DUPONT™ ELVAMIDE® NYLON MULTIPOLYMER RESINS
ADHESIVE GUIDE
INTRODUCTION
DuPont™ Elvamide® nylon multipolymer resins are thermoplastic polyamides that combine the inherent toughness of nylon with ease of processing in solvent as well as melt systems.

Elvamide® resins differ from conventional nylons in that they offer:

- Alcohol solubility
- Lower melt-processing temperatures
- Ability to cross-link with thermosetting resins

Elvamide® resins can be used singly or in a combination and can be further modified by formulating with plasticizer or other resins to meet specific end-use requirements. For most uses, they are applied from solvent solutions. They can also be melt compounded as, for example, in the manufacture of pigment concentrates or for extrusion into film adhesives for heat reactivation. Their relatively low melt-processing temperature allows use with heat-sensitive pigments and substrates.

Like Zyte® nylon resins, Elvamide® resins are suitable for molding and extrusion. They are tough, withstand impact and resist abrasion, but are softer and more flexible than conventional nylons. Melting point for Elvamide® multipolymer resins is around 156°C, compared with 265°C (509°F) for high temperature resistant 66 nylon homopolymer.

FEATURES AND USES
The important features of Elvamide® resins are listed below:

- Abrasion resistance
- Impact resistance
- Resistance to most oils, solvents and gasolines
- Pigment dispersing ability
- Melting point
- High tensile strength
- Natural lubricity
- Toughness at high and low temperatures
- Alkali resistance
- Antioxidant ability

It is this combination of outstanding properties which results in benefits for a variety of uses.

CHEMICAL PROPERTIES
Elvamide® resins are insoluble in water. They resist hot or cold aqueous alkali solutions and most salt solutions for weeks or months. Acetic acid attacks the resin slowly; stronger acids react more rapidly. Formic acid will dissolve Elvamide® resins. Most oxidizing agents react with Elvamide® but oxygen and oxygen-containing gases including ozone have little effect unless elevated extrusion temperatures are used. Elvamide® resins are highly resistant to petroleum-based products, showing little change after prolonged contact with lubricating oils and greases, or aliphatic and aromatic hydrocarbons.

The higher fatty acids, such as stearic acid have no appreciable effect on Elvamide® until a temperature of 150°C (302°F) is reached. The nylon resins are also resistant to most organic solvents including conventional lacquer solvents and diluents, carbon disulfide, esters, ethers, and amides.

Elvamide® resins contain carboxyl, amide and amine groups which react with thermosetting resins to form cross-linked structures. With epoxy resins, the amide groups along the nylon resin chain take part in the reaction.

SOLUTION TECHNIQUE
Solvent Selection
Selection of a solvent or solvent system for formulating and applying Elvamide® resin is very important and depends on the desired solids level and solution viscosity, solution stability requirements, nature of the substrate, processing equipment as well as the ultimate application technique.

The most popular solvents for Elvamide® resin are methanol, ethanol and 2-propanol, and mixtures of these with water. Other solvents for Elvamide® resin include benzyl alcohol, furfuryl alcohol, formic acid, phenol and m-cresol.

Anhydrous methanol is the most effective solvent and will dissolve up to 50% by weight of Elvamide® 8061 or 8063 with heating.

Typical Stability
On prolonged storage at room temperature or below, solutions of Elvamide® resin may show clouding or gelation; solution stability is increased as the temperature increases. Gelled solutions can be restored by gentle heating (no open flame) and stirring prior to use.

In alcohol-water solvent systems, the intermolecular nylon hydrogen bonding is reduced and thereby decreases solution time and the tendency for gel formation.

Stability of Elvamide® 8061 in alcohol/water mixtures can be improved by the addition of small amounts of benzyl alcohol or other high-boiling solvents. See Table 3. With multicomponent solvent systems the boiling point of any azeotrope should be considered.

As shown in Tables 1 and 2, Elvamide® 8063 gives lower viscosity for a given solids content than Elvamide® 8061 and is more gel resistant.
Methanol solutions containing 40 wt% Elvamide® 8061 should be used promptly as gelation occurs in less than 3 hours at 25°C (77°F). At 50% solids, the maximum stability is reduced to 30 min.

For suggested preparation equipment see Figure 1. The use of a reflux condenser is preferable for solution preparation. Explosion-proof electric or air motor agitator drives are adequate for most solution operations.

Heating and stirring should continue for at least one hour after solution appears complete in order to insure that all particles have dissolved. Solvent-swollen resin particles are colorless and transparent, and consequently are difficult to detect.

### Table 1. Solution Stability of Elvamide® 8061

<table>
<thead>
<tr>
<th>Parts (wt)</th>
<th>Solvent Composition</th>
<th>Brookfield Viscosity, mPa·s (cP)</th>
<th>10% Solids</th>
<th>20% Solids</th>
<th>10% Solids</th>
<th>20% Solids</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>Methanol</td>
<td>39</td>
<td>280</td>
<td>10^b</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>85/15</td>
<td>Methanol/water</td>
<td>39</td>
<td>610</td>
<td>10-11</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>90/10</td>
<td>Ethanol/water</td>
<td>103</td>
<td>1860</td>
<td>10-11</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>80/20</td>
<td>Ethanol/water</td>
<td>111</td>
<td>1960</td>
<td>10-11</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>1-Propanol</td>
<td>66</td>
<td>---</td>
<td>2</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>90/10</td>
<td>1-Propanol/water</td>
<td>76</td>
<td>---</td>
<td>10</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

^a Stability (gelation) tests and viscosity measurements were made at 25°C (77°F).
^b Solution cloudy but still mobile.

### Table 2. Solution Stability of Elvamide® 8063

<table>
<thead>
<tr>
<th>Parts (wt)</th>
<th>Solvent Composition</th>
<th>Brookfield Viscosity, mPa·s (cP)</th>
<th>10% Solids</th>
<th>20% Solids</th>
<th>10% Solids</th>
<th>20% Solids</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>Methanol</td>
<td>14</td>
<td>155</td>
<td>30-31</td>
<td>&lt;1</td>
<td></td>
</tr>
<tr>
<td>85/15</td>
<td>Methanol/water</td>
<td>21</td>
<td>253</td>
<td>30-31</td>
<td>25-26</td>
<td></td>
</tr>
<tr>
<td>90/10</td>
<td>Ethanol/water</td>
<td>37</td>
<td>---</td>
<td>&lt;1</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>80/20</td>
<td>Ethanol/water</td>
<td>42</td>
<td>730</td>
<td>25-26</td>
<td>25-26a</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>SDA^ #30 alcohol, 200 proof</td>
<td>28</td>
<td>gel</td>
<td>2-3</td>
<td>1 hr</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>SDA^ #2B, 190 proof</td>
<td>36</td>
<td>578</td>
<td>25-26</td>
<td>&lt;1</td>
<td></td>
</tr>
</tbody>
</table>

^a Solution cloudy but still mobile.
^b See Chemical Handbook for SDA (specially denatured alcohol) formulas.

### Table 3. Stability Improvement with High Boiling Solvents

<table>
<thead>
<tr>
<th>High Boiling Solvent</th>
<th>Amount</th>
<th>70/30 Ethanol/Water</th>
<th>80/20 Ethanol/Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>---</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>Benzyl alcohol</td>
<td>5%</td>
<td>16</td>
<td>26</td>
</tr>
<tr>
<td>Furfuryl alcohol</td>
<td>5%</td>
<td>4</td>
<td>26</td>
</tr>
<tr>
<td>m-Cresol</td>
<td>5%</td>
<td>4</td>
<td>15</td>
</tr>
</tbody>
</table>

### Preparation

For solutions of Elvamide® resins up to 20% solids, the resin pellets should be added to the solvent with continuous stirring. The mixture should then be heated (no open flame) with continued stirring to a temperature that is 5–10°C (9–18°F) below the reflux point of the solvent or solvent mixture. Usual temperatures are 54–60°C (130–140°F).
Table 4. Typical Solution Times

<table>
<thead>
<tr>
<th>Solvent, wt%</th>
<th>Temperature, °C (°F)</th>
<th>Solution Time, hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elvamide® 8061</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100 methanol</td>
<td>57 (135)</td>
<td>2</td>
</tr>
<tr>
<td>100 methanol</td>
<td>39 (103)</td>
<td>4.5-5</td>
</tr>
<tr>
<td>80/20 methanol/water</td>
<td>42 (107)</td>
<td>3</td>
</tr>
<tr>
<td>70/30 methanol/water</td>
<td>44 (112)</td>
<td>3</td>
</tr>
<tr>
<td>100 2-propanol</td>
<td>71 (160)</td>
<td>Insoluble after 3 hr</td>
</tr>
<tr>
<td>80/20 2-propanol/water</td>
<td>71 (160)</td>
<td>2.75</td>
</tr>
<tr>
<td>Pre-wet® Elvamide® 8061</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100 methanol</td>
<td>39 (103)</td>
<td>4</td>
</tr>
<tr>
<td>Pre-dried® Elvamide® 8061</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100 methanol</td>
<td>39 (103)</td>
<td>5.5-6</td>
</tr>
<tr>
<td>Elvamide® 8063</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100 methanol</td>
<td>39 (103)</td>
<td>3</td>
</tr>
</tbody>
</table>

NOTE: All solutions contained 8% solids.

* Elvamide® 8061 was pre-wet by soaking in water at 39°C (103°F) for 16 hr.
* Elvamide® 8061 was pre-dried for 7 days in a vacuum desiccator.

When solvent solutions are stored or handled, adequate ventilation should be provided. See the section on Safety Precautions in this bulletin. Detailed information on safe handling of flammable liquids can be obtained from the National Fire Protection Association* or from your solvent supplier.

The above precautions are not intended to be all inclusive. They should be supplemented by good manufacturing procedures, prevailing industry standards and the recommendations of solvent suppliers.

Dispersions of Elvamide® 8063 in water at 10% solids are available from General Plastics Corp.* For information, contact your sales representative. (See back cover.)

* NFPA Std. No. 30, “Flammable Combustible Liquid Code,” NFPA, Battery March Park, Quincy, MA 02269

Processing

Solutions of Elvamide® resins can be applied by dipping, brushing, spraying, or with conventional coaters designed to handle solvent-based systems.

Because of their relatively low melting temperature compared to molding grade nylon resins, Elvamide® resins also can be processed using standard melt compounding techniques.

Unless heat is used during drying, atmospheric moisture may cause a cloudy or opaque coating. Clear coatings can be obtained from anhydrous solvent systems if the drying temperature is sufficiently high to offset the cooling effect of evaporation and prevent condensation of atmospheric moisture on the surface. The required temperatures can be maintained with infrared heat or a circulating-air oven designed for use with flammable solvents.

To obtain a clear film using an aqueous solvent system (such as an alcohol/water mixture), a fusion treatment is recommended. By heating the coating above the resin melting point, optimum clarity, adhesion and physical properties can be developed.

**Formulating Solutions**

Grades of Elvamide® resins can be formulated with each other or with modifiers to produce a variety of properties. Generally modifiers are used with Elvamide® to improve adhesion to specific substrates, to vary blend toughness and flexibility, or for an optimum balance between cost and performance.

Typical modifiers for Elvamide® resins include plasticizers, thermosetting resins, thermoplastic resins and elastomers. See Table 6 for a listing of modifiers compatible with Elvamide® resins.

One plasticizer commonly used with Elvamide® resin is 2-ethyl-1, 3 hexanediol at amounts up to 15 parts per hundred resin.

Table 5. Typical Modifiers Compatible with Elvamide®

<table>
<thead>
<tr>
<th>Plasticizers</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Glycols</strong></td>
<td>Ethylene glycol, 2-Ethyl-1,3-hexanediol</td>
</tr>
<tr>
<td><strong>Phenols</strong></td>
<td>Octyl phenol, Resorcinol, Bisphenol A</td>
</tr>
<tr>
<td><strong>Sulfonamides</strong></td>
<td>n-butyl benzene sulfonamide</td>
</tr>
<tr>
<td><strong>Thermosetting Resins</strong></td>
<td>Araldite®, Derakane®, Epon®</td>
</tr>
<tr>
<td><strong>Epoxies</strong></td>
<td>Cymel®, Resimene®</td>
</tr>
</tbody>
</table>

In blends with epoxies or phenolics, 15–20% Elvamide® resin significantly improves the toughness and flexibility of the cured resin without impairing tensile strength or chemical resistance. The amine and carboxyl end groups on Elvamide® resins as well as the amide hydrogens along the chains enable Elvamide® resins to cross-link with thermosetting resins during the curing cycle. These blends with thermosetting resins are especially useful in high-strength structural adhesives discussed in more detail in the following section.

Combinations of Elvamide® resin and thermoplastic materials (Table 5) can be applied as resin solutions or hot melts.
THERMOSETTING ADHESIVE USES
High-strength, fatigue-resistant polyamide/thermoset resin adhesives were initially developed to meet requirements set by aerospace engineers designing lightweight, smooth-surfaced, honeycomb structures of aluminum. (These developed into a range of uses mentioned on pages 1 and 2 under "Adhesives.") They found adhesive bonded metal/metal laminates to have many advantages:

- no rivets to cause buckling of surfaces between points of contact
- no stress concentrations at isolated points of contact
- no high-temperature distortion of bonded parts
- no electrochemical corrosion between dissimilar metals
- simplification of design

Today, interest in adhesive bonding extends through wide segments of the metal-fabricating industry. Laminates of stainless steel to sheets of carbon steel for architectural panels, automotive trim, and window frames are examples of the cost-saving specialties possible. Adhesive bonding also permits the laminating of metal to other materials - such as glass and plastics. Formulation requirements differ from one use to another. The development of high lap shear strengths may be the dominant need in one application; high peel strengths in another.

Although Elvamide® 8061 can function as heat-activated adhesives (good shear and peel strength), the addition of a thermoset resin, e.g. 20%, which cross-links with polyamide during curing, eliminates creep and gives an adhesive of superior toughness and flexibility. The bonds formed during the curing of compositions of Elvamide® 8061 and thermoset resins are capable of withstanding severe deformation; they are also significantly stronger than the bonds developed in adhesives based on thermoset resins alone. Adhesives of Elvamide® 8061 and epoxy resin, for example, develop much higher peel strengths than the corresponding straight epoxy formulations.

Blends of Elvamide® 8061 and thermoset resin are useful in preparing postformable laminates as well as for other metal-to-metal bonding operations, for sandwiching honeycomb cores between metal sheets, and for bonding metals to various other substrates.

Formulating Adhesives
Structural adhesive formulations combine Elvamide® 8061 (65–90% of total resin) with a thermosetting resin (35–10%), a thermoset-curing agent, fillers (optional), and a solvent (evaporated if adhesive is used in film form). On heat-curing, the polyamide cross-links with the thermosetting resin to become an integral part of the cured adhesive. Elvamide® 8061 contributes toughness, flexibility, and good flexibility retention to the cured blend while giving bonds higher in both peel strength and shear strength than those obtained with the thermosetting resin alone. Application of Elvamide® 8061/thermoset adhesives can be from solution or as dry film.

Selection of Thermosetting Resins
Many thermosetting resins are sufficiently compatible with Elvamide® 8061 to permit their use in adhesive blends. Combinations of Elvamide® 8061 with epoxy resins of the bisphenol-A type and relatively high epoxy content are particularly effective in providing high-strength, flexible bonds. Table 6 compares the shear strength of aluminum- to-aluminum bonds prepared in the laboratory using typical thermosetting resins in combination with Elvamide® 8061. Note the superior lap shear strengths given by the epoxy-type resin. (Peel strengths are likewise optimum.)

Table 6. Typical Adhesive Formulations Based on Elvamide® 8061 and Thermoset Resins
(Material bonded: unprimed 0.16 cm [0.064 in] Alclad 2024-T3 aluminum alloy sheet; 1.3 cm [0.5 in] lap)

<table>
<thead>
<tr>
<th>Thermosetting Resin</th>
<th>Curing Agent</th>
<th>Zn Dust Filler, %a</th>
<th>Lap Shear Strength, mPa (psi)c</th>
</tr>
</thead>
<tbody>
<tr>
<td>epoxy</td>
<td>DICY</td>
<td>10</td>
<td>42.7–45.5 (6200–6600)</td>
</tr>
<tr>
<td>epoxy</td>
<td>DICY</td>
<td>33.3</td>
<td>30.3–32.4 (4400–4700)</td>
</tr>
<tr>
<td>phenolic</td>
<td>TETA</td>
<td>10</td>
<td>21.4–22.8 (3100–3300)</td>
</tr>
<tr>
<td>melamine-formaldehyde</td>
<td>Phenol</td>
<td>50</td>
<td>14.5–20.7 (2100–3000)</td>
</tr>
</tbody>
</table>

a Parts (wt)/100 parts thermosetting resin  
b Based on total solids  
c Ambient conditions

Ratio of Elvamide® 8061 to Thermosetting Resin
The optimum combination of bond strength and flexibility is generally achieved with blends containing 60–80% Elvamide® 8061, based on total resin content (see Figure 2). At concentrations of Elvamide® 8061 above this range, shear strength declines and the adhesive begins to assume the thermoplastic character of unmodified Elvamide® 8061. Adhesive blends containing less than 60% Elvamide® 8061 are less flexible, have lower peel strength and lower shear strength. However, as little as 20% Elvamide® 8061 significantly improves the flexibility of brittle thermosetting resins.

Curing Agents and Cure Schedules
The polyamide chains of Elvamide® 8061 resin contain carboxyl and amine end groups which react with thermosetting resins during cure to form cross-linked structures. With epoxy resins, the amide groups along the nylon resin chain also take part in the reaction. There is no specific epoxide equivalency of Elvamide® resins. Complete cure of an epoxy resin with Elvamide® 8061 takes place at high temperatures (e.g., 60 min at 232°C [450°F]) in the absence of a conventional curing agent. However, the addition of a curing agent for the thermosetting resin in an adhesive based on Elvamide® 8061 gives a more practical curing cycle.
In formulations of Elvamide® and thermosetting resin, the curing agent concentration depends on the type and amount of thermosetting resin used. Figure 2 shows the effect of both epoxide equivalency of the epoxy resin and curing agent concentration on the lap shear strength of adhesives of Elvamide® 8061 and epoxy resin.

In general, the resin manufacturer’s recommendations should be followed with regard to type and amount of curing agent and cure schedules for the particular thermosetting resin used. To develop maximum bond strength, however, the glue line should be heated above the melting point of the Elvamide® nylon multipolymer resin, i.e., above 160°C (320°F) for adhesives based on Elvamide® 8061.

With blends of Elvamide® 8061 and epoxy resin containing rapid curing agents, high peel strength bonds have been obtained in as short a time as 10–15 sec at 177–204°C (350–400°F). Longer cure schedules and suitable pretreatment of the substrate surface can increase the peel strength.

Examples of curing agents suitable for use in formulations of Elvamide® 8061 and epoxy resin are given in Table 7. Suggested concentrations for use with epoxy resins having an epoxide equivalent of 189 (e.g., “Epon 828,” “Araldite 6005”) are shown.

### Table 7. Curing Agents for Formulations of Elvamide® 8061 and Epoxy Resin

<table>
<thead>
<tr>
<th>Curing Agent</th>
<th>phr</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dicyandiamide (DICY)</td>
<td>10</td>
<td>Latent curing agent requiring high temperature for cure; suggested for developing maximum bond strength.</td>
</tr>
<tr>
<td>Triethylenetetramine (TETA)</td>
<td>10</td>
<td>Active curing agent for use where rapid cure is required; can be further accelerated by catalysts, e.g., 1 phr of phenol or resorcinol; gives high peel strength bonds in less than 1 minute at 177°C (350°F).</td>
</tr>
<tr>
<td>Epon® C-111</td>
<td>100</td>
<td>Active curing agent; chemically an amine adduct of an epoxy resin; slower than TETA but tends to develop higher bond strength.</td>
</tr>
<tr>
<td>DICY + USB-110 Aminoborane</td>
<td>10</td>
<td>Rapid cure system; stable at 27°C (80°F); gives superior peel strengths in 60 sec or less at 232°C (450°F).</td>
</tr>
</tbody>
</table>

* Parts (wt) curing agent per 100 parts epoxy resin (epoxide equivalent, 189).
**Effect of Fillers**

Adding 20–40% of a suitable filler to a formulation of Elvamide® 8061 and thermosetting resin increases the peel strength of the adhesive, but usually at a sacrifice in shear strength. Table 8 illustrates the effect of fillers on the peel and shear strengths of a typical blend of Elvamide® 8061 and epoxy.

### Table 8. Effect of Fillers on Bond Strength

<table>
<thead>
<tr>
<th>Filler</th>
<th>% Based on Total Solids</th>
<th>Peel Strength (b)</th>
<th>Lap Shear Strength (c,d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>—</td>
<td>10.5–14.0 (60–80)</td>
<td>42.7–45.5 (6200–6600)</td>
</tr>
<tr>
<td>Alumina</td>
<td>33.3</td>
<td>14.9–27.0 (85–154)</td>
<td>(not determined)</td>
</tr>
<tr>
<td>Glass, hammer-milled</td>
<td>33.3</td>
<td>10.5–14.0 (60–80)</td>
<td>(not determined)</td>
</tr>
<tr>
<td>Zinc dust</td>
<td>33.3</td>
<td>14.7–16.5 (84–94)</td>
<td>30.3–32.4 (4400–4700)</td>
</tr>
</tbody>
</table>

*Adhesive is 75/25/10 Elvamide® 8061/Epoxy® 828/DICY. Curing conditions are 60 minutes at 163°C (325°F).*

*Material bonded: 24 gauge Al foil to 0.16 cm (0.064 in) Alclad 2024-T3 sheet (unprimed). Peel strength of adhesive determined (ambient conditions) by climbing drum method, 180° angle.

*Material bonded: unprimed 0.16 cm (0.064 in) Alclad 2024-T3 sheet; 1.3 cm (0.5 in) lap.

*Adhesive is 75/25 Elvamide® 8061/Epoxy.

Fillers assist in maintaining the desired glue line thickness, because filled compositions have less tendency than unfilled resin blends to exude from the glue line during heat-curing. With some thermosetting resins, addition of fillers may be necessary to prevent excessive bond shrinkage during cure.

### Effect of Exposure on Bonds

The effect on bond strength of heating, exposure to ultraviolet light, and immersion in water and typical solvents is illustrated in Table 10. Adhesives of Elvamide® 8061 and epoxy resin lose approximately 50% of their bond strength at temperatures approaching 93°C (200°F), but show excellent strength at cryogenic temperatures.

### Preparation of Adhesives

In preparing adhesives for application from solvent, the Elvamide® 8061 resin should be put into solution before adding the thermosetting resin. The most practical solvents for Elvamide® 8061 are the lower aliphatic alcohols and mixtures of these with water. Anhydrous methanol [b.p., approx. 64°C (148°F)], the most efective solvent of the series, will give hot mixtures containing up to 50 wt% Elvamide® 8061.

### Preparing Liquid Adhesives

Adding the thermosetting resin to the solution of Elvamide® 8061, then stirring briskly, gives a solution which, for solids concentrations of 10–30%, will remain stable at room temperature over several months. Formulations containing latent catalysts designed for high temperature cure have also shown good stability at room temperature.

Systems containing active curing agents must be stored in tight containers in a cool location to prevent evaporation of the solvent. Loss of solvent results in rapid cure of the adhesive at room temperature.

When preparing a liquid adhesive for immediate use, one simply combines the solution of Elvamide® 8061 with the thermosetting resin, curing agent (if used), and filler (if used) at room temperature, stirs briskly for 15–30 min, then applies—e.g., by brush.

### Preparing Adhesive Films

Adhesives for application in film form can be formulated using latent curing agents. The Elvamide® 8061 and thermosetting resin are first dissolved in a compatible solvent system just as in preparing solvent-type adhesives. Curing agent, fillers, and any other additives are then incorporated. The solution is cast on a release surface, dried at 93–121°C (200–250°F) or below, and stripped. Suitable casting surfaces include stainless steel, films of Elvano®, polyvinyl alcohol, and PTFE (Polytetrafluoroethylene) film.

### Table 9. Effect of Exposure on Bond Strength

(Material bonded: unprimed 0.16 cm [0.064 in] Alclad 2024-T3 sheet; 1.3 cm [0.5 in] lap)

<table>
<thead>
<tr>
<th>Exposure Test</th>
<th>Lap Shear Strength (Epoxy: Araldite® 6005, Epon® 828)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>33.8 (5200)</td>
</tr>
<tr>
<td>Heat</td>
<td>29.0 (4200)</td>
</tr>
<tr>
<td>Ultraviolet light (Weatherometer)</td>
<td>20.7 (3000)</td>
</tr>
<tr>
<td>Tap Water</td>
<td>32.1 (4650)</td>
</tr>
<tr>
<td>Salt Spray</td>
<td>35.0 (5080)</td>
</tr>
<tr>
<td>Isopropanol</td>
<td>33.1 (4800)</td>
</tr>
<tr>
<td>n-Hexane</td>
<td>31.7 (4600)</td>
</tr>
</tbody>
</table>

*All tests at 21°C (70°F) except that for heat; test effect of heat on bond, specimen was held at 82.2°C (180°F) during test procedure. Although the effect of low temperature has not been determined in DuPont laboratories, Elvamide® 8061 epoxy adhesives are known to have excellent strength characteristics under cryogenic conditions.

*Adhesive is 75/25 Elvamide® 8061/Epoxy.

*Ciba Specialty Chemicals resin cured 60 minutes at 204°C (400°F); no curing agent.

*Shell Chemical resin cured 60 minutes at 163°C (325°F); 10 phr dicyandiamide.

As with any coating operation, adhesion depends not only on the composition of the adhesive but also on the extent of contact of the adhesive with the substrate. Maximum bonding requires uniform contact and this, in turn, requires a clean substrate surface and an even coat of adhesive.
Application Techniques

Surface Preparation
Cleaning and etching the metal substrates before bonding insures maximum bond strength. In the work reported in Tables 6, 8, and 9, the aluminum alloy sheet or aluminum foil was vapor degreased, then immersed for 10 min at 66°C (150°F) in a pickling bath of the following composition:

Parts by Weight

- Sodium dichromate: 31
- Concentrated sulfuric acid: 50
- Water: 170

The test specimens were rinsed in cold then hot tap water, dried in an oven at 60°C (140°F), and used immediately. Etching the solvent-cleaned surfaces increased bond strength by approximately 10%.

Adhesive Application
Whether the adhesive is applied from solution or in film form, the amount should be sufficient to give a final cured glue line at least 0.025 mm (1 mil) thick. Solution-type adhesives are evenly applied to one or preferably both of the surfaces to be joined and allowed to dry before the parts are assembled. Formulations containing active curing agents are unstable even at room temperature once the solvent has evaporated. Films deposited from adhesives of Elvamide® 8061 and epoxy resins formulated with active curing agents are no longer fusible after 24 hr at room temperature. To avoid premature cure, solvent should be driven off at or near room temperature, the parts assembled, then heat-cured promptly.

Bond Formation and Cure
In the bonding operation, surfaces previously coated with solution-type adhesive, or interleaved with film-form adhesive, are brought together under sufficient pressure to maintain good contact. Heat is then applied to bring the glue line to cure temperature. To develop maximum bond strength, the adhesive layer must be heated above the melting point of Elvamide® 8061. The optimum temperature will depend on the system—usually 177–191°C (350–375°F) for conventional curing schedules, 210–232°C (410–450°F) for quick cures. The objectives are to permit good wetting of the surfaces by the molten adhesive and to insure homogeneous interaction of the Elvamide® and thermosetting resin for maximum cross-linking during curing.

Adhesives containing active curing agents should be brought to flow-temperature rapidly, i.e., within 5 min or less. Otherwise, cure will have advanced too far by the time the prescribed temperature is reached to permit good flow and wetting, and bond strength will be poor.

The cure times specified in Tables 8 and 9 and in the section on curing agents refer to duration of heating after the glue line has reached the temperature designated.

Film Casting
Since Elvamide® resins have lower melting points than conventional nylon molding and extrusion resins, lower chill-roll temperatures are required. The maximum chill-roll temperature to prevent sticking of Elvamide® 8061 is about 41°C (105°F).

By operating the chill roll at as high a temperature as possible, the rate of crystallization is increased, less post-crystallization occurs and roll conformation problems are minimized.

The processing conditions of melt temperature, quench temperature, air gap and rate influence the physical properties of cast nylon film. The following general statements indicate the more significant effects of these conditions. The degree of the effect depends on the specific resin being processed.

Effect of increasing melt temperature
- Transparency and gloss increase
- Haze decreases
- Impact strength increases

Effect of increasing quench temperature
- Yield strength increases
- Haze increases
- Transparency and gloss decrease
- Impact strength decreases

Effect of increasing air gap
- Haze increases
- Transparency and gloss decrease

Effect of increasing rate
- Haze decreases
- Transparency and gloss increase

Of the above variables, rate and air gap have the greater influence on properties.

Resin Drying
Elvamide® resins readily absorb moisture. The resins, as packaged, have a low moisture content and the shipping bag protects against further uptake of moisture. In applications where moisture is detrimental, care should be exercised, if the bag is torn or opened, to prevent exposure to high humidities. If exposure occurs, the resin should be dried prior to use.

The equilibrium moisture content of the nylon decreases as the moisture content of the incoming air decreases. If the moisture content of the incoming air is too high, it is not possible to dry the nylon sufficiently at reasonable drying temperatures.
**Hopper Dryers**

A typical dehumidified hopper-dryer system consists of a filter, blower, dehumidifier, heater and a hopper. Air is circulated by the blower through the dehumidifier. The dehumidifier air is then heated and passed through the resin in the hopper and back to the dehumidifier via a filter. Pneumatic conveyers, or preferably vacuum systems, are used to feed resin into the hopper.

The rate of drying in a hopper dryer will be essentially the same as that in a tray oven for the same drying temperature and inlet air humidity. An advantage of the hopper-dryer system is the counter-current flow of polymer to air. The driest air contacts the driest polymer since the polymer is exiting at the bottom of the hopper and the dry air is entering at the bottom of the hopper.

A number of potential problems associated with hopper dryers includes:

- **Incoming dry virgin resin subjected to unnecessary heating or air tends to discolor.** Separate drying of regrind can eliminate this problem.
- **Uneven flow of resin through the hopper.** This problem is most noticeable in the conical section above the throat of the hopper. It is possible that in a poorly designed hopper, the moisture level of the molding powder might vary enough to produce erratic molding conditions.
- Insufficient holdup time for drying wet nylon on a fast cycle.
- Inability to maintain a truly closed system.
- Inability to maintain a constant drying temperature. Insulation of the hopper minimizes this problem.

**Vacuum Drying**

Elvamide® resins can be dried in vacuum ovens or in rotary vacuum tumbler dryers. Figure 4 shows the absolute pressure required to achieve a given equilibrium moisture content for nylon at various drying temperatures.

![Figure 4. Vacuum Required to Dry Nylon Resins](image)

The preferred way to operate a vacuum drying oven is as follows:

Charge the oven with the nylon resin to be dried. Apply vacuum to the drying vessel. Heat the vessel to the selected drying temperature. The drying process is complete when the oven pressure reading corresponds to the pressure required at the desired moisture level given in Figure 4. One precaution that must be taken in this case is to measure the vacuum in the drying vessel itself and not at the vacuum source. To minimize color formation, it is desirable to evacuate the vessel before heating the polymer.

Any leakage of room air into the oven will make the above-described drying technique invalid. This does not mean that nylon cannot be dried in a vacuum vessel that has some leaks. In such cases, estimation of the final moisture content of the nylon is not possible unless the amount of leakage and the relative humidity of the air leaking into the oven are known.
SPECIAL SAFETY PRECAUTIONS

Solution Preparation
When preparing solutions of Elvamide® resins in flammable solvents, precautions must be taken to avoid ignition of flammable vapors by static electricity during the transfer of the resin to a dissolving kettle.

All metal parts of the mixing and processing equipment must be grounded. In addition, precautions must be taken to avoid discharging the static charges which may be generated within the bags of Elvamide® or on the operator during the transfer operation. It is not recommended that Elvamide® resin be transferred from the bag directly to the blend tank unless the resin has previously been wet down with water.

Some suggested alternatives for minimizing the hazard are:

- Transfer Elvamide® resin from the bag to an unlined metal container at a location away from the flammable vapor area. Ground the container to the blend tank. Then transfer Elvamide® resin from this container to the blend tank using a metal funnel which is grounded to the tank. The free fall distance for the resin should be minimized.

- Mount a grounded metal funnel or trough above the blend tank. The cubes of Elvamide® resin should travel for at least several feet along the metal surface. The point where Elvamide® is transferred from the bag to the funnel or trough should be well ventilated to reduce the concentration of flammable vapors. With floor-level tank openings, a grounded metal tray may be used.

After pouring Elvamide® resin from a bag, the operator should ground himself in a safe location before he approaches the potentially flammable environment near the opening of the blend tank.

Operations involving solvents must be adequately ventilated to limit operator exposure to permissible levels. Protect eyes and skin from contact with solvents by using goggles, gloves and other protective equipment.

These suggestions are not intended to be all inclusive. They should be supplemented by good manufacturing procedures, prevailing industry standards and the recommendations of the equipment manufacturers. In any operation that involves the handling of flammable solvents, the utmost care should be taken to avoid static accumulation and other possible ignition sources. Open flames should be prohibited, and nonsparking motors and tools should be used.

DuPont supplies Safety Data Sheet (SDS) of Elvamide® resins to its customers with the initial order and upon the next order if there is a significant update to the SDS. SDSs include such information as hazardous components, health hazards, emergency and first aid procedures, disposal procedures, and storage information.

Epoxy Resins
Certain formulations utilize mixtures of Elvamide® resin and epoxy resins. Epoxy resins are combustible and must be kept away from heat and open flame. Avoid prolonged contact with skin and breathing vapor or spray mist. Keep container closed when not in use. Provide adequate ventilation when epoxy formulations are being prepared. Before proceeding with any compounding work, consult and follow label directions and handling precautions from suppliers of epoxy resins.
Visit us at plastics.dupont.com

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