Kirk-Othmer Encyclopedia of Chemical Technology.

FLUOROCARBON ELASTOMERS

Fluorocarbon elastomers are synthetic, noncrystalline polymers that exhibit elastomeric properties when crosslinked. They are designed for demanding service applications in hostile environments characterized by broad temperature ranges and/or contact with chemicals, oils, or fuels.

Military interest in the development of fuel and thermal resistant elastomers for low temperature service created a need for fluorinated elastomers. In the early 1950s, the M. W. Kellogg Co. in a joint project with the U.S. Army Quartermaster Corps, and 3M in a joint project with the U.S. Air Force, developed two commercial fluorocarbon elastomers. The copolymers of vinylidene fluoride, $CF_2{=}CH_2$, and chlorotrifluoroethylene, $CF_2{=}CFCl$, became available from Kellogg in 1955 under the trademark of Kel-F (1–3) (see Fluorine compounds, organic–polychlorotrifluoroethylene; Poly(vinylidene) fluoride). In 1956, 3M introduced a polymer based on poly(1,1-dihydroperfluorobutyl acrylate) trademarked 3M Brand Fluororubber 1F4 (4). The poor balance of acid, steam, and heat resistance of the latter elastomer limited its commercial use.

In the late 1950s, the copolymers of vinylidene fluoride and hexafluoropropylene, $CF_2{=}CFCF_3$, were developed on a commercial scale by 3M (Fluorel) and by Du Pont (Viton) (5–8). In the 1960s, terpolymers of vinylidene fluoride, hexafluoropropylene, and tetrafluoroethylene, $CF_2{=}CF_2$, were developed (9) and were commercialized by Du Pont as Viton B. At about the same time, Montedison developed copolymers of vinylidene fluoride and 1-hydropentafluoropropylene as well as terpolymers of these monomers with tetrafluoroethylene, marketed as Tecnoflon polymers (10, 11).

In the 1960s and 1970s, additional elastomers were developed by Du Pont under the Viton and Kalrez trademarks for improved low temperature and chemical resistance properties using perfluoro(methyl vinyl ether), $CF_2{=}CFOCF_3$, as a comonomer with vinylidene fluoride and/or tetrafluoroethylene (12, 13) (see Fluorine compounds, organic–tetrafluoroethylene polymers and copolymers).

Bromine- and iodine-containing fluoroolefins have been copolymerized with the above monomers in order to allow peroxide cure (14–21). The peroxide cure system does not require dehydrofluorination of the polymer backbone, resulting in an elastomer that shows improved properties after heat and fluid aging.

Copolymers of propylene and tetrafluoroethylene, which are sold under the Aflas trademark by 3M, have been added to the fluorocarbon elastomer family (21–26). Also 3M has introduced an incorporated cure copolymer of vinylidene fluoride, tetrafluoroethylene and propylene under the trademark Fluorel II (27). These two polymers (Aflas and Fluorel II) do not contain hexafluoropropylene. The substitution of hexafluoropropylene with propylene is the main reason why these polymers show excellent resistance toward high pH environments (28). Table 1 lists the principal commercial fluorocarbon elastomers in 1993.

1. Properties

Table 2 summarizes general characteristics of vulcanizates prepared from commercially available fluorocarbon elastomer gumstocks.

Table 1. Commercial Fluorocarbon Elastomers

Copolymer	CAS Registry Number	Trademark	Supplier
poly(vinylidene fluoride-*co*-hexafluoropropylene)	[9011-17-0]	Dai-el Fluorel Tecnoflon Viton	Daikin 3M Ausimont Du Pont
plus cure-site monomer[a]		Fluorel	3M
poly(vinylidene fluoride-*co*-hexafluoropropylene-*co*-tetrafluoroethylene) with and without cure-site monomer[a]	[25190-89-1]	Dai-el Fluorel Tecnoflon Viton	Daikin 3M Ausimont Du Pont
poly(vinylidene fluoride-*co*-tetrafluoroethylene-*co*-perfluorovinyl ether) plus cure-site monomer[a]		Viton Tecnoflon	Du Pont Ausimont
poly(tetrafluoroethylene-*co*-perfluoro(methyl vinyl ether) plus cure-site monomer[b]		Kalrez	Du Pont
poly(tetrafluoroethylene-*co*-propylene)[a]	[27029-05-6]	Aflas Aflas	Asahi Glass 3M
poly(vinylidene fluoride-*co*-chlorotrifluoroethylene)[a]	[9010-75-7]	Kel-F	3M
poly(vinylidene fluoride-*co*-tetrafluoroethylene-*co*-propylene)[b] plus cure site	[54675-89-7]	Fluorel II Aflas Aflas	3M Asahi Glass 3M

[a] Peroxide curable.
[b] Proprietary cure system.

1.1. Thermal Stability

The retention of elongation after thermal aging of fluorocarbon elastomers is an indication of their thermal stability. Figure 1 is a plot of percent retention of initial elongation vs days exposure to dry heat (150°C) for a number of oil-resistant elastomers (29), and shows that fluorocarbon elastomers are far superior to hydrocarbon elastomers. A more severe test at 205°C shows that a typical fluorocarbon molded goods compound retains 95% of initial elongation after one year. Retention of tensile strength is another important characteristic of fluorocarbon elastomers. Figure 2 shows the results of long-term heat aging on a typical O-ring compound made from vinylidene fluoride/hexafluoropropylene copolymer. Fifty percent of the initial tensile strength is retained after a period of one year at 205°C or after more than two months at 260°C.

1.2. Chemical Resistance

Fluorocarbon elastomer compounds show excellent resistance to automotive fuels and oils, hydrocarbon solvents, aircraft fuels and oils, hydraulic fluids, and certain chlorinated solvents, and may be used without reservation.

They show good to excellent resistance to highly aromatic solvents, polar solvents, water and salt solutions, aqueous acids, dilute alkaline solutions, oxidative environments, amines, and methyl alcohol. Care must be taken in choice of proper gum and compound. Hexafluoropropylene-containing polymers are not recommended for use in contact with: ammonia, strong caustic (50% sodium hydroxide above 70°C), and certain polar solvents such as methyl ethyl ketone and low molecular weight esters. However, perfluoroelastomers can withstand these fluids. Propylene-containing fluorocarbon polymers can tolerate strong caustic.

Table 2. Fluorocarbon Elastomers Physical Property Ranges

Property	Value
Physical properties	
tensile strength, MPa[a]	7.00–20.00
100% modulus, MPa	2.00–16.00
elongation at break, %	100–500
hardness range, Shore A	50–95
compression-set[b]	
70 h at 25°C	9–16
70 h at 200°C	10–30
1000 h at 200°C	50–70
specific gravity (gumstock)	1.54–1.88
low temperature flexibility, °C[c]	0 to −30
brittle point (ASTM D746), °C	0 to −50
thermal degradation temperature, °C	400 to 550
General characteristics	
gas permeability	very low
flammability	self-extinguishing or nonburning (when properly formulated)
radiation resistance	good to fair
abrasion resistance	good and satisfactory for most uses
weatherability and ozone resistance	outstanding (unaffected after 200 h exposure to 150 ppm ozone)

[a] To convert MPa to psi, multiply by 145.
[b] ASTM method B, 3.5 mm O-ring.
[c] Highly dependent on grade of material used.

Recent innovations in fluorocarbon elastomer development have led to more highly fluorinated materials that possess greater solvent resistance. Included in this class of highly fluorinated materials are Fluorel FLS 2530 and 2650, Viton GF and GFLT, Dai-el G-912, and Kalrez. Figure 3 demonstrates the effect of high fluorine incorporation on volume swell resistance. These highly solvent resistant materials are expected to find wide applicability in the automotive, pollution control, and petrochemical markets.

1.3. Compression Set Resistant

One property of fluorocarbon elastomers that makes them uniquely valuable to the sealing industry is their extreme resistance to compression set. Figure 4 plots compression set vs time for compounds prepared especially for compression set resistance (O-ring grades).

2. Manufacture and Processing

2.1. Manufacture of Fluorocarbon Elastomers

Elastomers listed in Table 1 are typically prepared by high pressure, free-radical, aqueous emulsion polymerization techniques (30–33). The initiators (qv) can be organic or inorganic peroxy compounds such as ammonium

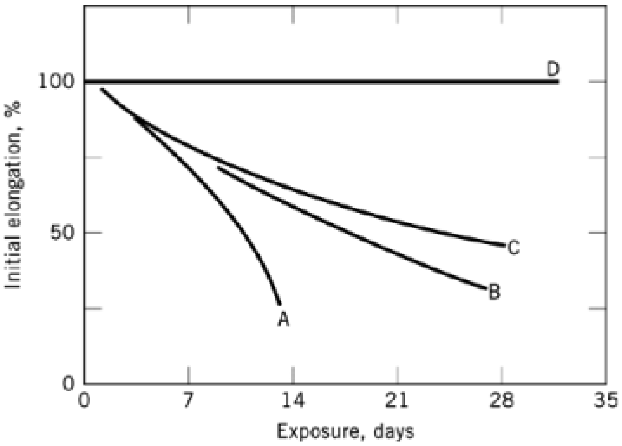

Fig. 1. Retention of elongation of vulcanized elastomers at 150°C. A, nitrile rubber, NBR; B, ethylene–propylene–diene rubber, EPDM; C, acrylic elastomer, AM; D, fluorocarbon elastomer.

persulfate [7727-54-0]. The emulsifying agent is usually a fluorinated acid soap, and the temperature and pressure of polymerization ranges from 30 to 125°C and 0.35 to 10.4 MPa (50–1500 psi). The molecular weight of the resultant polymers is controlled by the ratios of initiator to monomer, by the choice of chain-transfer reagents, or both. Typical chain-transfer agents are 2-propanol, methanol, acetone, diethyl malonate [105-53-3], and dodecylmercaptan (34–36). A typical polymerization recipe is as follows.

Component	Amount, g
vinylidene fluoride	61
hexafluoropropylene	39
diethyl malonate	0.1
ammonium persulfate	0.5
ammonium perfluorooctanate	0.12
potassium phosphate, dibasic	1.0
water	304

The aqueous emulsion polymerization can be conducted by a batch, semibatch, or continuous process (Fig. 5). In a simple batch process, all the ingredients are charged to the reactor, the temperature is raised, and the polymerization is run to completion. In a semibatch process, all ingredients are charged except the monomers. The monomers are then added continuously to maintain a constant pressure. Once the desired solids level of the latex is reached (typically 20–40% solids) the monomer stream is halted, excess monomer is recovered and the latex is isolated. In a continuous process (37), feeding of the ingredients and removal of the polymer latex is continuous through a pressure control or relief valve.

The polymer latex is then coagulated by addition of salt or acid, a combination of both, or by a freeze–thaw process. The crumb is washed, dewatered, and dried. Since most fluorocarbon elastomer gums are sold with incorporated cure systems, the final step in the process involves incorporation of the curatives. This can be done on a two-roll mill, in an internal mixer, or in a mixing extruder.

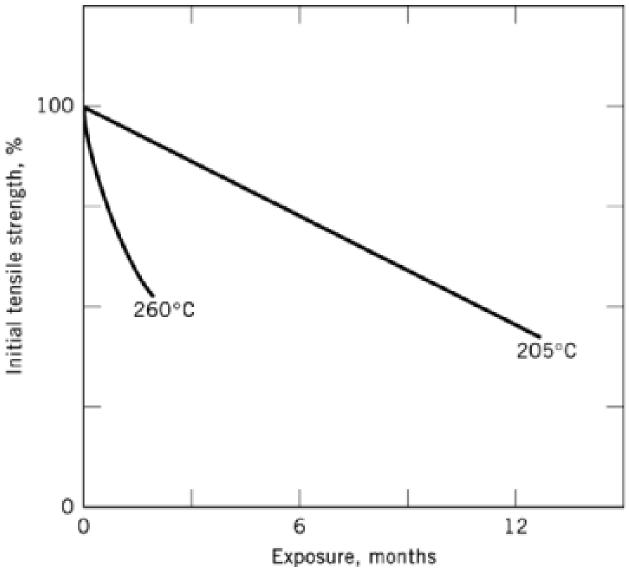

Fig. 2. Tensile strength retention, continuous service, for fluorocarbon elastomers, Compound I (see Table 4).

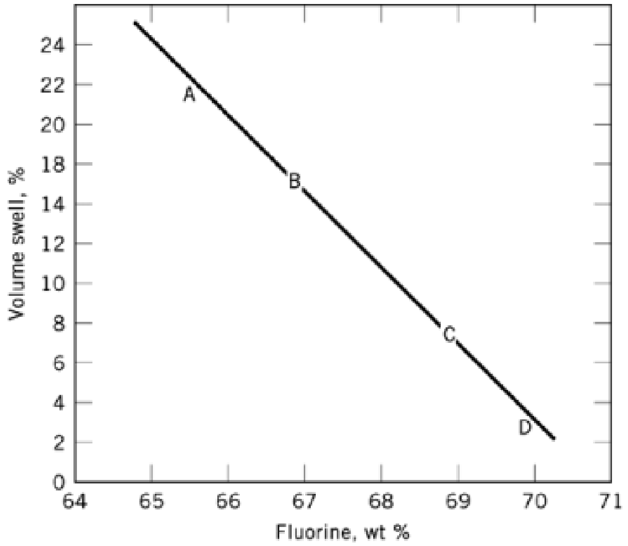

Fig. 3. The percent volume swell in benzene after seven days at 21°C compared with the wt % of fluorine on standard recommended compounds. A, copolymers of vinylidene fluoride–hexafluoropropylene; B, terpolymers of vinylidene fluoride–hexafluoropropylene–tetrafluoroethylene; C, terpolymers of vinylidene fluoride–hexafluoropropylene–tetrafluoroethylene-cure site monomer; D, copolymer of tetrafluoroethylene–perfluoro(methyl vinyl ether)-cure site monomer.

2.2. Cross-Linking Chemistry

Like other thermosetting elastomers, fluorocarbon elastomers must be cured in order to get useful properties. Three distinct cross-linking systems have been developed to achieve this goal: diamine, bisphenol–onium, and

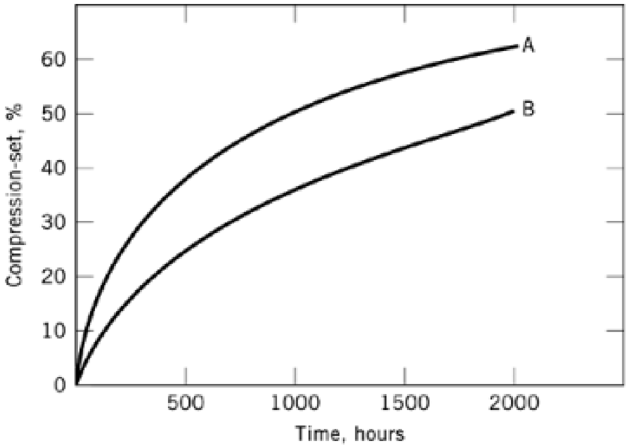

Fig. 4. Compression-sets of fluorocarbon elastomers at 200°C, 3.5 mm O-rings; A, Compound I (see Table 4); B, Compound II (see Table 4).

peroxide curing agents (Table 3). Over the years, the bisphenol–onium cure system, which is the most practical in terms of processing latitude and cured properties, has become the most widely used.

Table 3. Cure Systems for Fluorocarbon Elastomers

Property	Diamine	Dihydroxy cross-linker/accelerator	Peroxide/coagent
rheology			
cure	slow	excellent	good
scorch	poor	excellent	good
compression set	poor	excellent	intermediate
chemical resistance	typical	typical	typical[a]
thermal resistance	excellent	excellent	good
processing	poor	excellent	poor to good[b]
other	FDA approved good bondability	easy to modify	HAV[c] curable

[a] Improved steam and base resistance.

[b] Special grades required.

[c] HAV = hot air vulcanization.

These three cure systems have in common the need for a two-step cure cycle to generate the best cured properties. The first step is the application of heat and pressure in a mold to shape the article (press cure). The second step is a high temperature oven cycle at atmospheric pressure to obtain the final cured properties.

The manufacture of the majority of fluorocarbon elastomer gums includes the addition of an incorporated cure system comprising an organic onium cure accelerator, such as triphenylbenzylphosphonium chloride [1100-88-5] and a bisphenol cross-linking agent, such as hexafluoroisopropylidenediphenol [1478-61-1]. These incorporated cure systems offer improved compression set performance, processing safety, and fast cure cycles to fabricators, who need add only metal oxides as acid acceptors and reinforcing fillers for a complete formulation (38–43).

The chemistry of this cure system has been the subject of several studies (44–47). It is now generally accepted that the cure mechanism involves dehydrofluorination adjacent to hexafluoropropylene monomer

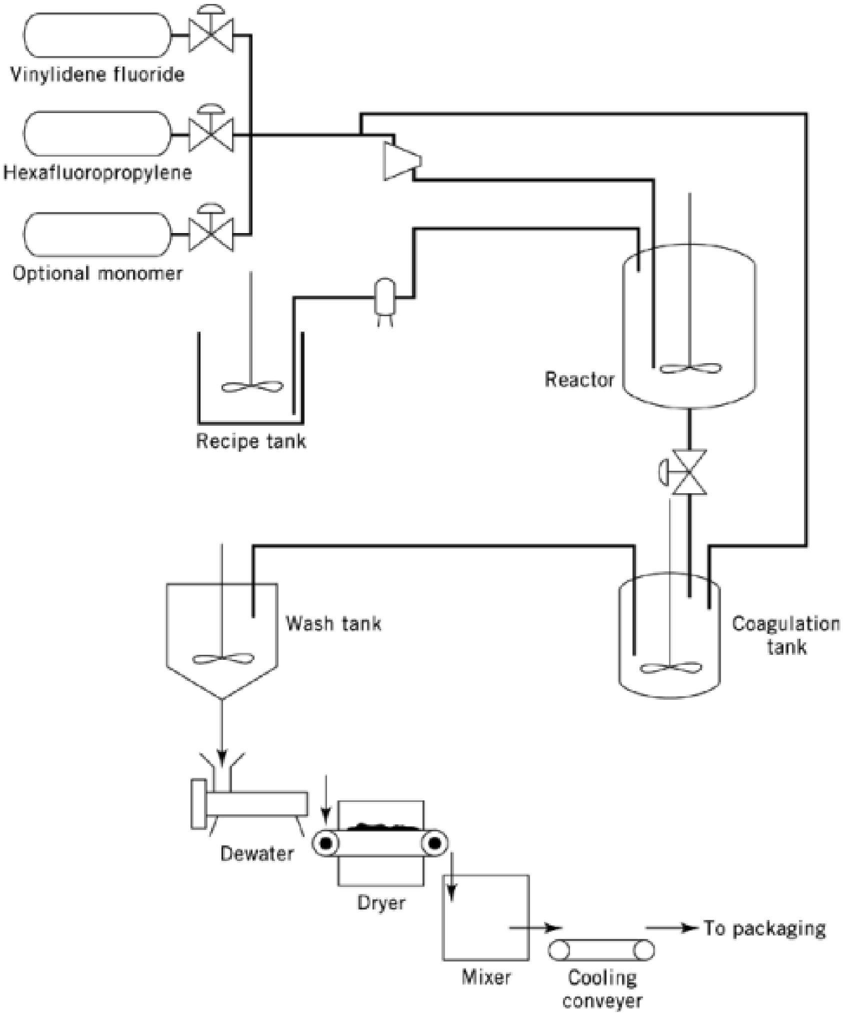

Fig. 5. Production of fluorocarbon elastomers.

units. The subsequent fluoroolefin is highly reactive toward nucleophilic attack by a variety of curatives (eg, diamines, diphenols).

In addition to the incorporated cure gums, there are also raw gums that contain no curative, to which the fabricator adds cure ingredients, such as diamines, bisphenols, or peroxides (48), in addition to formulation (compound) ingredients. Although peroxide cure systems historically have suffered a poor reputation with respect to processibility (mold sticking and mold fouling), recent advancements in these areas have yielded greatly improved products. The use of iodine–bromine containing fluorinated chain-transfer agents has resulted in high fluorine grade polymers with iodine–bromine end groups. The rheology of these materials is characterized by very fast cure rates. In addition, these materials exhibit much better mold release properties than earlier grades (49–51). The advantages and disadvantages of the cure systems are given in Table 3.

2.3. Compounding

Owing to the number of ingredients required in a conventional rubber recipe, fluorocarbon elastomer compounding seems simple compared to typical hydrocarbon elastomer recipes. However, the apparent simplicity of such formulations makes a selection of appropriate ingredients especially important in order to obtain the excellent properties inherent in available gumstocks. A typical recipe in parts per hundred of rubber (phr) by weight is as follows:

Component	Amount, phr
rubber	100
inorganic base: magnesium oxide, calcium hydroxide	6 – 20
filler (reinforcing or nonreinforcing)	0 – 60
accelerators or curatives (if not included in base rubber)	0 – 6
process aids	0 – 2

With a clear idea of use requirements and rubber response to specific additives, a formulation may be selected. Uses generally fall into one of three classes: O-rings, molded goods, and extruded forms.

2.3.1. O-Rings

In O-ring applications, the primary consideration is resistance to compression set. A fluorocarbon elastomer gum is chosen for O-ring applications based on its gum viscosity, cross-link density, cure system, and chemical resistance so that the best combination of processibility and use performance is obtained. Sample formulations for such uses are given in Table 4.

Long-term compression set resistance is described in Figure 4. Lower set values are achievable by use of higher viscosity gumstock at comparable cross-link densities. Compression set resistance is also very dependent on the cure system chosen. The bisphenol cure system offers the best compression set resistance available today, as shown in Table 5.

2.3.2. Molded Goods

In molded goods compounding, the most important physical property in the final vulcanizate is usually elongation to break, with compression set being a secondary consideration. Since complex shapes are often required, compound flow is also an important parameter. These objectives generally are best met by beginning with gum of the lowest initial viscosity that is consistent with good physical properties. This gum is then cured to lower cross-link density, compared to O-ring formulations, to permit high elongation.

Comparison of starting viscosities and properties of a molded goods compound (Table 6) with an O-ring compound (see Table 4) shows differences in elongation as a result of lower cross-link density. Even higher elongations are achievable with special formulations, or products designed for exceptionally high tear strengths in the press cured state.

The effects of specific fillers in molded goods applications are known (52), and are of special importance for water- and acid-resistant compounds. It is good policy to contact the suppliers for specific recommendations to meet the balance of properties required.

Table 4. Fluorocarbon Elastomer O-Ring Compounds

Typical formulation	I[a]	II[b]	III[c]
Compound ingredients, phr			
MT black (N-990)	30	30	25
calcium hydroxide	6	6	
magnesium oxide	3	3	
hexafluoroisopropylidenediphenol	2.1	2.1	
triphenylbenzylphosphonium chloride	0.45	0.45	
triallyl isocyanurate			5
α,α-bis(*t*-butylperoxy)diisopropylbenzene			1
sodium stearate			1
Physical properties[d]			
tensile strength, MPa[e]	15.0	15.0	16.0
elongation at break, %	200	200	300
hardness, Shore A	75	75	71
compression-set (3.5 mm O-rings), % for 70 h at 200°C, (ASTM D395)	15	10	35
specific gravity	1.8	1.8	1.6

[a] 100 phr FKM223O $(\mathrm{ML}1+10 \text{ at } 121^\circ\mathrm{C} = 40)$ where FKM2230 is poly(vinylidene fluoride-*co*-hexafluoropropylene); available from 3M.

[b] 100 phr FKM2178 $(\mathrm{ML}1+10 \text{ at } 121^\circ\mathrm{C} = 100)$ where FKM2178 is poly(vinylidene fluoride-*co*-hexafluoropropylene); available from 3M.

[c] 100 phr FKM100S $(\mathrm{ML}1+10 \text{ at } 121^\circ\mathrm{C} = 90)$ where FKM100S is poly(tetrafluoroethylene-*co*-propylene); available from 3M.

[d] Press cure: 5 min at 177°C; post-cure: 24 h at 230°C.

[e] To convert MPa to psi, multiply by 145.

2.3.3. Extruded Articles

In extruded article compounding, the most important parameters are scorch safety and flow characteristics (53). The bisphenol cure system again offers the best scorch resistance of the available fluorocarbon elastomer cure systems. Good flow characteristics can be achieved through proper selection of gum viscosities. Also, the addition of process aids to the formulation can enhance the flow characteristics. Typical formulations for extrusion grade fluorocarbon elastomers are given in Table 7.

2.4. Formulation Parameters

Gum viscosity is of primary importance to the determination of processibility, as this factor affects vulcanizate properties, especially compression set. Gums are available with Mooney Viscosity ($\mathrm{ML}1+10$ at 121°C) values of 5–160; a range of 20–60 is preferred for the optimum combination of flow and physical properties. Higher viscosities can cause excessive heat buildup during mixing without a compensatory gain in physical strength. Compound viscosity depends on gum viscosity and on filler selection (type and loading). A preferred range, as measured by Mooney scorch (MS at 121°C), is 25–60.

Compound stability and safety must also be considered when determining processibility, as they are strongly affected by compounding ingredients and cure systems. The data in Table 5 clearly show the effect that choice of cure system can have on scorch stability and processing minimums as determined by standard testing techniques (MS at 121°C). The most workable formulations are compounded with raw gums containing

Table 5. Effect of Cure System on Processing Safety and Compression Set Resistance for FKM2260[a]

Formulation	Amine	Bisphenol	Peroxide
Compound ingredients, phr			
MT black (N-990)	30	30	35
magnesium oxide	10	3	
calcium hydroxide		6	3
N,N′-dicinnamylidene-1,6-hexanediamine	2.5		
hexafluoroisopropylidenediphenol		2.1	
triphenylbenzylphosphonium chloride		0.45	
triallyl isocyanurate			2.5
2,5-dimethyl-2,5-di-*t*-butylperoxyhexane			2.5
Properties			
Mooney scorch[b] at 121°C			
minimum	68	66	48
point rise (25 min)	76	2	6
compression-set, %[c]	48	13	25

[a] 100 phr of this material, which has $\mathrm{ML}1 + 10$ at 121°C = 60 and is poly(vinylidene fluoride-*co*-hexafluoropropylene) plus cure site monomer; available from 3M.

[b] ASTM D1646.

[c] 3.5 mm O-rings for 70 h at 200°C (ASTM D395).

the bisphenol or incorporated cure systems. These elastomers offer the processor the best starting point for maximum processibility.

2.5. Mixing

Fluorocarbon elastomer formulations can be compounded by any standard rubber mixing technique. Open mill mixing can be used since most commercial gums mix well. Exceptions to this are very low viscosity gums that have a tendency to stick to the rolls, and very high viscosity gums that are excessively tough.

Internal mixing is widely used with fluorocarbon elastomers. Gumstocks and compounds that are particularly successful fall in the viscosity ranges discussed earlier, and use both incorporated bisphenol-type and peroxide cure systems. A typical internal mix cycle runs 6–8 min with a drop temperature of 90–120°C. The typical formulations in Tables 4 and 7 are readily mixed in an internal mixer.

2.6. Preforming

Extrusion preforming is easily accomplished if relatively cool barrel temperatures are used with either a screw or piston type extruder (Barwell). It is important that the gums be used in the appropriate viscosity ranges, and that scorching be avoided.

Calendering operations are done routinely, and warm rolls (40–90°C) are recommended for optimum sheet smoothness. A process aid, such as low molecular weight polyethylene wax, is often used. Sheet thicknesses of 0.5–1.3 mm (20–50 mils) can normally be produced.

Table 6. Fluorocarbon Elastomer Molded Goods Compound

Typical formulation	1[a]	II[b]
Compound ingredients, phr		
MT black (N-990)	30	25
calcium hydroxide	6	
magnesium oxide	3	
triphenylbenzylphosphonium chloride	0.4	
hexafluoroisopropylidenediphenol	1.7	
triallyl isocyanurate		5
α,α-bis(*t*-butylperoxy)diisopropylbenzene		1
sodium stearate		1
Post-cured physical properties[c]		
tensile strength, MPa[d]	14.4	13.5
elongation at break, %	265	315
hardness, Shore A	74	71
compression set, (1.27 cm disk), % for 70h at 200°C (ASTM D395)	20	40
specific gravity	1.8	1.6

[a] 100 phr FKM223O $(M\Lambda 1 + 10 \text{ at } 121^\circ\text{C} = 40)$ where FKM2230 is poly(vinylidene fluoride-*co*-hexafluoropropylene); available from 3M.

[b] 100 phr FKM P $(\text{ML}1 + 10 \text{ at } 121^\circ\text{C} = 75)$ where FKM 150 P is poly(tetrafluoroethylene-*co*-propylene); available from 3M.

[c] Press cure: 5 min at 177°C; post-cure: 24 h at 230°C.

[d] To convert MPa to psi, multiply by 145.

2.7. Molding

Compression molding is generally used when it is desirable to conserve material, and when a molding operation is set up to allow preparation of large numbers of preforms with minimum labor costs. Flow requirements are minimal and high viscosity gums may be used.

Transfer molding minimizes preforming, and is usually used for the production of very small parts; however, this technique may generate excessive amounts of scrap material. Flow requirements can be quite high, but fluorocarbon elastomers are available that are effective in this application.

Injection molding is finding expanded usage in the rubber industry. Fluorocarbon elastomers can be successfully molded via this technique. Selection of the proper viscosity and cure rheology are very important due to the occurrence of high shear and fast cures.

All types of molding may be carried out at 150 to 200°C. This allows molding times of five minutes or less for most fluorocarbon elastomer parts, but this time is dependent on part size.

2.8. Extrusion

Extrusion techniques are used in the preparation of tubing, hose, O-ring cord, preforms and shaped gaskets. Typical extrusion conditions are 70 to 85°C for the barrel temperature and 95 to 110°C for the head temperature. The extruded forms are normally cured in a steam autoclave at 150 to 165°C. Some special grades of peroxide curable fluorocarbon elastomers can be hot air vulcanized.

Table 7. Fluorocarbon Elastomer Extrusion Grade Compound

Formulation	I[a]	II[a]
Compound ingredients, phr		
hexafluoroisopropylidenediphenol	1.9	1.9
triphenylbenzylphosphonium chloride	0.45	0.45
MT black (N-990)	35	15
HAF black (N-326)		5
SRF black (N-762)		7
magnesium oxide	3	9
calcium hydroxide	6	
carnauba wax	1	1
Physical properties[b]		
tensile strength, MPa[c]	7.6	12.4
elongation at break, %	280	330
hardness, Shore A	75	75

[a] 100 phr FKM2145 ($ML1 + 10$ at $121°C = 30$) where FKM2145 is poly(vinylidene fluoride-*co*-hexafluoropropylene); available from 3M.

[b] Press cured 45 min at 160°C.

[c] To convert MPa to psi, multiply by 145.

2.9. Post-Curing

Post-curing at elevated temperatures develops maximum physical properties (tensile strength and compression-set resistance) in fluorocarbon elastomers. General post-cure conditions are 16 to 24 h at 200 to 260°C.

3. Economic Factors

Annual worldwide fluorocarbon elastomer usage totals about 7300 metric tons. Approximately 40% of this usage is in the United States, 30% in Europe, and 20% in Japan. Prices in 1991 were $30–110/kg.

4. Specifications

Commercially available fluorocarbon elastomers meet automotive specifications in the HK section of ASTM D2000 and SAE J-200. ASTM D1418 specifies designations of composition, eg, fluorocarbon elastomers are designated CFM, FKM, or FFKM. Commercially available fluorocarbon elastomers offer a balance of those properties needed to meet the major O-ring specifications, such as AMS 7276, AMS 7280A, AMS 7259, MIL 83248 Amendment 1 Type II, Class I and II.

Certain grades and formulations of the fluorocarbon elastomers are qualified under the code of Federal Regulations, 21, Food and Drugs, Part 177.2600 for use as rubber articles whose intended applications require repeated or continuous contact with food. Elastomer suppliers will provide assistance in formulating for specified uses.

5. Test Methods

The fluorocarbon elastomer raw gums provided for rubber molding are tested for Mooney viscosity (ASTM D1646) and for specific gravity (ASTM D297). When compounded as described above, the stocks are tested for Mooney cure (ASTM D1646), Mooney scorch (ASTM D1646), and oscillating-disk rheometer cure rate (ASTM D2084). The vulcanizates are evaluated regarding original physical properties (ASTM D412, D2240, and D1414), aged physical properties (ASTM D573), compression set (ASTM D395), and fluid aging (ASTM D471). Low temperature properties are measured by low temperature retraction TR10 (ASTM D1329) and brittle point (ASTM D2137) tests.

6. Health and Safety Factors

In general, under normal handling conditions, the fluorocarbon elastomers have been found to be low in toxicity and irritation potential. Specific toxicological, health, and safe handling procedures are provided by the manufacturer of each fluorocarbon elastomer product upon request.

7. Uses

About 60% of the United States usage is in ground transportation. Typical components include engine oil seals, fuel system components such as hoses and O-rings, and a variety of drive train seals. Growth in this area is expected to continue with the general strength of the U.S. automotive industry coupled with increased demands from higher underhood temperatures, alcohol containing fuels, and more aggressive lubricants. Other major U.S. segments include petroleum/petrochemical, industrial pollution control, and industrial hydraulic and pneumatic applications. These areas will be more dependent upon general industrial production and overall energy demands, and will show slower growth than the automotive segment.

The usage pattern in Europe and Japan is more dependent upon the automotive industry. However, with the recent concern about acid rain, the European and U.S. markets should show increased interest in fluorocarbon elastomers for pollution control applications. On the other hand, the Japanese market has a sizable outlet in electrical and general machinery manufacturing (eg, copiers). Petroleum applications are of little interest outside the United States.

The principal original use of fluorocarbon elastomers in the aircraft industry now accounts for less than 10% of the total fluorocarbon elastomer consumption.

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