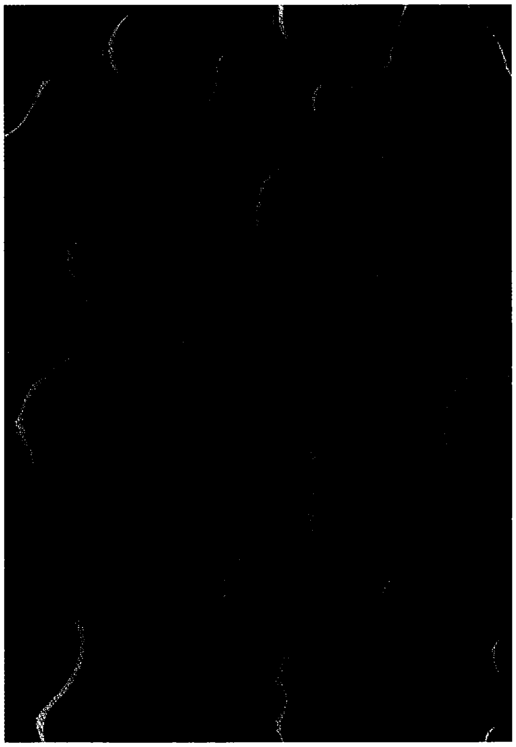
Shell Chemicals

CARILON® POLYMERS
CHEMICAL RESISTANCE GUIDE

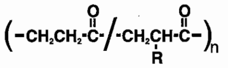


Carilon®

Thermoplastic Polymers

Introduction

Carilon® Polymers are a revolutionary new class of engineering thermoplastics developed by Shell Chemicals companies. They are an analiphatic polyketone, based on perfectly alternating olefin and carbon monoxide monomers (see Figure One), and combine an outstanding balance of physical and mechanical properties with chemical resistance.



$$\left(-CH_2CH_2-\overset{O}{\overset{\|}{C}}-/-CH_2\underset{R}{\underset{|}{CH}}-\overset{O}{\overset{\|}{C}}-\right)_n$$

Figure 1.

CARILON Polymers are semi-crystalline. They exhibit strong interchain forces and have a hydrolytically stable backbone – all of which contribute to the polymers' wide range of chemical resistance. They also provide a chemical resistance that exceeds that of many other engineering thermoplastics, including polyamides, polycarbonates, and polyesters.

CARILON Polymers are truly a multidimensional thermoplastic – engineered to solve more problems, in more applications. Our real-life testing has shown that CARILON Polymers work well for applications that come in contact with the following:

Automotive fuels, fluids, and lubricants
Organic solvents
Aqueous environments
Corrosive salts
Weak acids and bases

To help you make the most of CARILON Polymers, we have a team of market development specialists who can work with you to determine the most effective applications for you. So call your local Shell Chemicals company today or visit our website at <*www.shellchemicals.com*>.

Chemical Resistance

The chemical resistance of a polymer generally describes its ability to maintain mechanical integrity while being exposed to specific chemical environments. Temperature, concentration, state of mechanical stress and duration of exposure are key variables which influence the ultimate performance of a polymer in a particular environment. With these many critical variables, the final classification of "suitable for use" is largely dependent upon the application.

The two mechanisms by which chemical environments affect polymers are solvation (or plasticization) and chemical reaction. Dispersive, polar and hydrogen bonding interactions are primarily responsible for the plasticization or dissolution of a polymer by a specific chemical. Chemical attack may result from specific reactions such as those catalyzed by acids, bases, or oxidizing agents.

Solvation and Plasticization

The detrimental effects of plasticization or catastrophic dissolution are easily understood. Sorption of low molecular weight species can lead to large dimensional changes and dramatic reductions in mechanical strength. While no engineering thermoplastic is insusceptible to all solvent environments, CARILON Polymers resist dissolution and severe plasticization from a broad range of the most common chemical environments.

At room temperature, there are no common solvents for CARILON Polymer D26HM100, which places it among a select class of chemically resistant polymers. For laboratory purposes, hexafluoroisopropanol is used as a room temperature solvent. In this case, solvation is driven by the strong hydrogen bonding character of the fluorinated alcohol. At high temperatures, reagents such as m-cresol can dissolve CARILON Polymers via similar hydrogen bonding interactions.

CARILON Polymer D26HM100 is particularly insensitive to plasticization in most aqueous environments. In Table 1, the tensile yield stress values for this polymer are shown after being exposed to various aqueous solutions at 80 °C for 25 days. For comparison purposes, data for polyamide 66 are also included in Table 1. Polyamide 66 is an engineering resin widely accepted for its strength, toughness, and good chemical resistance. At room temperature and 50% relative humidity, the yield stress of CARILON Polymers is roughly equivalent to that of polyamide 66. However, after exposure to aqueous environments, the yield stress of polyamide 66 drops to a level roughly 40% below that of CARILON Polymer D26HM100. Since CARILON Polymers sorb only 2 wt% water at saturated conditions, they exhibit superior reisistance to plasticization in aqueous environments tested. The most common organic solvents tested also have little effect on the plasticization of CARILON Polymers over the testing period.

Table 1. Yield stress values for CARILON® Polymer D26HM100 and polyamide 66 after 25 days exposure to various aqueous environments at 80 °C. Tensile testing was conducted at 23 °C.

Chemical	CARILON® Polymer D26HM100 (MPa)	Polyamide 66* (MPa)
Control (50%rh)	57.9	57.2
Water	59.2	33.1
Seawater	60.0	33.1
5 wt% Acetic Acid	57.9	33.8
5 wt% Calcium Chloride	60.0	33.8
50/50 Antifreeze	59.2	35.8

* DuPont Zytel 101 polymer

In Table 2, the yield stress and weight gain are recorded for CARILON Polymer samples after exposure to various organic solvents at 80 °C for 25 days. Common hydrogen bonding solvents such as water, methanol and ethanol show little effect on the polymers' ultimate tensile strength. In general, the plasticization of CARILON Polymer D26HM100 by solvents with similar chemical structure, such as ketones and esters, is minor. Like alcohols, 25-day exposure to ketones and esters at elevated temperatures results in only a 5–10% reduction in tensile strength. This is in contrast to some chemically resistant polymers such as polyvinylidene fluoride (PVDF) which are highly plasticized and may even be dissolved by ketones and esters. Chemical reagents which significantly swell and plasticize CARILON Polymers are also included in Table 2. Methylene chloride and chloroform, which are capable of forming hydrogen bonds, show a 30 wt% uptake in CARILON Polymer D26HM100. The high level of sorption leads to roughly a 30% reduction in tensile strength. Polar aprotic solvents such as dimethyl sulfoxide (DMSO) and n-methyl pyrrolidone (NMP) are also somewhat effective in plasticizing CARILON Polymers.

Table 2. Yield stress values and percentage weight gain for CARILON® Polymer D26HM100 after 25 days exposure to various organic solvents at 80 °C. Tensile testing was conducted at 23 °C.

Chemical	Weight Gain (Wt%)	Yield Stress (MPa)
Control (50%rh)	—	57.9
Water	2.3	59.2
Methanol	4.5	53.1
Ethanol	4.2	56.9
Ethyl Acetate	3.8	57.2
Methyl Ethyl Ketone	4.8	56.9
Gasoline	1.2	62.0
Trichloroethylene	8.0	55.1
Methylene Chloride	33.0	38.6
Chloroform	32.0	40.0
DMSO	16.0	45.5

Chemical Attack

In addition to the loss of properties from plasticization, chemical attack by a number of mechanisms is of particular interest to the engineering thermoplastic polymer arena. The most common types of chemical reactions, which are observed in polymer applications, are hydrolysis and oxidation.

Because of the predominance of condensation polymers in today's family of engineering thermoplastics, hydrolysis is a particularly difficult problem to avoid. The molecular weight reduction which accompanies hydrolysis can lead to a serious reduction in the long-term performance of most of these engineering thermoplastics. Acids, bases, and salts tend to catalyze the hydrolysis of amide, ester, and carbonate linkages. The backbone chemistry of CARILON Polymers precludes chain scission by simple hydrolysis.

Table 3. Yield stress values for CARILON® Polymer D26HM100 and polyamide 66 after 25 days exposure to various aggressive aqueous environments at 80 °C. Tensile testing was conducted at 23 °C.

Chemical	CARILON® Polymer D26HM100 (MPa)	Polyamide 66* (MPa)
Control (50%rh)	57.9	57.2
Water	59.2	33.1
10 wt% NaOH	60.0	28.9
1 wt% NaOH	58.6	28.2
10 wt% HCl	64.7	Dissolved
1 wt% HCl	59.3	Embrittled
30 wt% H_2SO_4	59.3	Dissolved
50 wt% $ZnCl_2$	46.2	Dissolved

*DuPont Zytel 101 polymer

As shown in Table 3, CARILON Polymers exhibit resistance to hydrolytic attack in a variety of aggressive aqueous environments. After 25 days at 80° C in the acidic environments, the polyamide 66 test specimens dissolved or were severely embrittled, while the CARILON Polymer D26HM100 samples remained intact with virtually no reduction in tensile strength. CARILON Polymers also exhibit performance advantages in concentrated salt solutions such as chloride.

While CARILON Polymer D26HM100 does not undergo hydrolysis, it is somewhat susceptible to stronger acids and bases, especially at higher temperatures and longer-term exposures. Color development and increased stiffness are typically observed. These effects are seen in Table 3, where the yield stress increases after immersion in 10 wt% sodium hydroxide or hydrochloric acid solutions. Amines and strong oxidizing agents such as in certain concentrations of perchloric acid, nitric acid or hypochlorites, can also be problematic for CARILON Polymers.

Chemical Resistance Table For CARILON® Polymer D26HM100

The following tables describe the chemical resistance of CARILON® Polymer D26HM100 to a wide variety of chemicals at various concentrations and temperatures. Data included in these tables are changes in appearance, weight, and yield strength. It should be noted that for CARILON Polymers, color changes are frequently not indicative of a deterioration of mechanical properties. The testing was conducted on 1/8-inch-thick, ASTM D-638 type V molded tensile bars. The specimens were totally immersed in the various chemicals at a controlled temperature. The tensile bars were removed after a period of days and subjected to the following procedure:

- samples were blotted dry
- samples were weighed and measured to determine weight gain and volume change
- changes in color and surface appearance were recorded
- samples were tested for mechanical deterioration by determining stress at yield in accordance with ASTM D-638

Environmental Stress Crack Resistance

Environmental stress crack resistance (ESCR) was evaluated by using the "bent loop" method. Here, the polymer specimens were immersed in various solutions at controlled temperatures while imposing a 20% constant strain from bending the polymer in a fixed loop. From these tests, it is evident that CARILON Polymer D26HM100 is quite resistant to stress cracking in a wide variety of chemical environments. The solutions which showed stress cracking behavior are noted accordingly.

Reagent	Conc. (%)	Temp. (°C)	Time (Days)	Appearance	Weight Change (%)	Stress @ Yield (% Change)
Acetic Acid	5	23	100	No change	2.5	-8
	5	23	365	No change	2.8	-9
	5	23	730	No change	2.7	-11
	5	23	1095	No change	3.0	-7
	5	80	25	Slight yellow	3.3	5
	5	80	100	Yellow	3.0	1
	5	80	300	Yellow	3.0	1
Acetone	100	23	100	No change	4.8	-16
	100	23	365	Light yellow	5.0	-10
	100	23	730	Light yellow	5.2	-13
	100	50	100	Light yellow	4.5	-11
	100	50	300	Light yellow	4.5	-11
Ammonium Hydroxide	10	23	100	Orange brown	-0.6	0
	10	23	365	Orange brown	-2.6	13
	10	80	25	Brown, tacky	-3.6	-8
Ammonium Sulfate	20	23	100	Light yellow	1.4	-4
	20	23	365	Yellow	1.2	-4
	20	23	730	Dark yellow	1.6	-1
Aniline	100	23	100	Orange brown, swollen	25.9	-73
	100	23	365	Dark brown	15.2	-84
Anisole	100	23	100	No change	2.7	-11
	100	23	365	No change	5.9	-13
	100	23	730	Light yellow	6.6	-13
Antifreeze	100	23	100	No change	-0.1	5

Reagent	Conc. (%)	Temp. (°C)	Time (Days)	Appearance	Weight Change (%)	Stress @ Yield (% Change)
Antifreeze (cont.)	100	23	365	Slight green	-0.2	5
	100	23	730	Light yellow	0.6	1
	100	45	100	No change	1.0	5
	100	45	300	Yellow	1.0	9
	100	80	25	Light gold	2.8	12
Antifreeze	50	23	763	No change	1.0	-1
	50	45	100	No change	1.0	4
	50	45	360	Yellow	1.0	8
Barium Hydroxide	10	23	100	No change	1.6	-7
	10	23	365	Slight yellow	1.6	-2
	10	23	730	Yellow	2.1	-7
Beer	100	23	100	No change	1.9	-5
	100	23	365	Slight yellow	2.0	-6
Benzaldehyde	100	23	100	No change	2.8	-8
	100	23	365	No change	7.0	-16
	100	23	730	No change	8.4	-18
n-Butanol	100	23	100	No change	-0.5	9
	100	23	365	No change	-0.3	11
	100	23	730	Light yellow	0.2	3
Butylacetate	100	23	365	No change	0.0	-2
	100	80	365	Dark yellow	2.0	10
Brake Fluid	100	23	763	Brown	0.0	1
	100	45	100	Dark yellow	0.0	7
	100	45	360	Brown	0.0	9
Calcium Chloride	5	23	100	No change	1.6	-7
	5	23	365	Light cream	1.7	-2
	5	23	730	Yellow	1.1	-8
	5	80	25	No change	2.2	7
	5	80	100	Creamy tan	1.8	12
	30	23	320	No change	0.0	0
Calcium Hydroxide	2	23	100	No change	2.0	-6
	2	23	365	Slight yellow	1.7	-4
Carbon Tetrachloride	100	23	100	No change	1.0	-1
	100	23	365	No change	0.8	3
Chassis Lube	100	23	763	Dark yellow	0.0	3
	100	45	100	Dark yellow	0.0	8
	100	45	360	Dark yellow	0.0	10
Chloroform	100	23	100	Swollen	25.8	-32
	100	23	365	Swollen	26.6	-35
	100	23	730	Slight yellow	25.4	-25
	100	80	25	Gold yellow	32.0	-30
	100	80	100	Dark brown	25.8	No yield
Cupric Chloride	20	23	100	Light yellow	1.4	-5
	20	23	365	Yellow	1.3	-3
	20	23	730	Gold brown	1.4	0

Reagent	Conc. (%)	Temp. (°C)	Time (Days)	Appearance	Weight Change (%)	Stress @ Yield (% Change)
Detergent, Tide®	5	23	100	No change	1.9	-7
	5	23	365	No change	1.8	-6
Dichlorobenzene 1,2	100	23	100	No change	1.1	-4
	100	23	365	No change	1.9	0
Dimethyl Formamide	100	23	100	No change	7.2	-19
	100	23	365	Yellow orange	8.0	-15
	100	23	730	Gold yellow	8.6	-17
	100	80	100	Brown, swollen	11.3	-13
	100	80	300	Brown, swollen	11.3	-83
Dishwash, Cascade®	5	23	100	Yellow	1.7	-5
	5	23	365	Orange	1.7	-5
	5	23	730	Gold brown	1.8	-3
Dimethyl Sulfoxide	100	23	100	No change	3.9	-13
	100	23	365	No change	9.9	-18
	100	23	730	Slight yellow	9.8	-20
	100	80	25	No change, blooming	16.0	-21
Ethanol	100	23	100	No change	0.4	-2
	100	23	365	No change	1.3	-4
	100	23	730	Slight yellow	1.9	-6
	100	80	25	No change	4.2	-1
	100	80	100	Cream	3.2	2
Ethyl Acetate	100	23	100	No change	0.6	-1
	100	23	365	No change	2.2	-7
	100	23	730	Slight yellow	3.4	-12
	100	80	25	No change	3.8	2
	100	80	100	Off-white	4.0	4
Ethylene Glycol	100	23	763	No change	0.0	2
	100	80	25	Light yellow	3.6	4
	100	80	100	Gold yellow	3.2	18
Ferrous Sulfate	20	23	100	No change	1.7	-6
	20	23	365	No change	1.6	-2
	20	23	730	No change	2.0	6
Formic Acid	10	23	100	No change	4.3	-15
	10	23	365	No change	4.4	-7
	10	23	730	Slight yellow	4.7	-14
Gasoline	100	23	100	Slight yellow	0.4	3
	100	23	365	Slight yellow	0.4	-1
	100	23	730	Slight yellow	0.9	-1
	100	45	100	No change	1.0	0
	100	45	360	Light yellow	1.0	0
	100	80	25	Slight yellow	1.2	9
	100	80	100	Cream	1.3	10
	100	95	40	No change	2.0	5
Gasoline (10% EtOH)	100	23	763	Light yellow	2.0	-8
	100	45	100	No change	1.0	-6
	100	45	300	Light yellow	2.0	-5

Reagent	Conc. (%)	Temp. (°C)	Time (Days)	Appearance	Weight Change (%)	Stress @ Yield (% Change)
Sodium Hypochlorite†	5	23	100	Light brown	-10.9	-3
	5	23	365	Light brown	-10.3	-4
Sulfuric Acid	5	23	365	No change	1.5	-5
	30	23	100	Light yellow	0.6	-3
	30	23	365	Light brown	0.6	-10
	30	23	730	Light brown	0.9	-11
	30	80	25	Light yellow	2.0	4
	30	80	100	Light brown	1.4	12
Tetrachloroethylene	100	23	100	No change	0.0	-2
	100	23	300	No change	0.8	-1
Toluene	100	23	100	No change	1.1	-3
	100	23	365	No change	1.7	-4
	100	23	730	Slight yellow	2.8	-9
	100	80	100	Yellow	3.8	1
	100	80	300	Yellow	3.8	7
Transmission Fluid	100	23	763	Yellow	0.0	1
	100	45	100	No change	0.0	7
	100	45	360	Light yellow	0.0	10
Trichloroethane, 1,1,1	100	23	100	No change	0.8	-1
	100	23	300	No change	0.8	-1
	100	80	100	No change	3.8	2
	100	80	300	Light yellow	3.8	0
Trichloroethylene	100	23	100	No change	4.3	-10
	100	23	365	Yellow	7.0	-12
	100	23	730	Slight yellow	7.2	-2
	100	80	25	Gold yellow	8.0	-3
	100	80	100	Dark brown	9.1	0
Water	100	23	100	No change	2.2	-5
	100	23	365	No change	2.0	-6
	100	23	730	Slight yellow	2.0	0
	100	80	25	No change	2.3	5
	100	80	100	Tan	2.1	11
Water (seawater)	100	23	100	No change	1.8	-7
	100	23	365	No change	1.8	-4
	100	23	730	Slight yellow	1.8	-1
	100	80	25	Slight yellow	2.2	6
	100	80	100	Light brown	1.7	12
Wine, Red	100	23	365	Red	2.5	-4
Zinc Chloride	10	23	365	Yellow	2.0	-4
	50	23	100	Yellow brown	5.2	-10
	50	23	365	Dark brown	8.9	-17
	50	80	25	Dark brown	17.9	-19
	50	80	100	Dark brown	18.1	-13

* Mild stress cracking agent at 80°C

† Stress cracking agent.

Reagent	Conc. (%)	Temp. (°C)	Time (Days)	Appearance	Weight Change (%)	Stress @ Yield (% Change)
Motor Oil	100	23	763	Dark yellow	0.0	1
	100	45	100	Yellow	0.0	8
	100	45	300	Dark yellow	0.0	16
MTBE	100	23	100	No change	-0.2	1
	100	23	365	No change	0.0	4
	100	23	730	Slight yellow	0.0	2
Mustard	100	23	365	Bright yellow	2.9	-5
N-Methyl Pyrrolidone	100	23	100	No change	2.3	-5
	100	23	365	Tan	6.0	-13
	100	23	730	Tan	9.3	-18
Nitric Acid	1	23	100	No change	1.7	6
	1	60	100	Red brown	1.9	-6
	5	23	100	Yellow	2.7	13
	5	60	100	Yellow, cracks	-4.0	No yield
	10	23	100	Red brown	3.0	No yield
Phosphoric Acid	1	23	100	No change	1.1	6
	1	60	100	Slight yellow	2.3	6
	5	23	100	No change	1.3	6
	5	60	100	Slight yellow	2.3	6
	10	23	100	No change	1.4	6
	10	60	100	Slight yellow	1.8	6
	20	23	100	No change	1.2	6
	20	60	100	Light brown	2.4	6
Potassium Hydroxide	45	23	100	Light tan	-0.2	8
	45	23	365	Tan	-0.7	10
	45	23	730	Light brown	-1.0	9
Propylene Carbonate	100	23	100	No change	1.3	1
	100	23	365	No change	3.4	-7
Propylene Glycol	100	80	25	Light yellow	4.3	14
	100	80	100	Orange yellow	3.6	19
Skydrol 500	100	45	100	No change	0.0	8
	100	45	300	No change	0.0	15
Sodium Bisulfite	20	23	100	No change	3.8	-6
	20	23	365	White	-6.6	-44
Sodium Hydroxide	1	80	25	Golden	2.8	3
	1	80	100	Golden brown	2.2	13
	10	23	100	Amber brown	1.0	-4
	10	23	365	Amber brown	0.9	-3
	10	80	25	Dark brown	1.7	-24
	10	80	100	Dark brown	1.2	No yield
	10	23	730	Brown	0.6	-5
	50	23	100	Slight yellow	-0.7	9
	50	23	365	Light gray	0.1	8
	50	23	730	Tan	-0.9	3

Reagent	Conc. (%)	Temp. (°C)	Time (Days)	Appearance	Weight Change (%)	Stress @ Yield (% Change)
Gasoline (15% MeOH)	100	95	40	No change	3.8	-9
Gasoline (15% MTBE)	100	95	40	No change	1.9	5
Heptane	100	23	100	No change	0.0	0
	100	23	300	No change	0.0	0
	100	80	100	Light yellow	0.0	18
	100	80	300	Yellow	0.0	15
Hexane	100	23	100	No change	0.0	-1
	100	23	365	No change	-0.2	5
	100	23	730	Slight yellow	0.2	2
Hydrochloric Acid	1	23	100	No change	2.0	-6
	1	23	365	No change	1.9	-5
	1	80	25	Light yellow	2.6	4
	1	80	100	Caramel	2.0	9
	10	23	100	Yellow	1.4	-3
	10	23	365	Brown	1.5	No yield
	10	80	25	Brown	1.0	13
	10	80	100	Dark brown	0.2	29
	37	23	100	Black	5.0	30
	37	23	365	Black	5.1	No yield
Hydrogen Peroxide	3	23	100	Slight yellow	1.9	-6
	3	23	365	Light yellow	1.8	-5
	3	80	25	Light yellow	2.5	6
	3	80	100	Caramel	2.4	13
	35	23	365	Slight yellow	3.1	-7
Isopropyl Alcohol	100	23	100	No change	-0.4	5
	100	23	365	No change	-0.1	5
	100	23	730	Slight yellow	0.4	1
Ketchup	100	23	365	Light yellow	1.6	-1
Lactic Acid	20	23	100	No change	2.6	-8
	20	23	365	No change	3.3	-7
	20	23	730	Light yellow	3.7	-7
Liquor, Tequila	100	23	100	No change	3.1	-11
	100	23	365	No change	3.3	-5
Methanol	100	23	100	No change	2.9	-13
	100	23	365	No change	2.9	3
	100	23	730	Slight yellow	2.9	-15
	100	23	1095	Slight yellow	2.9	-11
	100	80	25	No change	4.5	-7
Methyl Ethyl Ketone (MEK)	100	23	100	No change	1.4	-8
	100	23	365	No change	4.1	-10
	100	23	730	Slight yellow	4.0	-11
	100	23	1095	Slight yellow	4.2	-11
	100	80	25	No change	4.8	0
	100	80	100	No change	5.0	-1
Methylene Chloride	100	23	100	No change	23.4	-36
	100	23	365	No change	24.4	-38
	100	80	25	No change	33.0	-32
	100	80	100	Slight yellow	34.3	-31

Shell has assembled a global sales and technical support team that is ready to assist you, anywhere in the world.

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THE EFFECT OF STERILIZATION PROCESSES ON CARILON[*] POLYMERS

By Keith Stone and Anne Lacroix

INTRODUCTION

CARILON Polymers, a revolutionary new class of semi-crystalline thermoplastics also referred to as aliphatic polyketones, offer a unique balance of processing and performance properties which, when combined, can satisfy a very broad range of applications, including those where sterilization is required on a once-only or repetitive basis.

This paper examines the effect of steam sterilization on the mechanical properties of two grades of CARILON Polymers, both recommended for general-purpose injection molding. It also considers the materials' hydrolytic stability and examines the effect of Gamma Υ and Beta β sterilization and Ethylene Oxide sterilization (EtOx) upon test specimens of these grades.

TESTING

The grades tested include CARILON Polymer D26HM100 and CARILON Polymer DB6G3A10. CARILON Polymer D26HM100 is a general-purpose injection molding grade with mechanical properties that classify it as an engineering thermoplastic. This material shows excellent impact resistance at room temperature and lower temperatures, high resilience and good creep performance. It can withstand short-term exposure to elevated temperatures and also exhibits excellent resistance to hydrocarbons, solvents, salt solutions, weak acids and weak bases.

CARILON Polymer DB6G3A10 is a 15% short glass fiber-reinforced general-purpose injection molding grade with mechanical properties that classify it as an engineering thermoplastic. It shows a unique balance of toughness and high modulus combined with good creep performance, strength and elevated temperature performance. It also exhibits excellent resistance to hydrocarbons, solvents, salt solutions, weak acids and weak bases.

RESULTS AND DISCUSSION

Steam Sterilization

For the purposes of comparison with other sterilization processes, a process consisting of five autoclave cycles[†] at 134 °C followed by drying and conditioning at 50% RH before testing was selected as a "typical" example.

Steam sterilization of CARILON Polymer D26HM100 caused a small increase in stress at yield, strain at yield and impact strength. Plasticization of the polymer by water absorbed during sterilization is the most likely explanation for these changes.

Steam sterilization of CARILON Polymer DB6G3A10 caused a small increase in break stress. In tests, a decrease in the modulus and impact strength was observed. The most likely explanation for these changes is plasticization of the polymer matrix by water absorbed during sterilization, with the additional effect of changes to the fiber matrix interface.

CARILON Polymer D26HM100 absorbs approximately 3.5% of water at 100 °C. The water absorption for CARILON Polymer DB6G3A10, under similar conditions, is estimated to be approximately 2.5%. It can be assumed that the test specimens absorb at least this amount of water during steam sterilization. It also can be assumed that this water would remain in the specimens for a considerable amount of time if they were not subject to vacuum drying at an elevated temperature.

Multiple Steam Sterilization Cycles

The effect of multiple steam autoclave cycles is of interest for a number of applications where repeated exposure to steam or hot water is required.

Figures 1 and 2 demonstrate the effect of multiple autoclave cycles on the modulus and impact strength of CARILON Polymers D26HM100 and DB6G3A10, respectively. Polymer specimens were dried and conditioned before testing. In the case of CARILON Polymer D26HM100, an increase in impact strength and decrease in modulus were observed as the number of cycles increased. The most likely explanation for this change remains plasticization by water. In the case of CARILON Polymer DB6G3A10, there was a decrease in both modulus and impact strength as the number of cycles increased. While plasticization is likely to play a role, moisture may also affect the fiber matrix interface, leading to the decrease in toughness, which was observed in testing.

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[†] 12-minute vacuum – 12-minute steam – 12-minute vacuum.

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FIGURE 1: INFLUENCE OF STEAM STERILIZATION ON MECHANICAL PROPERTIES OF CARILON POLYMER D26HM100

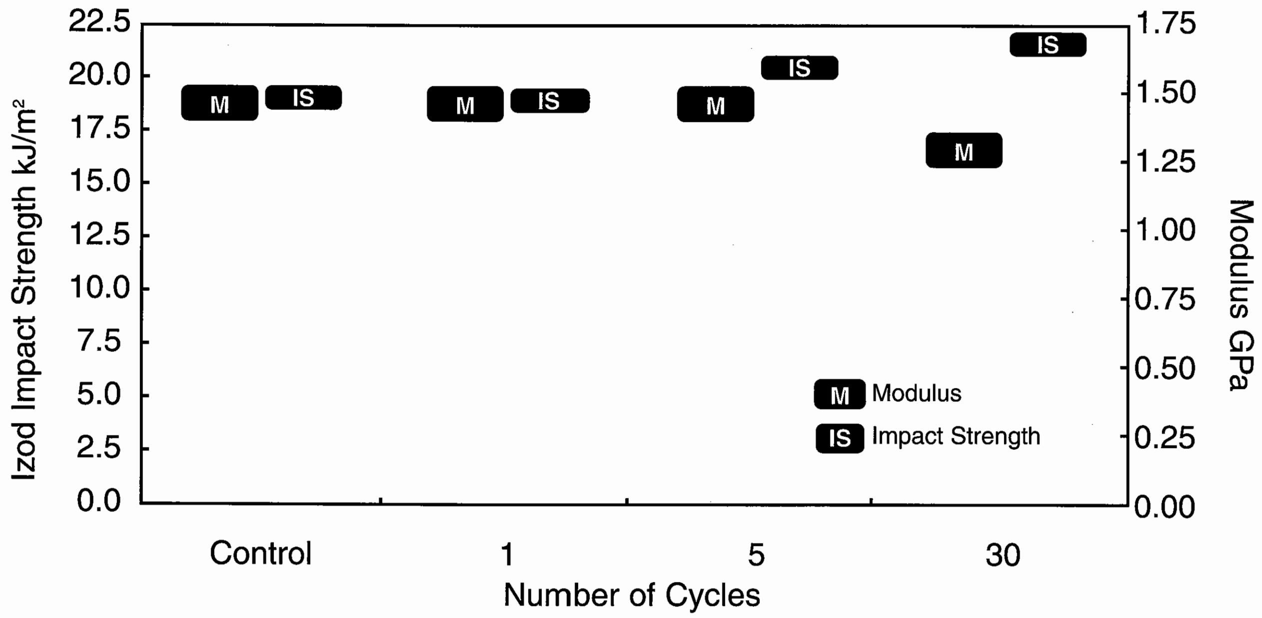
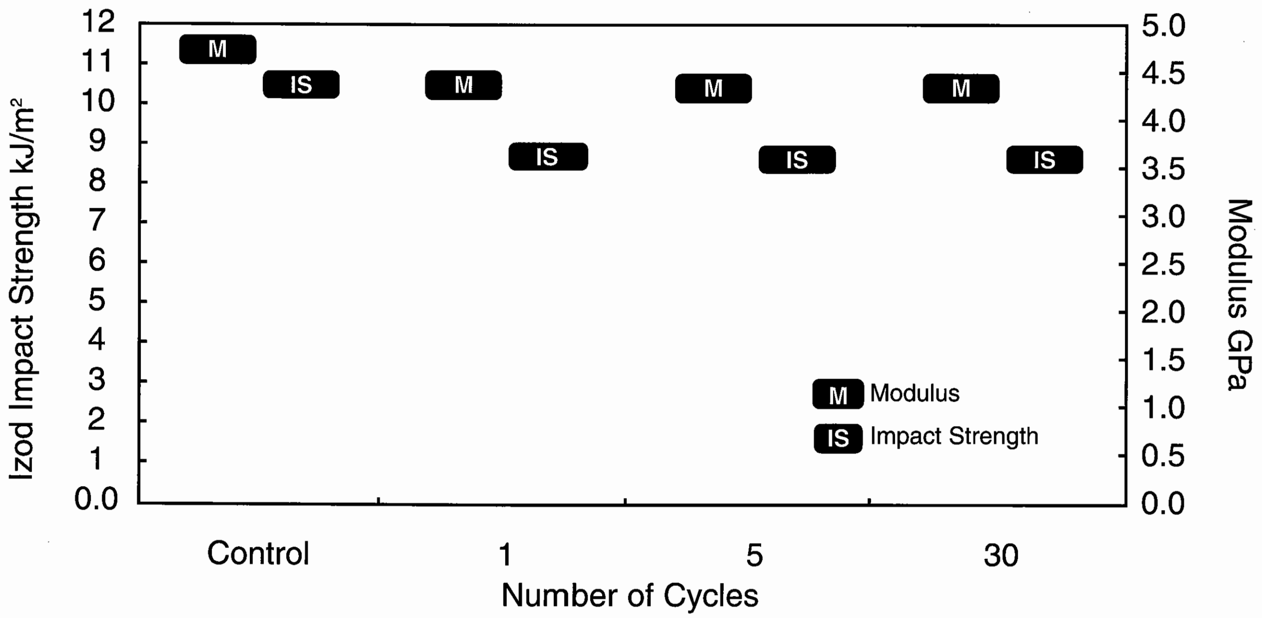


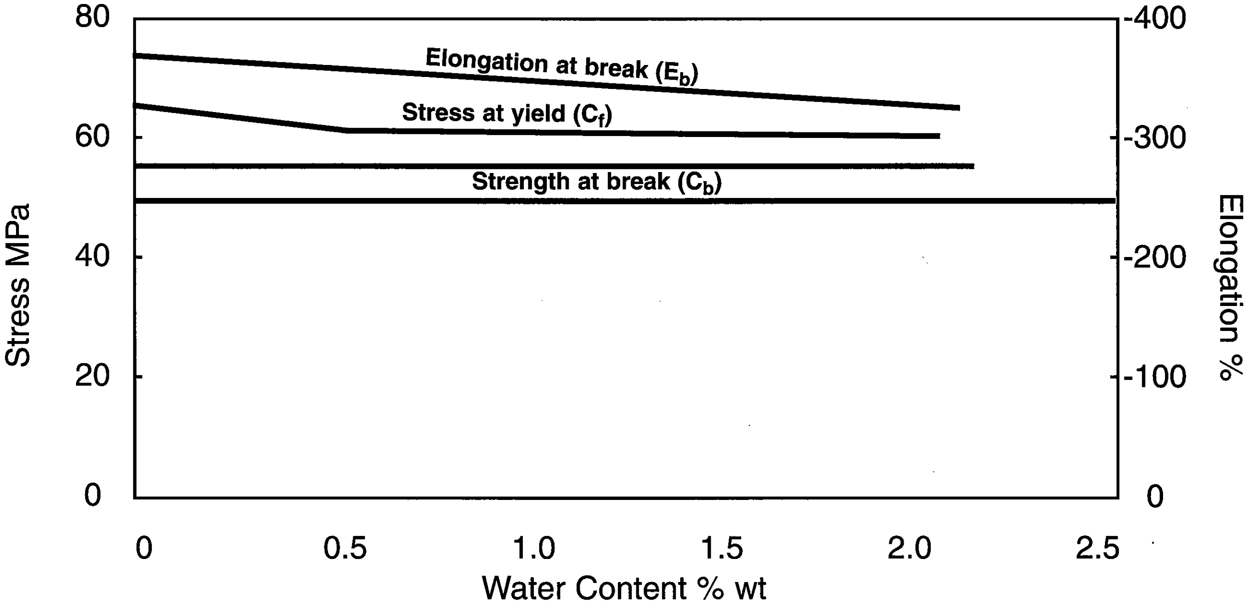
FIGURE 2: INFLUENCE OF STEAM STERILIZATION ON MECHANICAL PROPERTIES OF CARILON POLYMER DB6G3A10



Hydrolytic Stability

CARILON Polymers exhibit excellent hydrolytic stability and low moisture absorption, which means they are not susceptible to hydrolysis upon processing, exhibit resistance to hydrolysis in a broad range of aqueous environments (temperature, pH, salts, etc.) and absorb small amounts of water (0.5% at 50% RH) resulting in a mild plasticizing effect on stiffness but almost no effect on strength (Figure 3).

FIGURE 3: LOW WATER SENSITIVITY



Gamma Y and Beta β Sterilization – CARILON Polymer D26HM100

Neither Y nor β sterilization caused significant short-term change in the tensile properties of CARILON Polymer D26HM100 (Figures 4, 5 and 6).

Both of these sterilization processes did, however, cause yellowing of the polymer (Figure 7).

The toughness of the polymer was affected by both Y and β sterilization, as demonstrated by a reduction in impact strength (Figure 8).

After storage of the Y sterilized polymer, significant increase in the tensile modulus and decrease in impact strength were observed.

NOTE: The mechanical properties of many polymers change as a result of exposure to high-energy radiation. These changes are symptomatic of structural alterations within the polymer backbone occurring as a result of chain scission. When irradiated in the absence of oxygen, chain scission may be followed by "cross linking" or other similar modifications to the polymer (e.g. branching), resulting in an increase in molecular weight. When irradiated in the presence of oxygen, photo oxidative degradation occurs in competition with the "cross linking" process, resulting in an overall decrease in molecular weight and a consequent reduction in associated mechanical properties, such as toughness.

FIGURE 4: INFLUENCE OF STERILIZATION PROCESSES ON THE MODULUS OF CARILON POLYMER D26HM100

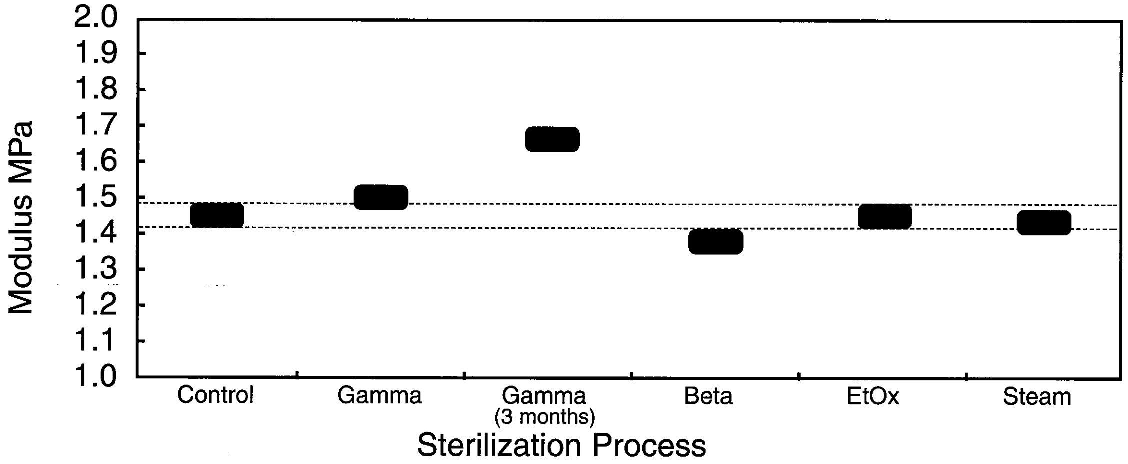


FIGURE 5: INFLUENCE OF STERILIZATION PROCESSES ON THE STRESS AT YIELD ON CARILON POLYMER D26HM100

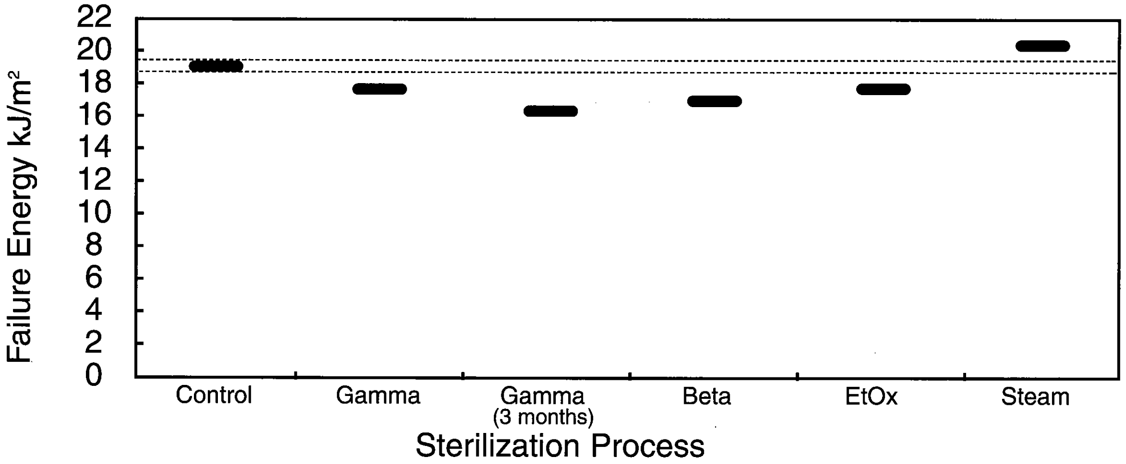


FIGURE 6: INFLUENCE OF STERILIZATION PROCESSES ON THE STRAIN AT YIELD ON CARILON POLYMER D26HM100

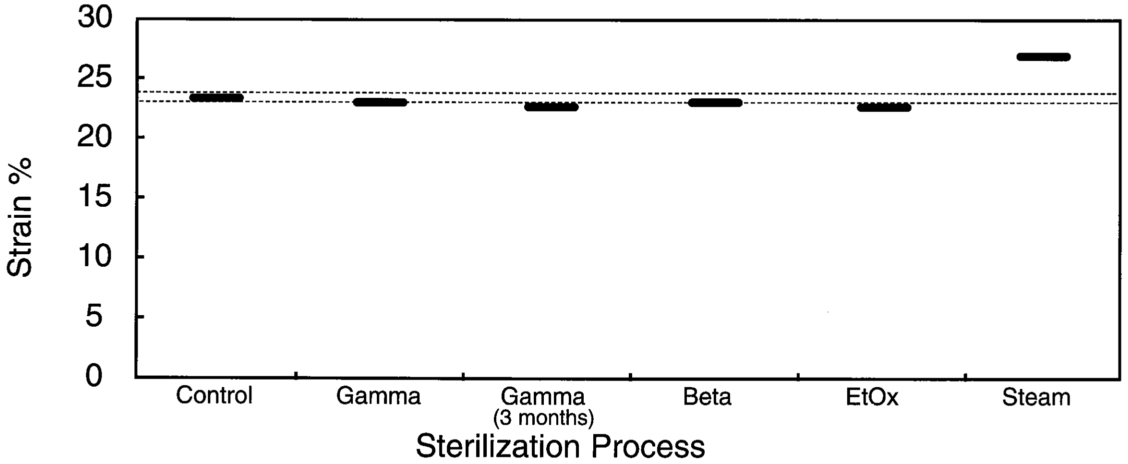


FIGURE 7: DISCOLORATION OF CARILON POLYMER D26HM100 AS A RESULT OF STERILIZATION PROCESSES

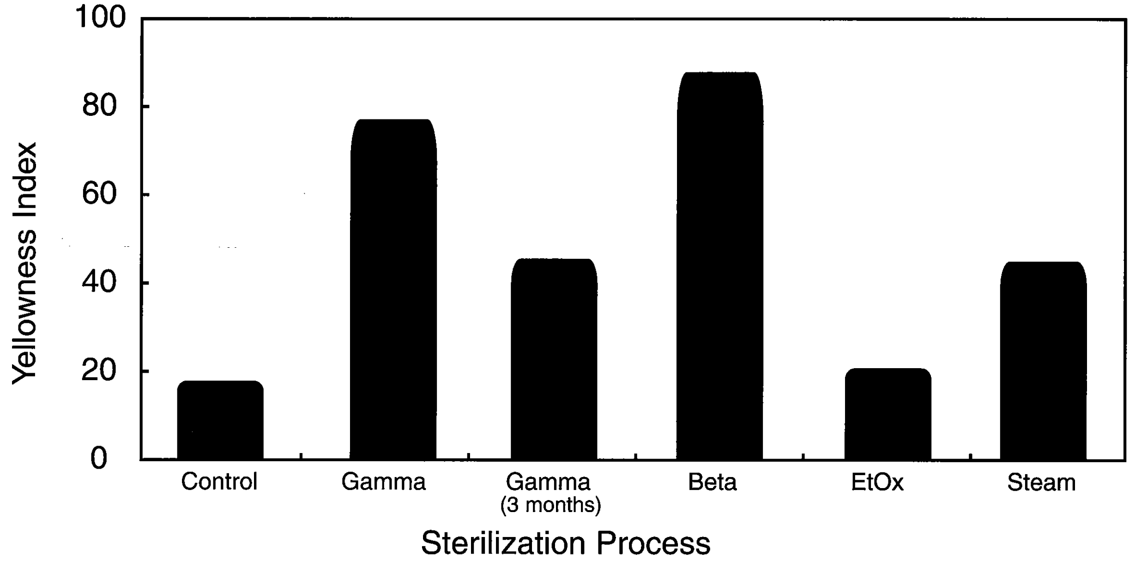
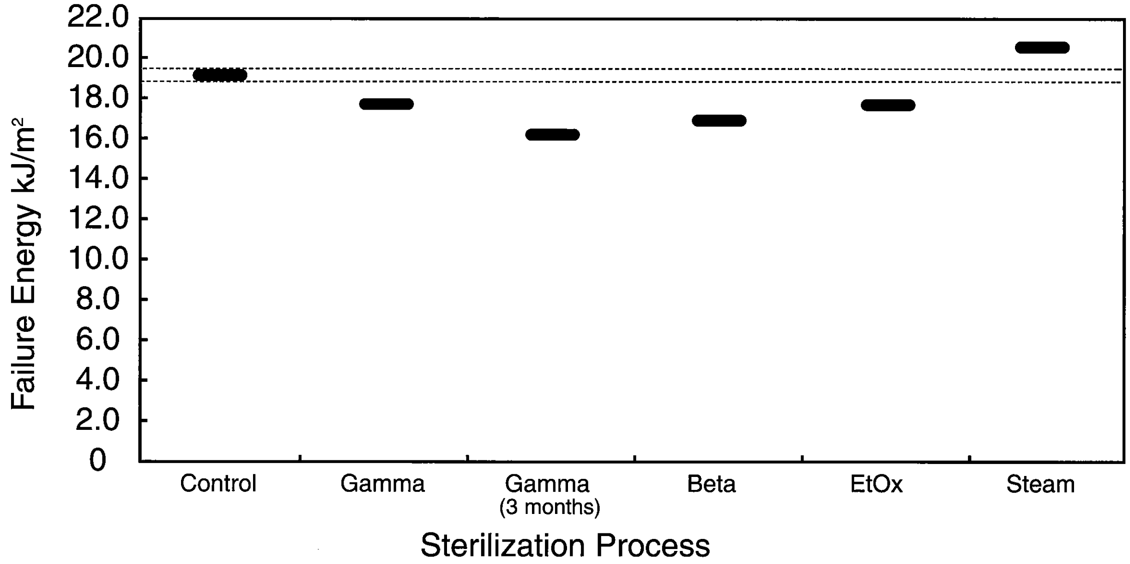


FIGURE 8: INFLUENCE OF STERILIZATION PROCESSES ON NOTCHED IZOD IMPACT STRENGTH OF CARILON POLYMER D26HM100



Gamma Υ and Beta β Sterilization – CARILON Polymer DB6G3A10

The changes in properties of CARILON Polymer DB6G3A10 on Υ or β sterilization followed similar trends to those observed for CARILON Polymer D26HM100. However, the changes to the polymer matrix were substantially masked by the reinforcing effect of the glass fiber.

Neither Υ nor β sterilization caused significant short-term change in the tensile properties of CARILON Polymer DB6G3A10 (Figures 9, 10 and 11).

The impact strength of the polymer was also unaffected by either Υ or β sterilization (Figure 12).

After storage of the Υ sterilized compound, significant increase in the tensile peak stress and decrease in toughness were observed. This is associated with continuing free radical degradation of the polymer matrix.

FIGURE 9: INFLUENCE OF STERILIZATION PROCESSES ON THE MODULUS OF CARILON POLYMER DB6G3A10

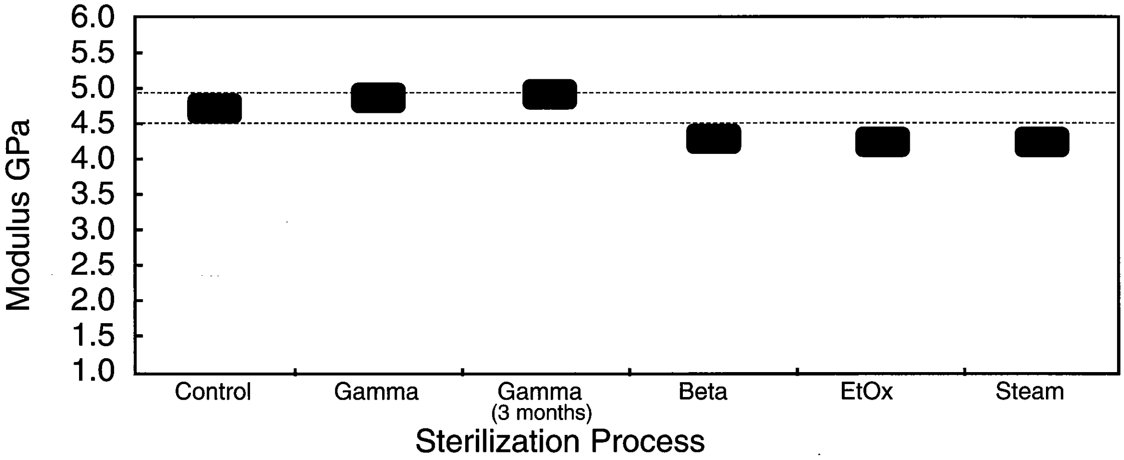


FIGURE 10: INFLUENCE OF STERILIZATION PROCESSES ON BREAK STRESS OF CARILON POLYMER DB6G3A10

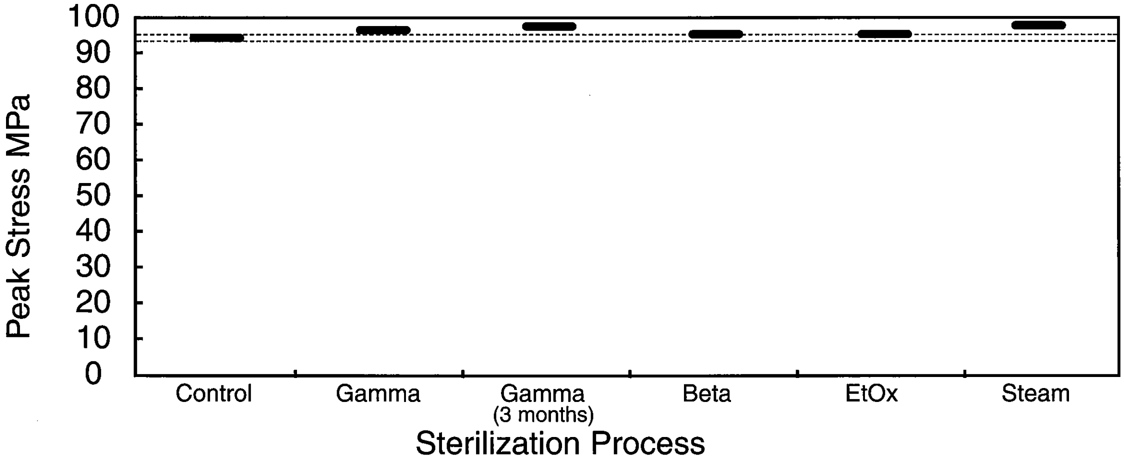


FIGURE 11: INFLUENCE OF STERILIZATION PROCESSES ON STRAIN AT BREAK OF CARILON POLYMER DB6G3A10

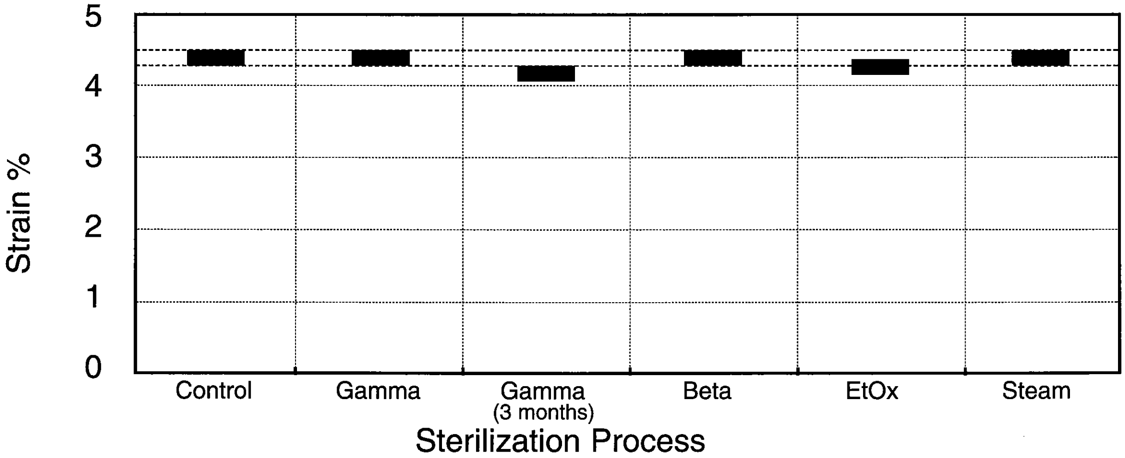
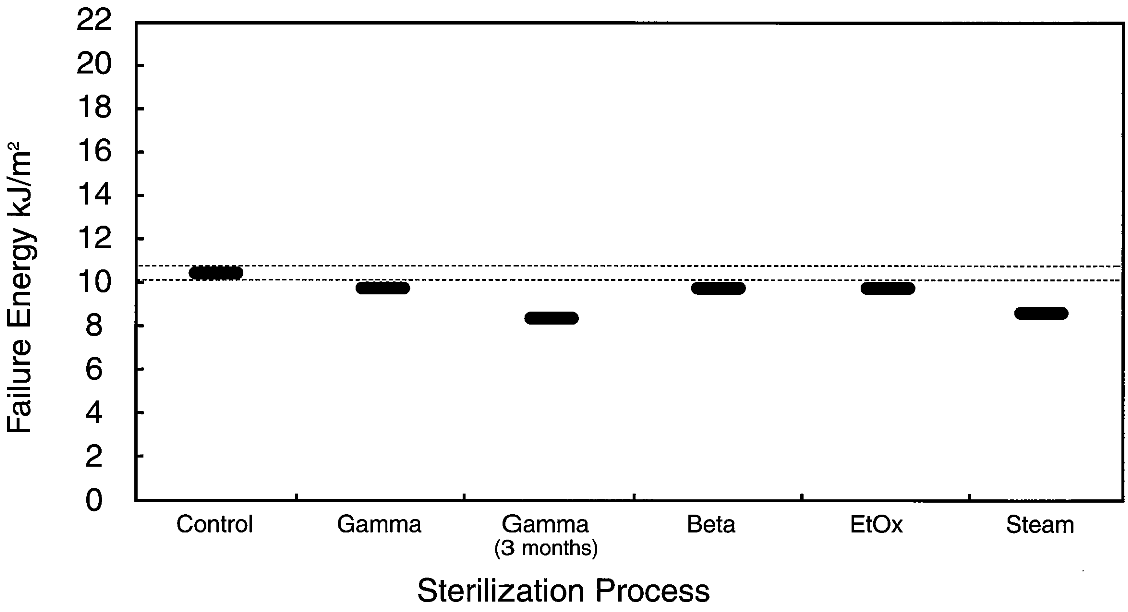


FIGURE 12: INFLUENCE OF STERILIZATION PROCESSES ON THE NOTCHED IZOD IMPACT STRENGTH OF CARILON POLYMER DB6G3A10



Ethylene Oxide Sterilization (EtOx) – CARILON Polymer D26HM100

As can be seen from Figures 4, 5 and 6, EtOx sterilization had no significant effect upon the tensile properties of CARILON Polymer D26HM100.

There was a reduction in toughness and impact strength following EtOx sterilization (Figure 8), but this change is judged not to be of practical significance.

Ethylene Oxide Sterilization (EtOx) – CARILON Polymer DB6G3A10

As can be seen from Figures 10, 11 and 12, EtOx sterilization had no effect on the break stress, strain at break or impact strength of CARILON Polymer DB6G3A10.

There was a reduction in modulus after EtOx sterilization (Figure 9), but this change is judged not to be of practical significance in the context of fiber-reinforced materials.

NOTE: The EtOx concentrations in 4mm samples of CARILON Polymer D26HM100 were observed to reach a value of 17 ppm after a five-day degassing phase. The EtOx concentrations in 4mm samples of CARILON Polymer DB6G3A10 were observed to reach a value of 20 ppm after a five-day degassing phase. It is important to determine minimum degassing times for individual applications in order to comply with regulations that specify the maximum level of residual EtOx.

CONCLUSION

CARILON Thermoplastic Polymers can withstand different widely used sterilization processes. Unlike some other materials, their excellent hydrolytic stability makes them of special interest for steam sterilization. Even after multiple steam sterilization cycles, the tested materials still demonstrated an attractive balance of mechanical properties, making them materials to consider for end uses requiring reusable sterilized injection-molded parts. Additional development work is under way.

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