# 4 MATRIX MATERIALS

## MATRIX MATERIALS FOR FIBER COMPOSITES

In most engineering composite systems the fiber plays the major role in determining the mechanical properties. The matrix functions to holds the fibers (which may be continuous or discontinuous) in place and to transfer the load to the fibers. The properties of the matrix are, never the less, very important in providing unique characteristics to the composite. Some of the properties of composites controlled by the matrix are given in Table 4-1.

Some applications, especially in aerospace components require that the composite structure have minimum levels of thermal conductivity and electrical conductivity. If sufficient conductivity properties can be achieved by the fiber then the designer must rely on the matrix properties. In some applications metal matrix composites are selected for just these properties. The matrix significantly influences the overall corrosion resistance, oxidation resistance and electrochemical properties of composites. Polymer matrix composites tend to be corrosion resistant while ceramic composites provide superior oxidation resistance. Although the thermal expansion properties of a composite are heavily influenced by the fibers, the influence of the matrix can be equally important. The matrix properties can also significantly affect high temperature strength and stiffness, especially in off-axis loading where the fibers are less efficient in transferring load. The matrix also controls the infiltration process that combines the fibers with the matrix and subsequent shaping and forming. The matrix material greatly influenced the cost of fabricating the composite.

Table 4-1.Matrix materials for engineering composites

| Matrix Type | Positive Attribute | Negative Attribute |
|---|---|---|
| Thermoset Polymer | Low Cost Processing | Brittle |
| Thermoplastic Polymer | Tough<br>Formable | Cost<br>Processing |
| Carbon | Thermal stability | Cost |
| Light Metals | Conductive<br>Thermal resistance | Reacts with most fibers |
| Superalloys | Oxidation resistance | Heavy |
| Refractory Metals | High temperature strength | Heavy<br>Oxidation |
| Glass | Corrosion resistance<br>Low thermal expansion | Brittle |
| Glass/Ceramic | Corrosion resistant<br>Thermal resistance | Brittle<br>Cost |
| Ceramic | High temperature resistance | Cost |

Thermoset composites are harden to permanent shape by an irreversible reaction (usually cross-linking). One of the more common class of thermosets used for composite processing is epoxy. Thermoplastics are also used but less frequently. This class of polymer will soften and melt at high temperatures and reharden when cooled.. This is due to the fact that thermoplastics are long chain polymers that are not cross-linked. Thermosets are rigid and are usually stiffer, stronger and more brittle than thermoplastics. Thermoplastics are often selected when high toughness is required. Table 4-2. lists some properties of commonly used polymer matrix materials. Table 4-3 lists some properties of commonly used metal matrix materials. Table 4-4 lists some properties of commonly used ceramic matrix materials.

Table 4-2 properties of typical polymer matrix materials

| Matrix | E $10^6$psi | $F_{TU}$ $10^3$psi | $\varepsilon_f$ % | $\rho$ g/cc | $\alpha$, $10^{-6}$/° F | Use Temp °F | Process Temp, °F |
|---|---|---|---|---|---|---|---|
| Polyimide | 0.610 | 12.0 | 6 | 1.43 | 26 | 750 | 900 |
| Epoxy (Bisphenol A - rigid) | 0.450 | 10.5 | 5 | 1.15 | 33 | 180 | 375 |
| Epoxy (Bisphenol A - flexi) | 0.125 | 4.5 | 30 | 1.16 | 35 | 110 | 325 |
| Epoxy (Novolac) | 0.450 | 10.0 | 4 | 1.24 | 19 | 450 | 350 |
| Epoxy (Cycloaliphatic) | 0.490 | 10.8 | 3 | 1.22 | 22 | 475 | 400 |
| Nylon (Type 6) | 0.350 | 9.5 | 25 | 1.11 | 65 | 175 | 500 |
| Nylon (Type 6/6) | 0.435 | 14.4 | 30 | 1.18 | 41 | 230 | 600 |
| Polyester (Thermoset - rigid) | 0.350 | 7.0 | 2 | 1.30 | 45 | 275 | 450 |
| Polyester (Thermoset - flexi) | 0.035 | 4.0 | 150 | 1.10 | 50 | 175 | 400 |
| Polyetheretherketone | 0.160 | 14.5 | 100 | 1.32 | 22 | 600 | 850 |
| Poly(amide-imide) | 0.750 | 26.9 | 14 | 1.40 | 20 | 500 | 800 |
| Polyetherimide | 0.480 | 15.1 | 30 | 1.28 | 30 | 340 | 650 |
| Polybenzimidizole | 0.850 | 23.0 | 3 | 1.30 | 13 | 800 | 1000 |
| Polyethylene (low density) | 0.021 | 1.4 | 725 | 0.91 | 110 | 125 | 500 |
| Polyethylene (UHMW) | 0.150 | 6.2 | 450 | 0.94 | 90 | 150 | 550 |
| Polypropylene (gen purpose) | 0.220 | 5.2 | 30 | 0.90 | 38 | 230 | 400 |
| Polypropylene (high impact) | 0.150 | 3.6 | 200 | 0.91 | 59 | 200 | 400 |
| Polyvinyl chloride (non-rig) | 0.001 | 1.0 | 450 | 1.20 | 40 | 150 | 450 |
| Polyvinyl chloride (rigid) | 0.400 | 8.0 | 220 | 1.58 | 27 | 165 | 500 |
| Polystyrene (gen purpose) | 0.460 | 10.0 | 2 | 1.04 | 33 | 160 | 450 |
| Polystyrene (med impact) | 0.390 | 6.0 | 20 | 1.04 | 47 | 125 | 450 |
| Polystyrene (high impact) | 0.150 | 3.3 | 50 | 1.07 | 56 | 125 | 450 |
| Acetals (homopolymer) | 0.410 | 10.0 | 50 | 1.43 | 45 | 195 | 500 |
| Acrylics (molding) | 0.425 | 10.5 | 4 | 1.18 | 35 | 190 | 550 |
| Phenolic (general) | 1.300 | 10.0 | 0.4 | 1.45 | 16 | 350 | 850 |
| Polycarbonate (general) | 0.340 | 9.0 | 90 | 1.19 | 38 | 150 | 550 |
| Phenylene ether (PPE/PPO) | 0.380 | 8.5 | 55 | 1.11 | 40 | 212 | 500 |
| Polysulfone | 0.360 | 10.2 | 75 | 1.24 | 31 | 340 | 600 |

Table 4-3 Properties of typical metal matrix materials

| Matrix | E $10^6$psi | $\varepsilon_f$ % | $F_{TU}$ $10^3$psi | $F_{TY}$ $10^3$psi | $\rho$, g/cc | $\alpha$, $10^{-6}$/° F | Tm °F |
|---|---|---|---|---|---|---|---|
| Gray Iron | 9.6 | 1 | 20 | 20 | 6.92 | 6.0 | 2400 |
| Ductile Iron | 24.0 | 10 | 90 | 65 | 7.11 | 6.6 | 2400 |
| Low Carbon Steel | 30.0 | 30 | 43 | 24 | 7.83 | 8.4 | 2650 |
| Med Carbon Steel | 30.0 | 18 | 75 | 42 | 7.83 | 8.3 | 2600 |
| 4340 Steel (Norm) | 30.0 | 21 | 142 | 130 | 7.83 | 8.3 | 2600 |
| 4340 Steel (Q&T) | 30.0 | 11 | 287 | 270 | 7.83 | 8.3 | 2600 |
| 18 Ni Mar Steel | 26.9 | 11 | 255 | 245 | 7.92 | 5.6 | 2700 |
| 316 Stainless | 28.0 | 60 | 80 | 30 | 8.03 | 8.9 | 2700 |
| Al 1100 (O) | 10.0 | 47 | 13 | 5 | 2.71 | 13.1 | 1190 |
| Al 6061 (T6) | 10.0 | 17 | 45 | 40 | 2.71 | 13.0 | 1090 |
| Al 201 (STA) | 10.0 | 9 | 65 | 55 | 2.80 | 10.7 | 1060 |
| Al A356 (STA) | 10.0 | 10 | 41 | 30 | 2.68 | 11.9 | 1035 |
| Co | 30.0 | 22 | 110 | 48 | 8.86 | 6.8 | 2723 |
| Co Alloy S-816 | 35.0 | 35 | 140 | 70 | 8.58 | 9.3 | 2350 |
| Ni | 30.0 | 50 | 50 | 16 | 8.89 | 8.6 | 2650 |
| Cu (OFHC) | 17.0 | 55 | 35 | 11 | 8.94 | 9.8 | 1981 |
| Be Copper | 18.5 | 35 | 68 | 28 | 8.25 | 9.9 | 1590 |
| Mg HK31A T6 | 6.5 | 6 | 31 | 16 | 1.80 | 14.0 | 1092 |
| Mg AZ61A F | 6.5 | 7 | 46 | 33 | 1.80 | 14.0 | 950 |
| Inconel 625 | 29.7 | 59 | 124 | 53 | 8.44 | 7.1 | 2350 |
| Ni Alloy 713C | 29.9 | 8 | 123 | 107 | 8.24 | 5.9 | 2300 |
| Ti | 15.5 | 25 | 35 | 25 | 4.51 | 5.5 | 3000 |
| Ti-6Al-4V | 17.3 | 12 | 149 | 128 | 4.43 | 4.2 | 3000 |
| Sn | 6.4 | 53 | 1 | 1 | 7.31 | 13.0 | 450 |

Table 4-4 properties of typical ceramic matrix materials

| Matrix | E, $10^{-6}$ psi | ν | MOR, ksi | $K_{IC}$ | ρ, g/cc | α, $10^{-6}$/° F | Tm °F |
|---|---|---|---|---|---|---|---|
| LAS | 17 | 0.24 | 20 | 2.2 | 2.61 | 3.2 | |
| Pyrex | 7 | 0.20 | 8 | 0.7 | 2.23 | 1.8 | 2285 |
| $Al_2O_3$ | 50 | 0.26 | 70 | 3.2 | 3.97 | 4.8 | 3722 |
| Mullite | 21 | 0.25 | 27 | 2.0 | 3.30 | 3.2 | 3362 |
| $ZrO_2$ PS | 30 | 0.23 | 94 | 7.7 | 5.75 | 4.4 | 5000 |
| $ZrO_2$ FS | 30 | 0.23 | 36 | 2.5 | 5.56 | 7.5 | 5000 |
| $TiO_2$ | 41 | 0.28 | 12 | 2.3 | 4.25 | 5.2 | 3360 |
| $Si_3N_4$ SN | 45 | 0.24 | 72 | 5.1 | 3.18 | 1.7 | 3398 |
| $Si_3N_4$ RB | 24 | 0.24 | 44 | 3.1 | | | |
| $Si_3N_4$ HP | 45 | 0.24 | 120 | 5.1 | 3.19 | 1.7 | 3398 |
| $SiO_2$ | 11 | 0.16 | | 0.7 | 2.2 | 0.3 | 2930 |
| SiC-α SN | 48 | 0.19 | 56 | 4.5 | 3.21 | 2.4 | 3596 |
| SiC -α HP | 60 | 0.19 | 67 | 4.5 | 3.21 | 2.4 | 3596 |
| $B_4C$ | 42 | | 45 | | 2.41 | 1.7 | 4262 |
| $TiB_2$ | 80 | 0.20 | 130 | 6.3 | 4.62 | 4.5 | 5252 |
| TiC | 62 | 0.19 | 36 | | 4.92 | 4.7 | 5684 |
| TaC | 41 | 0.24 | 29 | | 14.5 | 3.7 | 7016 |
| BeO | 52 | 0.24 | 34 | | 3.0 | 3.2 | 4586 |
| WC | 97 | 0.20 | | | 15.8 | 2.5 | 5198 |
| $Cr_2O_3$ | 15 | | 38 | 3.5 | 5.21 | 4.2 | 4415 |
| $Cr_3C_2$ | 56 | 0.20 | | | 6.7 | 5.7 | 3434 |
| BN Para | 5 | | 11 | | 1.94 | 3.7 | 5400 |
| BN Perp | 11 | | 16 | | 1.94 | 0.2 | 5400 |
| NbC | 65 | 0.21 | | | 7.82 | 3.7 | 6330 |