Property comparison

Eastman Spectar™ copolyester and APET

This paper addresses physical property and performance characteristic differences between Eastman Spectar™ copolyester and APET (amorphous polyethylene terephthalate). Both products have unique features that factor into any decision about which material to use. However, some material comparisons can be difficult to make without reliable testing data. To help Eastman's customers with these comparisons and obtain a better overall, unbiased perspective of similar materials, we offer the following information. This report offers discussion supported by data on the following points:

- Rigidity
- Coefficient of linear thermal expansion
- UV radiation transmission and absorbance
- Weatherability
- Environmental claims
- Thermoforming
- Chemical resistance
- Impact strength
- Fabrication

Rigidity

Stiffness or rigidity is important when considering how a thermoplastic will perform under load. A material may need to be thicker or have more bracing so that it does not sag or bend under its own weight. APET is slightly more rigid than Eastman Spectar™ copolyester. This is reflected in the flexural modulus of the two materials. The flexural modulus of APET is about 2,420 MPa, and the flexural modulus of Spectar is about 2,200 Ppa. The rigidity of a sheet is defined by the following formula:

$$D = E \times h^3$$

E = Flexural modulus
h = Thickness

Arranging the above equation to determine the thickness needed in a Spectar sheet to achieve equivalent rigidity of an APET sheet results in the following relationship:

$$h_{\text{Spectar}} = h_{APET} \times (E_{APET} / E_{\text{Spectar}})^{1/3}$$

Solving the above equation at various thicknesses of APET to determine the thickness of Spectar to achieve equivalent rigidity is presented in Table 1.

Table 1 Rigidity equivalence of APET and Eastman Spectar™ copolyester

Thickness of APET (mm)	Equivalent thickness of Eastman Spectar™ copolyester (mm)
1.5	1.55
3.0	3.10
6.0	6.19
9.0	9.29
12.0	12.39

As can be seen, the difference in rigidity between APET and Spectar results in about a 3% difference in sheet thickness. In reality, most commercial thermoplastic sheet is inventoried in standard thicknesses such as 1.5, 3, or 6 mm, for example, and a sheet manufacturer does not typically adjust sheet thickness to account for stiffness differences between materials. APET may be slightly more rigid than Spectar, but this difference is not significant.

Coefficient of linear thermal expansion

Every material expands or contracts in response to temperature changes including all thermoplastics. This response to temperature change can be measured as a material's coefficient of linear thermal expansion. APET's coefficient of linear thermal expansion is slightly lower than that of Eastman Spectar™ copolyester. When presented in context, however, the coefficient of linear thermal expansion of Spectar is similar to most common thermoplastics. Since most thermoplastics expand and contract similarly in response to temperature changes, the difference between APET and Spectar is not significant.

Table 2 Coefficient of linear thermal expansion for a 244 cm long sheet

	Coefficient of linear thermal expansion cm/cm/°C	Change in length (cm) when temperature changes from 15° to 38°C	% difference
APET	0.00006	0.34	0.14
Eastman Spectar™ copolyester	0.000068	0.38	0.16

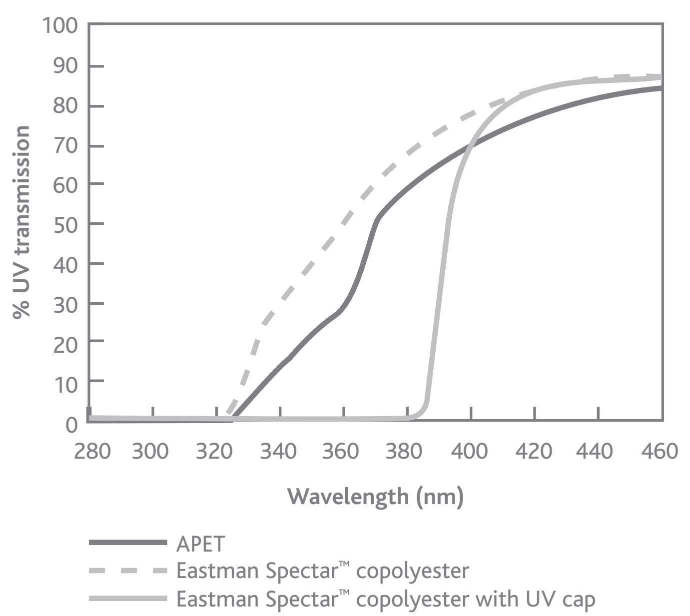
UV radiation transmission and absorbance

The earth receives ultraviolet radiation emitted from the sun. The highest energy UV radiation is in the UV-C range (<290 nm). The next highest is UV-B (290 to 320 nm) and finally UV-A (320 to 400 nm). Sunlight at the surface of the earth contains significant amounts of UV-A and UV-B radiation but little UV-C radiation since it is filtered by the atmosphere.

All polyester materials containing aromatic moieties including APET and Eastman Spectar™ copolyester can be degraded and lose physical properties due to ultraviolet radiation. They are especially susceptible to radiation in the 325 nm and below range according to the literature: "Photochemical degradation of poly(ethylene terephthalate)" M. Day and D. M. Wiles, *Journal of Applied Polymer Science,* Vol. 16, 1972. Figure 1 illustrates that there is not a significant absorption difference between APET and Spectar in the critical 325 nm range; therefore, both can be attacked by UV radiation.

For polyesters to be UV stable, they must be protected in the 325 nm and below wavelength range. This can be accomplished through the incorporation of ultraviolet-absorbing or -screening ingredients. Such UV-stabilizing ingredients absorb the UV radiation and convert it into heat that is harmlessly absorbed by the sheet.

Figure 1 % UV transmission



Weatherability

Thermoplastics used in outdoor applications can degrade through several mechanisms, the two most significant being degradation by UV radiation and a process called physical aging. These processes can be simulated and accelerated by laboratory testing, Xenon arc, and QUV being the most common methods, as well as exposing materials to real-time aging. Thermoplastics may be protected from UV radiation through the incorporation of bulk-load UV-screening ingredients or with a UV-screening cap layer on the sheet.

Figures 2 and 3 show the results of an aging study performed on APET and Eastman Spectar™ copolyester. Samples of APET and Spectar sheet with and without a UV-absorbing layer were exposed to real-time weathering in Arizona as well as accelerated Xenon-arc testing. Figure 2 illustrates that UV-stabilized Spectar retains much more impact resistance after exposure in real-time Arizona testing than UV-stabilized APET. Figure 3 illustrates that both APET and Spectar sheet turn yellow at about the same rate. The results of accelerated Xenon-arc testing in Figures 4 and 5 corroborate the real-time Arizona results. The large difference in impact retention between UV-stabilized APET and Spectar is not caused by UV radiation but instead is due to a phenomenon known as physical aging (Struik, L. C. E. *Polym. Eng. Sci.* 1977, *17,* 165.). Physical aging is a process of molecular relaxation that occurs in all amorphous polymers held at temperatures below their glass transition temperature. During physical aging, the molecules move toward equilibration to their lowest energy state which can result in a decrease in impact strength. APET sheet undergoes embrittlement due to physical aging at a much faster rate than Spectar sheet. Consequently, even though stabilized against UV degradation, APET will become brittle when exposed to sunlight.

Figure 2 Flatwise impact strength as a function of months in Arizona

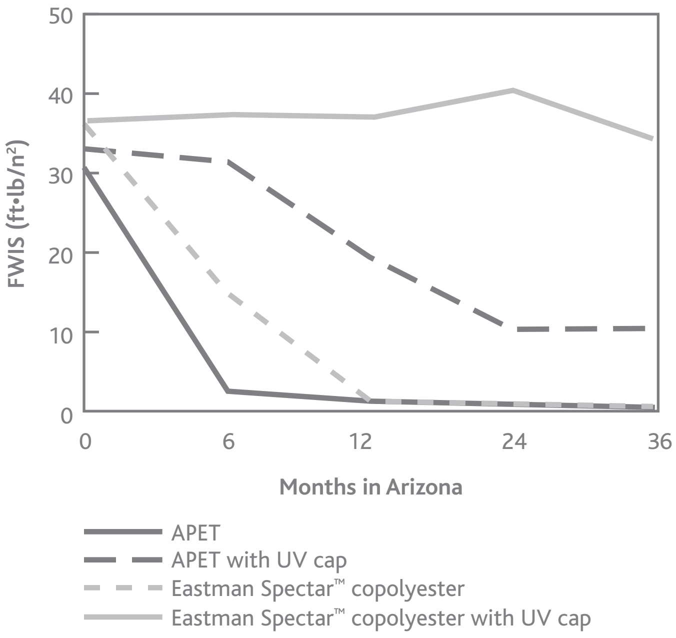


Figure 3 Yellowness (b*) as a function of months in Arizona

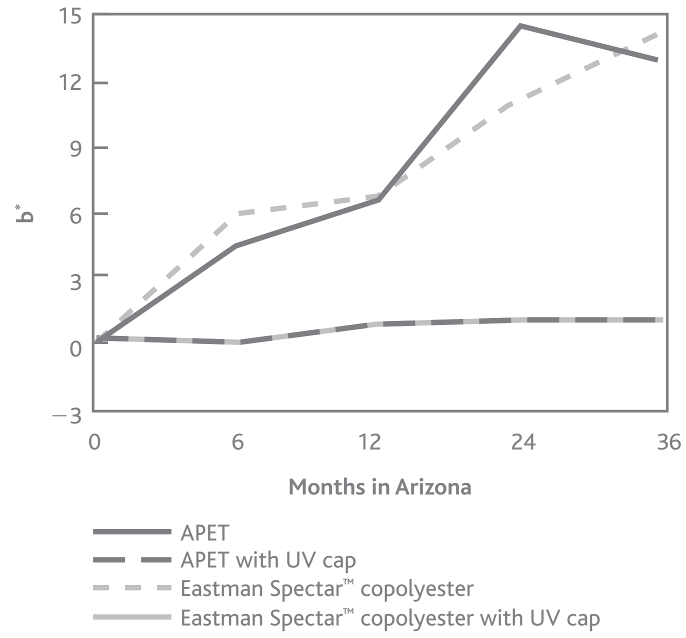


Figure 4 Flatwise impact strength as a function of Xenon-arc exposure

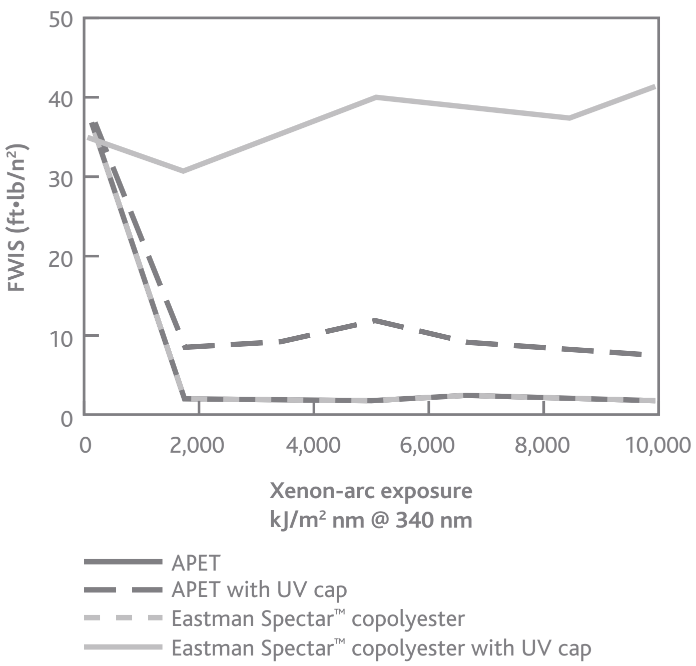
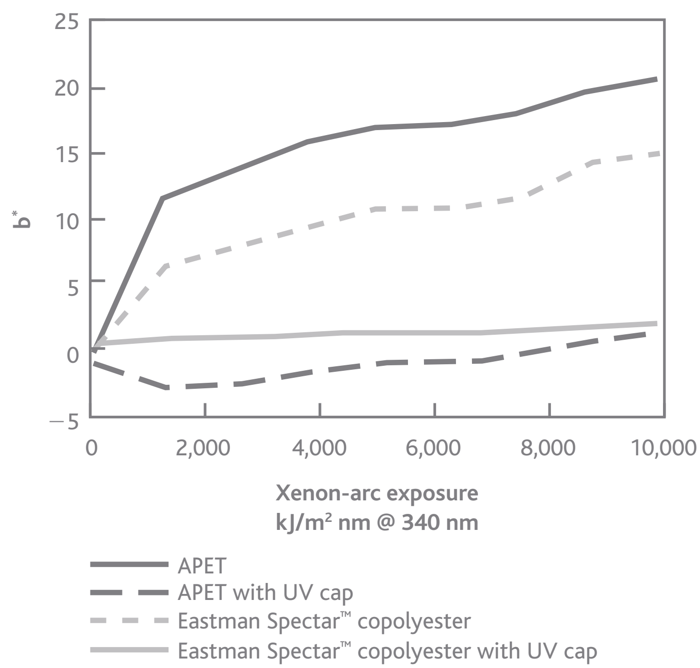


Figure 5 Yellowness (b*) as a function of Xenon-arc exposure



Thermoforming

Sheet made from Eastman Spectar™ copolyester is very forgiving because of its amorphous nature. It has a wide thermoforming window, allows very deep draws, and stays crystal clear. Both optical and physical properties are maintained after thermoforming. APET, on the other hand, has a narrow processing window. If too cold, it will haze due to crazing. If too hot, it will start to haze after a short time due to crystallization. With high levels of crystallinity, the sheet becomes white, opaque, and brittle, making APET difficult to thermoform, especially in thicker gauges. Optical properties after thermoforming with Spectar are as good as and usually better than after thermoforming with APET. For thinner gauges, thermoforming cycle times are similar.

Chemical resistance

Thermoplastic materials have a wide range of resistance to various chemical substances. APET and Eastman Spectar™ copolyester are close enough in chemical composition to have similar chemical resistances to many chemicals including detergent solutions and oil-based products.

Table 3 shows that APET and Spectar are comparable in chemical resistance.

The data shows little difference between APET and Spectar, even when exposed to detergent solutions and oil-based products.

Table 3 Chemical resistance of Eastman Spectar™ copolyester and APET

Chemical	Method	(hr)	Temp (°C)	Eastman Spectar™ copolyester PETG	APET
2-Ethylhexyl sebacate	Immersion	20	23	No effect	No effect
Acetic acid—5% vol/vol	Immersion	20	23	No effect	No effect
Acetic acid (s.p. gr. 1.05)	Immersion	20	23	No effect	No effect
Acetone	Immersion	20	23	Haze	Haze
Ammonium hydroxide (sp. gr. 0.90)	Immersion	20	23	No effect	No effect
Ammonium hydroxide (10%)	Immersion	20	23	No effect	No effect
Aniline	Immersion	20	23	Dissolving	Discoloration
Antifreeze/coolant	Immersion	20	23	No effect	No effect
Brake fluid	Immersion	20	23	No effect	No effect
Citric acid—1%	Immersion	20	23	No effect	No effect
Cottonseed oil	Immersion	20	23	No effect	No effect
Detergt. sol. (0.025%)	Immersion	20	23	No effect	No effect
Diesel fuel	Immersion	20	23	No effect	No effect
Diethyl ether	Immersion	20	23	No effect	No effect
Dimethyl formamide (dmf)	Immersion	20	23	Haze	Haze
Distilled water	Immersion	20	23	No effect	No effect
Ethyl acetate	Immersion	20	23	Haze	No effect
Ethyl alcohol—50%	Immersion	20	23	No effect	No effect
Ethyl alcohol—95%	Immersion	20	23	No effect	No effect
Ethylene dichloride	Immersion	20	23	Dissolving	Haze
Gasoline	Immersion	20	23	No effect	No effect
Heptane	Immersion	20	23	No effect	No effect
Hydrochloric acid (sp. gr. 1.19)	Immersion	20	23	Haze	Haze
Hydrogen peroxide—28%	Immersion	20	23	No effect	No effect
Hydrogen peroxide—3%	Immersion	20	23	No effect	No effect
Isooctane	Immersion	20	23	No effect	No effect
Isopropyl alcohol	Immersion	20	23	No effect	No effect
Kerosene	Immersion	20	23	No effect	No effect
Lipid soln—2%	Immersion	20	23	No effect	No effect
Methanol	Immersion	20	23	No effect	No effect
Mineral oil	Immersion	20	23	No effect	No effect
Motor oil	Immersion	20	23	No effect	No effect
Nitric acid—10%	Immersion	20	23	No effect	No effect
Nitric acid—40%	Immersion	20	23	No effect	No effect
Nitric acid (sp. gr. 1.42)	Immersion	20	23	Dissolving	Bubbling
Oleic acid	Immersion	20	23	No effect	No effect
Olive oil	Immersion	20	23	No effect	No effect
Phenol soln—5%	Immersion	20	23	Swelling	Haze
Soap soln—1%	Immersion	20	23	No effect	No effect
Sodium carbonate soln—2%	Immersion	20	23	Haze	No effect
Sodium carbonate soln—20%	Immersion	20	23	No effect	No effect
Sodium chloride soln—10%	Immersion	20	23	No effect	No effect
Sodium hydroxide—10% w/v in water	Immersion	20	23	No effect	No effect
Sodium hydroxide—60%	Immersion	20	23	No effect	Haze
Sodium hydroxide—1%	Immersion	20	23	No effect	No effect
Sodium hypochlorite solution	Immersion	20	23	No effect	No effect
Sulfuric acid—30%	Immersion	20	23	No effect	No effect
Sulfuric acid (sp. gr. 1.84)	Immersion	20	23	Dissolving	Dissolving
Sulfuric acid—3%	Immersion	20	23	No effect	No effect
Toluene	Immersion	20	23	Haze	Haze
Transformer oil	Immersion	20	23	No effect	No effect
Transmission fluid	Immersion	20	23	No effect	No effect
Turpentine	Immersion	20	23	No effect	No effect

Impact strength

Both APET and Eastman Spectar™ copolyester have relatively high impact strength. Flatwise impact strength is excellent. Spectar has notched Izod impact strength about one third higher than APET. In addition, APET suffers a significant loss of impact at lower temperatures (below –20°C). Because of its toughness, Spectar is easier to fabricate than APET, as APET tends to chip and break.

Fabrication

Eastman Spectar™ copolyester is easier to saw, rout, die-cut, and drill than APET. APET tends to chip and break due to lower notched impact strength.

Solvents used in adhesives tend to induce crystallization in APET, causing whiteness or opaqueness and brittle bonds. This makes APET difficult to solvent bond. It is possible to use "superglues," but these are expensive. For Spectar, solvents as well as common adhesives can be used to form strong, clear bonds, with shorter setup times.

Environmental benefits

The specific gravity of APET is 1.34 g/cm^3 versus 1.27 g/cm^3 for Eastman Spectar™ copolyester. This makes sheets of equal thickness 5% lighter when made with Spectar. In sheet form, more APET material is required to make the same sheet thickness as Spectar.

This means that less Spectar by weight is required to make the same amount of sheet as APET. This can lead to lower shipping costs since more sheets of Spectar can be placed on a truck than APET sheet.

The combustion products of Spectar have been determined to be nontoxic by the Elektro Physik, Aachen when tested according to DIN 53436. Eastman copolyesters have also been certified by the Greenguard Environmental Institute for low chemical and particle emissions.

Value

Looking beyond sheet price to dimensioning, fabrication, packaging, and shipping costs, a number of other factors need to be considered:

- Higher toughness of Eastman Spectar™ copolyester and a generally more forgiving nature leads to faster and simpler and, therefore, less expensive fabrication and less breakage.
- The ability to solvent bond sheet made from Spectar increases design possibilities and often contributes to lowering costs. Solvent bonding APET typically results in crazing or whitening and poor bonds.
- Spectar can be thermoformed over a wider temperature range than APET, thus making processing easier and reducing the chance of producing scrap parts.
- It is easier to retain good optical properties with Spectar as there is no tendency to crystallize and whiten.

All factors considered, total costs are often lowest when using sheet from Spectar for a given application.

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