	–
LW9020 FR	PBT/ASA	20	V0	–
LW9030 FR	PBT/ASA	30	V0	–
RYNITE®				
935	PET	35 mica/glass	HB	–
530	PET	30	HB	–
FR530	PET	30	V0	–

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