JEFFAMINE® Amines as Curing Agents for Epoxy Resins in Composites

Composites are defined as those materials which consist of two phases, a reinforcing phase and a stress transfer phase, or matrix. Fibrous reinforcing phases may be chopped, woven, or continuous. Advanced composites, in which reinforcement is provided by continuous fibers, provide high strength/weight ratios and are increasingly used in commercial applications.

In addition to the high strength/weight ratio, advantages of composites can include lower maintenance, improved corrosion resistance, and automated part fabrication. Epoxy resins are the matrix polymers of choice in many of these applications because of their relatively low cost and high performance.

Important considerations for matrix resin selection are processing and performance. Several processing techniques are used in composites manufacture. Among them are pultrusion, compression molding, resin transfer molding, and filament winding.

**Processing criteria include:**

- Reactivity—the resin system must be slow enough to avoid inconvenient viscosity increase and premature cure, yet it should cure at a reasonable rate when fabrication of the item is complete.
- Viscosity—the resin system must be of sufficiently low viscosity to allow adequate fiber wet-out.

**Performance criteria include:**

- Strength/Modulus
- Toughness
- Corrosion resistance
- Temperature resistance ($T_g$, HDT)

Epoxy resins are the well-suited to many of these applications because of their relatively low cost and high performance. In general epoxy resins may offer:

- Good mechanical properties
- Low formulation viscosity
- Low shrinkage
- Good adhesion to the reinforcement
- Good chemical resistance.

Their processing properties and performance depend, of course, on which specific resin/curing agent combination is used.

A variety of curing agents for epoxy resins are available. Anhydrides provide good processing and mechanical properties but elongation is relatively low and the cure is rather slow. Aromatic amines present these problems as well as serious toxicity concerns in some cases. For many applications polyetheramines provide a good balance of processing and performance properties, and the JEFFAMINE amines are therefore finding wider use in composites.
JEFFAMINE® Amines in Epoxy Curing

Composite Applications

Features:
- Flexible polyether backbone
- Low viscosity
- Moderate reactivity
- Low volatility
- Low exotherm

The JEFFAMINE polyetheramines have a proven history in composite applications. One key structural characteristic is the steric hindrance (and resulting slower cure) provided by the presence of a methyl group on the amine-bearing carbon. As a result, these amines cure epoxy resins more slowly than do other aliphatic amines such as ethyleneamines. Another important structural feature is the flexible polyether backbone, which gives reduced brittleness in the cured resins. Good toughness, impact resistance, elongation, and low-temperature properties result from this flexibility.

Formulated viscosities of the JEFFAMINE amines with typical epoxy resins at room temperature are in the 500-1500 cP range, allowing for good wet-out of fibers in processes such as filament winding. The products are virtually colorless as well.

Features:
- Tough cured resins:
  - Higher elongations
  - Improved impact resistance
  - Good low-temperature properties
  - Good fiber wet-out
- Balanced curing properties:
  - Good working time
  - Convenient cure rates
  - Lower toxicity concerns
  - Lower safety concerns

Since these amines are higher in molecular weight and lower in vapor pressure than other aliphatic amines, safety concerns are reduced.

Molecular weights of the JEFFAMINE amines range from 148 to 5000, polyether backbones are based on ethylene glycol or propylene glycol, and amine functionality is one, two, or three. Products include

- D-230, T-403, D-400
- EDR-148
- D-2000, T-5000.

Of most interest for matrix resins are the diamines and triamines with molecular weights in the 200-500 range, the products known as JEFFAMINE D-230, T-403, and D-400 amines. In this product terminology the number gives the approximate molecular weight and the D- and T- denote diamine and triamine, respectively. The JEFFAMINE T-403 and D-230 amines have been the most widely used in composite applications. They are polypropylene glycol-based and are particularly well-suited because of their combination of moderate reactivity and good cured resin properties.

Useful epoxy resins for this application include Dow's D.E.R. 383 and Shell's Epon 825 and 826; these have somewhat lower viscosities than the more commonly used resins. As shown in the Table, the working times for these formulations are adequate for most filament winding applications.
Other properties are generally suitable as well. Elongation values of 10% or higher, tensile strengths in the 8,000-10,000 psi range, and flexural modulus values of around 400,000 psi or higher are typical. These high elongations lead to exceptional toughness and ductility which gives good damage tolerance, reducing the risk of catastrophic failure that might occur with more brittle systems. Cures with JEFFAMINE amines in general give lower $T_g$ values than some other curing agents--with T-403, for example, and a standard liquid bisphenol A resin, the $T_g$ is around 92°C (198°F). If a higher $T_g$ is required, other amines can be blended with the JEFFAMINE amines (see Table).

Other members of the JEFFAMINE curing agent family include the ED- and EDR-series amines, which are polyethylene glycol-based. The ED-series amines start at 600 molecular weight and have found little use in composites; XTJ-504 (prepared by amination of triethylene glycol diamine) is the lowest molecular weight amine in the series and may be suitable in some cases. This curing agent is more reactive than the amines mentioned earlier, because of its unhindered amine groups. High thermal shock resistance is a key feature of resins cured with this curing agent. The JEFFAMINE D-2000 and T-5000 curing agents, while not useful as sole curing agents for this application, may be included in blends with the other JEFFAMINE amines to increase flexibility and toughness. In some cases phase-separated systems are produced which may provide improved fracture resistance.

Summary

The JEFFAMINE polyetheramines are useful curing agents for composite matrix resins because of their curing characteristics and the cured resin properties they give. Their low viscosity, low volatility, and moderate cure rates make processing easier; the cured resins have good flexibility and toughness because of the amines' flexible polyether backbones. Compared with anhydride curing agents, these amines may give better composite matrices at lower cost.

References:


# Properties of Epoxy Systems Cured with JEFFAMINE® Amines

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<th>Liquid epoxy resin eew ~179(^1)</th>
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\(^1\) Viscosity ca. 9000 cP; \(^2\) DuPont; \(^3\) Parallel plate dynamic rheometry. Test panels were cured at 80°C for 2 hours and 125°C for 3 hours.