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Troubleshooting Rubber Problems

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4.38 Mountings, Bearings, and Bushings

Rubber mounts are widely used to prevent or minimize the transmission of dynamic oscillations to a supporting structure [306]. Vibration isolators are designed to give a natural frequency of the spring mass system that is considerably lower than the lowest frequency component in the forcing frequency [307].

NR is typically considered the elastomer of choice for use in vibration-isolation applications [308]. It is one of the few elastomers that is strain crystallizing, and as such possesses inherent strength without the addition of particulate reinforcement. This feature allows fabrication of NR mounts that exhibit very low modulus, high strength, and low damping. However, environmental factors, such as solvent resistance and high temperature, preclude NR use in some applications.

Rubber mounts often are combined with a higher modulus material, for example steel, to prevent excessive distortion and to provide for mount attachment [309]. Reasons for preventing vibration from traveling to or from a mechanism include noise reduction, higher operating speeds, more accurate operation, and reduced physical and physiological effects on humans.

Rigidity of a mount's supporting structure, along with mount system strength and geometry, are very important considerations [310]. This same principle applies to earthquake mounts. If a supporting structure is too flexible, it can defeat the purpose of using a mount; that is, the mount must be the most flexible element in a system.

Rubber mounts fail for a variety of reasons. Table 4.6 lists some problems, their causes, and suggested remedies [311].

DesiCal P is dispersion of CaO in paste form that serves as a desiccant for processing rubber [313]. It is individually wrapped in low-melt polyethylene for handling and convenience, extra moisture protection, and easier incorporation into rubber. It appears not only to reduce crosslink density but also to accelerate the cure rate at lower temperatures [314].

When joining rubber and plastic to form a composite, the plastic should generally have a heat deformation temperature near to or greater than 400 °F [316]. This requirement could exclude materials like PVC and polystyrene. A problem occurred with a rubber-polycarbonate article because the polycarbonate plastic leached plasticizer from the rubber and degraded the polycarbonate. Additional causes of rubber failure and suggested remedies follow in Table 4.7 [315].

Natural rubber is widely used in mountings because of its unique combination of properties: high strength, outstanding fatigue resistance, high resilience, low sensitivity to strain effects in dynamic applications, and good resistance to creep [317].

NR is among the few strain-crystallizing elastomers, a phenomenon that contributes to its high fatigue life and its high strength without the need for reinforcing fillers.

Table 4.6 Reasons, Causes, and Possible Remedies for Failure in Rubber Mountings

Problem	Cause	Possible Remedy
Excessive deformation	Work softening	Reduce dynamic and static stresses Improve compounding
Softening	Reversion in NR mount Rubber temperature too high	Optimize cure schedule Shield rubber from heat source Cool mount if possible
Blow-out	Internal heating	Use more resilient compound Use different-hardness compound and/or higher thermal conductivity Change mount design
Porosity	Undercure and/or moisture in compound	Optimize cure schedule Include CaO in compound
Swelling	Oil or solvent reaching compound	Shield rubber or coat it with oil-resistant coating
Surface crazing or cracking	Lack of ozone or weathering resistance	Incorporate effective protective system or change to alternate rubber
Delamination	Defective manufacture in compression molding of laminated sheets	Improve molding techniques

[a] Calcium oxide (CaO) is useful as a desiccant in rubber compounds to avoid porosity [312]. It generally causes a lower state of cure and significantly higher compression set properties. A chlorine-containing factice material is suggested to correct this problem.

Table 4.7 Additional Causes of Rubber Failure and Suggested Remedies

Symptom	Probable Cause	Possible Remedy
Excessive deformation	Work softening	Use more resilient rubber. Reduce dynamic and static stresses
Softening	Rubber splashed with solvent Rubber at too high temperature Overcure	Shield rubber from solvent Shield rubber from heat Reduce cure time
Hardening	Excessive heat	Shield rubber from heat Cool rubber
Large cracks	Local overstressing	Redesign

Hence, NR compounds can exhibit a combination of low modulus, high strength, and fatigue resistance, along with very low damping.

Silentbloc flexible bushings are widely used in a range of applications to reduce noise, vibration, and shock [318]. They provide high load-carrying capacity, accommodate component misalignment, and eliminate the need for lubrication.

A Silentbloc assembly consists of a rubber insert located between an inner and outer metal sleeve as shown in Figure 4.13 [319].

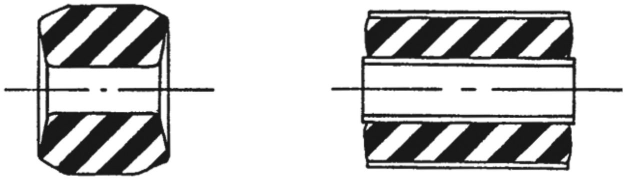

Figure 4.13 Silentbloc bushing that shows a rubber insert between inner and outer metal sleeves [319]

In-mold chemical bonding of the bushing is an option. High-frequency performance of a mount may be less than satisfactory if a metal component of a bonded mount has secondary frequencies in the frequency range of interest [320]. An elastomer ring in a bearing reduced axial and radial vibration and airborne noise.

4.38.1 Engine Mounts

Engine mounts, used in a wide range of applications, vary substantially in design. When designed for the shear-compression mode, they can develop substantially different stiffnesses in two perpendicular horizontal directions and a third stiffness in the vertical direction [321]. FEA can determine static and dynamic spring rates of engine mounts and then determine the effectiveness of a particular design in isolating vibrations at idle and other undesirable engine vibration modes.

Engine mounts operate in increasingly hostile environments; engine temperatures reach 130 °C near the catalytic converter of an automobile, and even higher temperatures are anticipated [322]. Higher temperatures necessitated the use of expensive silicone rubber in selected automotive engine mounts [323]. Decreased available space for ventilation can further increase engine mount temperature.

Service temperature varies both among and within mounts, as evidenced by a failed engine mount on the author's station wagon. Shore A hardness measurements on a failed mount ranged from 70 to 88, with the highest value occurring in the rubber nearest the exhaust manifold [324]. This result indicates that different locations within the failed mount experienced substantially different service temperatures.

Engine mounts on jet aircraft must withstand stress from sources not experienced by automobiles [325]. For instance, engine mounts for Cessna CJ3 aircraft had to withstand engine damage equivalent to two birds flying into an engine fan blade without failure.

Continuing changes in technology necessitate changes in product requirements. For instance, adhesion systems for automotive engine mounts formerly did not require resistance to ethylene glycol [326]. But with the introduction of mounts that contain ethylene glycol in chambers to control dynamic properties, new adhesives were developed that provided the needed glycol resistance.

Hydraulic engine mounts were developed to avoid the need to compromise engine bounce and engine isolation [327]. They permit the use of softer rubber, while an internal fluid controls engine bounce at resonance.

Engine mounts that incorporate a hydraulic fluid such as ethylene glycol have eliminated the need to compromise engine bounce and engine isolation [328]. Mounts provide high damping at low frequencies and low damping at high frequencies. They do this by transferring a fluid through an orifice between mount chambers that controls engine bounce [329]. Hence, the effects of fluid-flow damping and elastomeric damping are combined [330].

Figure 4.14 illustrates this principle wherein a fluid transfers between chambers 10 a and 10 b to provide damping in the radial direction [331]. The fluid provides high damping, and various types of orifices or tubes can be used to vary damping properties of bushings.

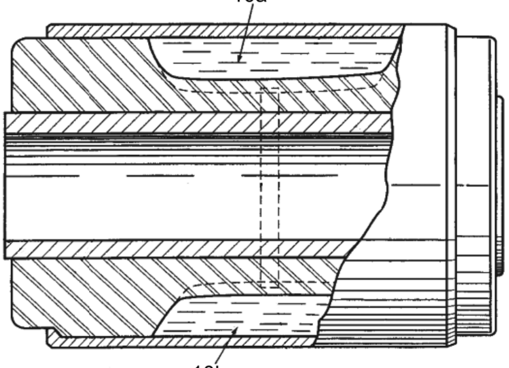

Figure 4.14 High-damping resilient bushing [331]

Magneto-rheological fluids encased in a shock absorber for vehicle seat damping represent another advance [332]. They consist of suspensions of minuscule magnetizable particles in oil, and magnetic fields soften or stiffen the mixture.

Another engine mount has a vacuum switchable bypass and decoupler that improves engine and idle isolation [333]. It provides sufficient damping to mitigate powertrain shake and provide comfort; however, it is still sufficiently soft to provide isolation during engine idling. This engine mount is expected to be especially useful with diesel engines.

Servohydraulic testing machines have typically been used for tests in axial testing, and newer machines can test in orthogonal axial torsion and even in triaxial modes [334]. Special requirements of the reaction frame and a control system for multiaxial test frequencies from static to 400 Hz have been considered [335]. ASTM provides a standard guide for dynamic testing of vulcanized rubber and rubber-like materials using vibratory methods [336].

Under-hood temperatures continue to increase, while available space for engine mounts decreases [337]. Silicone rubber mounts offer better temperature performance and can be tuned to the desired damping properties.

A troubleshooting guide for dynamic testing follows in Table 4.8 [338]. It shows several examples of symptoms, possible causes, and corrections.

Table 4.8 Symptoms, Possible Causes, and Corrections for Dynamic Testing Problems

Symptom	Possible Cause	Correction
Dynamic or static rate is higher than expected	Strain amplitude is too low; preload/strain is too high	Confirm machine is reaching desired strain inputs
Dynamic rate vs. frequency curve has a peak. Machine squeals	Resonance in tooling or specimen	Redesign tooling to move resonance from test range
Test machine cannot hold zero preload on soft articles	Test article is too compliant for load range	Use displacement control mode and hold zero displacement

An RPA 2000 testing machine can conduct troubleshooting and quality monitoring on both uncured and cured rubber compounds [339]. Careful modeling facilitates development of a specific test configuration to evaluate mixing, processing, and dynamic characteristics for a compound.

4.39 Hose and Tubing

Air conditioning, brake, and hydraulic hoses are examples of reinforced rubber hose [340]. High strength-to-weight ratios are said to be achieved for fiber-reinforced polymers through the use of Corpo technology, which provides optimized fiber paths on axially connected isotensoidal cells [341]. An isotensoid is a filamentary structure in which there is a constant stress in any given filament at all points in its path. Advantages for Corpo technology include higher potential pressure levels, increased durability, up to 50 % fiber reduction in rubber composites, increased flexibility, and cost reduction.

Yarn is used for air conditioning and brake hoses. In these hoses it must impart physical properties to meet defined elongation properties and tenacity, resistance to temperature and chemicals, and adhesion to a range of rubbers used in these products. Cotton was used earlier in a number of applications because it showed good mechanical bonding. However, modern textiles have largely replaced cotton because of cotton's low mechanical strength. The myriad of textiles and the range of rubbers available, especially low-polarity rubbers like EPDM, place considerable demands upon adhesion systems.

The RMA Hose Handbook describes many types of rubber and plastic materials, fibers, reinforcing cords, and manufacturing and vulcanization methods for hose [342]. It lists elastomers such as CR, NR, IIR, NBR, and FKM along with properties that include resistance to solvents, ozone, and aging. Plastics used in hoses include nylon, polyethylene, polyvinyl chloride, polyester, and fluorocarbon. Fibers include cotton, rayon, glass, nylon, and polyester.

Varied types of hose terminate with different connectors that must be leak proof [343]. A finite element model successfully simulated leakage of a hose with crimped connectors. Automotive hose that was reinforced with Santoweb cellulose fibers has been fabricated without a mandrel [344]. In a computerized extrusion operation, the die head shifted to create bends and angles in the hose and also to increase wall thickness in the area most likely to collapse under vacuum [345].

Another approach to manufacturing hose without a mandrel is said to apply to four-layer hose with textile reinforcement, hose with spiraled textile reinforcement, and hoses with knitted textile reinforcement [346].

Different types of rubber compounds respond differently to various fluids. Ideally, a hose would tolerate a range of fluids while maintaining acceptable swelling characteristics and other properties [347]. For example, one hose can handle biodiesel fuel and also ethanol and gasoline [348]. The cover on the latter hose resists degradation from fuel blends, and it also resists abrasion. The hose inner tube helps resist swelling, softening, and cracking that may be caused by alternative fuels. For hose that is used under vacuum, helix wire reinforcement reduces risk of hose collapse.

Heat from an exhaust system can shorten hose life [349]. Insulation on the hose exterior can delay hose degradation.

Laboratory tests concerned with the degree of swelling of a rubber compound generally establish whether a compound is sufficiently oil resistant [350]. They establish how much oil is absorbed by the compound and more importantly how much the oil affects a rubber compound. For many purposes it will not matter how much oil is present as long as it is confined near the surface of a product.

Analysis of a failed fuel hose established that an incompatible chemical agent contacted the hose and caused the hose to swell and distort while it was constrained by its wire jacket [351]. Volatilization of the agent left the hose in a severely stressed state. Because plasticizer had been leached from the hose prior to swelling, increased hardness made the hose prone to cracking under stress.

During the early stages of swelling, up to about one-half of the total equilibrium value, the amount of liquid absorbed per unit area of rubber is proportional to the square root of time. Figure 4.15 shows the relationship between liquid viscosity and penetration time.

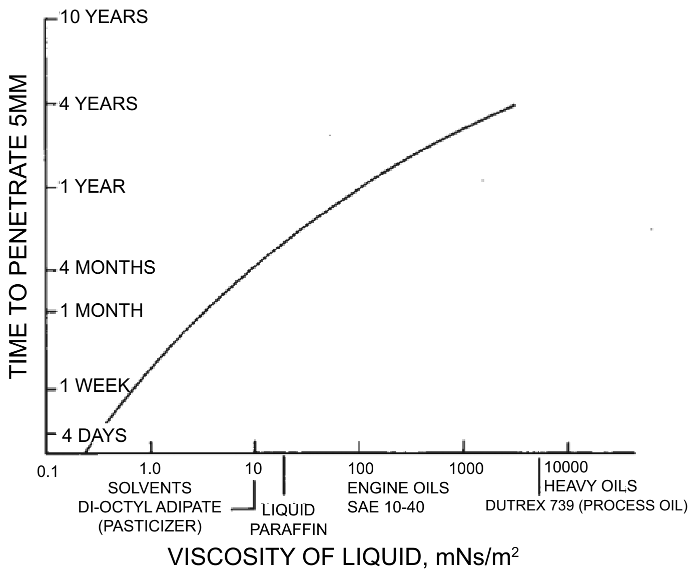

Figure 4.15 Relationship between liquid viscosity and penetration time [352]

Since the depth of penetration of the liquid depends on $(\text{time})^{1/2}$, it will take 100 times as long to penetrate 10 times a given distance [352]. The bulk of thick products such as bridge bearings and engine mounts essentially protect these products.

4.39.1 Self-Sealing Fuel Cells

Widely used in military aircraft, fuel cells must seal when pierced by a bullet and then retain sufficient fuel for an aircraft to return home [353]. Their construction includes an NBR inner lining that resists swelling so as to contain fuel. In service, a nonfuel-resistant rubber swells upon contacting the fuel and closes the opening caused by a penetrating bullet. The fuel cells can be fabricated over a core of papier-mâché, after which the core is crushed and the resulting crushed pieces are withdrawn through the largest available fuel cell opening.

4.39.2 Radiator Hose

Key properties of radiator hose include adequate tear strength for removal from a mandrel, low compression set to retain hose-clamping force, good burst strength, and good high-temperature heat resistance [354]. Coagents in EPDM compounds enhanced these properties, lowered viscosity, and increased scorch time.

Smaller, lighter, hotter-running engines are a part of the changing conditions for radiator hoses [355]. Temperatures around automotive hose reach temperatures as high as 150 °C locally, with coolant temperatures ranging between 110 and 125 °C. Different curing systems provide relative advantages and disadvantages for the hose; for example, peroxide curing is generally more expensive than sulfur curing. Peroxide is used despite this and other disadvantages. Peroxide-cured hose generally has less electrical conductivity because it doesn't contain zinc-based chemicals.

CSM-based hose can be used at up to 140 or 150 °C when properly compounded [356]. It generally requires the use of lead-based compounds as an acid accepter. Where lead is objectionable, hydrotalcite (magnesium aluminum hydroxycarbonate) is a potential alternative.

Electrochemical failure is a potential failure mode for radiator hose [357]. It was found that lower conductivity was needed in hose compounds to reduce or eliminate this failure mode. Specific types of carbon black have been developed to alleviate this problem.

Hose and liquid coolant form an electrical path between metal connectors, that is, between the engine or radiator and the hose tube material [358]. This can cause microcrack formation within the hose tube, after which the coolant can attack and weaken the hose reinforcement. Changing the electrical properties of the hose can correct this problem [359].

Microcracks, formed by an electrochemical process, occurred in the inner tubes of EPDM radiator and heater hose used in automobiles [360]. The use of noncarbon filler electrically isolated the hoses and corrected the cracking problem.

Hoses on cars registered a voltage in the range of 20 to 200 mV when voltmeter probes were placed on a radiator hose and on the engine or radiator connections [361]. Raising the voltage to 15 V was found to greatly accelerate the formation of striations on the hose.

Cooling system failures earlier accounted for 25% of major failures on a large fleet of transit buses [362]. The use of maintenance-free silicone rubber greatly reduced these costs, and special hose clamps were developed to prevent mechanical damage caused by hose removal and reassembly.

A hydraulically driven torque feeder supplies a constant amount of silicone rubber for extruded rubber hose and provides consistent pressure to a die plate [363]. It is also said to eliminate air inclusions and to increase output by 5 to 10%. For certain hose applications, it may be desirable to design the hose braid angle to produce a length change to improve coupling retention [364].

Electrical properties of rubber are important in other rubber products such as silica-based tires [365]. Too-low electrical conductivity caused an electrostatic discharge problem. Complaints ranged from shocks to toll booth operators to excessive radio static. Increased conductivity corrected the problems. Conductive rubber feet are used for hospital stools [366]; conductive silicone and fluorosilicone rubber are also used in electromagnetic shielding for gaskets [367].

Balancing required properties such as physical properties, conductivity, and processing characteristics can be problematic [368]. Materials such as silicone ECS4 are said to provide a favorable combination of properties.

4.39.3 Fuel Hose

Increasing use is being made of multilayered fuel hoses that contain a thin fluoropolymer layer to retain vapors during circulation of fuel in engines [369]. Replacing two extrusion processes with one saves factory space and costs [370]. Concentric layers of rubber can be formed in a cylindrical complex body that is said to be easy to clean.

Nonlead cure systems can effectively substitute for an ETU/lead system for fuel hose based on epichlorohydrin [371]. A new fuel hose combines an 8 mm layer of fluoroelastomer on the inner surface of the hose and a thicker PVC/NBR layer [372]. The combination, which resists scuffing and mechanical damage, meets emission regulations at lower cost.

Compounds based on two classes of polyepichlorohydrin were tested by immersion in various fuels and ethanol-fuel blends [373]. ECO-based compounds, which showed no significant change in low-temperature performance before and after immersion, remained consistently flexible near or below –45 °C even after 1008 hours of exposure to fuel media. E15 blend was the more aggressive media examined.

4.39.4 Turbocharger Hose

It is expected that turbocharger hose use will increase because turbocharged engines are more efficient [374]. Vamac Ultra HT is a high-viscosity AEM terpolymer designed for use in turbocharger hose, and compounds made from it have high green strength and favorable scorch characteristics that favor good extrusion behavior, along with good dynamic properties.

Turbocharger hoses must operate under both increasingly harsh chemical environments and at higher temperatures and pressures [375]. To meet these demanding requirements, hose typically consists of a layered construction that incorporates several different rubbers, such as a fluoroelastomer liner and a silicone cover. A partially crystalline fluorothermoplastic material replaced FKM in a hose compound. It improved tear strength, low-temperature flexibility, and chemical resistance and halved fuel diffusion/permeation [376].

Special fiber-winding techniques are said to reduce cost by using a technique that allows each fiber to support its maximum load [377]. Deviation of a reinforcing fiber by just 5° from its optimum angle is said to reduce its load-carrying ability by one-half. Turbocharger hoses are a major application for this new technology.

Calendered strips are used to feed an extruder to improve gauge control of silicone turbocharger hose [378]. These are then wrapped around a mandrel with four plies of aramid that impart the required strength. The hose is cured in an autoclave, and a subsequent test sequence at a temperature of 400 °F minimum, accompanied by vibration, ensures satisfactory service.

Single or multiple layers of a high-temperature fabric such as aramid reinforce a hose assembly. The use of aramid fiber as reinforcement is an alternative to aramid fabric [379]. A proprietary technique produces a homogenous predispersion of aramid pulp in an elastomeric matrix. The technique produces hose with high-surface-area aramid reinforcement without the problems associated with incorporating or dispersing the raw pulp. Currently, aramid fibers withstand the heat and pressure to which hose is subjected [380]. When fabricating multipolymer hose layers of different composition, it is important to invest considerable time and effort to ensure satisfactory behavior [381].

Many turbocharger hoses that previously incorporated acrylic rubbers, such as AEM, have changed to silicone rubber, which can operate continuously at temperatures greater than 170 °C [382]. When fabricating multipolymer hose layers that differ in composition, it is important to determine that hose will perform satisfactorily in its intended application [383].

Hose liner in turbocharger hoses must survive extended contact with hot engine oils [384]. Synthetic oils that contain additives affect hose degradation, and a sulfur donor cure combined with effective antidegradants is said to provide extended hose life [385]. For maximum heat resistance, peroxide cure systems are favored [386].

4.39.5 Refrigerant Hose

A thin layer of plasticizer-free polyamide is said to virtually eliminate pollutant emissions from refrigerant hose [387]. The hose retains its flexibility with a 0.06 mm thick foil lining, and emissions from it are about 5% of the amount that escape through butyl hose without a foil lining.

4.39.6 Heating Hose

Hydronic hose, buried in or attached to flooring for heating, is often fabricated from NBR and operates best over a temperature range of 100 to 160 °F [388]. It is important that proper fluid, for example half water and half propylene glycol, scavenge trace metals from the heat transfer fluid. Entran II heating or snow-melting hose was the subject of considerable litigation [389].

4.39.7 Brake Hose

Different fabric weaves are available to meet specific hose requirements. Reinforcing wire is used in a range of hydraulic and industrial hose to satisfy high-pressure requirements. Even cotton fabric can impart substantial resistance to high pressure as evidenced by an air brake hose that withstood 900 psi pressure [390]. Other important brake hose properties include flexibility, bend radius, and electrical resistance.

Brake-by-wire systems could potentially replace brake hose used in conventional hydraulic brake systems [391]. Such systems would eliminate from every car a gallon or more of hydraulic brake fluid, about six yards of brake hose, the master cylinder, and the vacuum booster unit.

A vehicle patented brake hose consists of multiple layers, comprising an inner tube, first and second reinforcing layers, an adhesion layer, and an outer tube rubber layer [392]. An adhesion layer bonds the first and second braided fiber reinforcing layers to the outer tube rubber layer as shown in Figure 4.16.

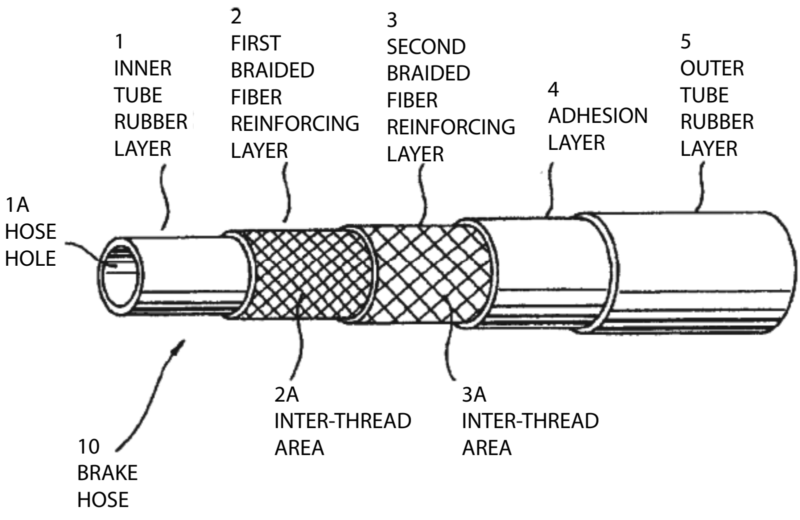

Figure 4.16 Multilayer brake hose [392]

4.39.8 Power-Steering Hose

Tearing energy values that correlated well with a previously developed model were involved in work to improve power-steering hose [393]. It was found that attack by molecular oxygen led to additional crosslinking in the hose cover. Initially, an additive in the power-steering fluid caused more crosslinking in the hose tube than oxygen did. However, after additive depletion, the fluid acted to protect the hose.

Ford had intended to incorporate 80% steer-by-wire systems by the year 2012 [394]. It further committed to fit electric power steering (EPS) on 80 to 90% of its Ford, Lincoln, and Mercury automobiles by 2012.

4.39.9 Hose Design

Hose should be capable of conforming to the smallest anticipated bending radius without becoming overstressed [395]. Static wires and conductive rubber components are used in some hose to dissipate electrical charges that could be hazardous around flammable liquids. In contrast, nonconductive hose is used around power lines for reasons of safety. It is critical to properly identify hoses used in these specific applications.

An important consideration with a lined hose is the relative age resistance of the hose lining and the hose cover [396]. The lining of an older hose can crack when bent, with the defect hidden.

Hose designers try to design the neutral angle (54°44') into the carcass of hose [397]. At this angle, assuming no elongation of the reinforcement, internal pressure does not change hose length or diameter. Departure from the neutral angle causes

- hose length to increase, and diameter to decrease, for braid angles greater than neutral
- hose length to decrease, and diameter to increase, for braid angles less than neutral.

However, in multilayer hoses, inefficient stress transfer within the hose wall causes the inner layer of reinforcement to carry most of the load [398]. Hence, to optimize efficiency, not every layer should be assembled at the neutral angle.

4.39.10 Hose Manufacture

Three principal methods of hose manufacture are nonmandrel, flexible mandrel, and rigid mandrel [399]. Nonmandrel hose, which is formed by extruding a tube and cover without a mandrel for support, is generally used at working pressures less than 500 psi.

Lubricants for hose mandrels must meet several requirements that include inertness to mandrel material and rubber, lubrication provided over a wide temperature range, low toxicity, and water solubility [400].

Flexible mandrels are used to manufacture hose with more accurate dimensions. These can be fabricated from rubber or with a wire core to minimize distortion. The rigid-mandrel method is used for larger size hose when flexible mandrels become difficult to handle. Rigid cores are usually made from aluminum or steel.

4.39.11 Hose Failure

Replacement of hydrocarbon fuels with nonhydrocarbon fuels such as ethanol (gasohol) can result in hose failure. The ethanol caused greater swelling of traditional hose compounds based on NBR and ECO [401].

4.39.12 Hose Abrasion

Abrasion resistance of hose is an especially important property in sandblast hose [402]. NR used in this application provides excellent abrasion resistance. NR's good electrical resistance causes static electricity to build up; use of a conductive carbon black in the hose compound can correct this problem. NR is used in concrete-spraying guns because of its excellent abrasion resistance [403]. For comparison, steel nozzles used in spraying operations lasted only one day; rubber nozzle tips lasted a week or more.

Hoses are also used to suck diamonds from the seabed, where both sand and diamonds are very abrasive to the inner tube of the hose [404]. The hose used in this application must have good abrasion resistance, bendability, and flexural strength.

4.39.13 Medical Hose

PVC has been used for many years for flexible medical tubing because of its favorable balance of functional properties and cost [405]. Although early TPEs did not match the functional properties of PVC, they have significantly improved over time. Factors involved in medical hose applications include kink resistance, clarity, sterilization stability, and the feel of the hose.

Hose used in medical applications requires close dimensional control [406]. While 90% wall thickness was accepted earlier, 95% is now more the norm. Phthalate plasticizer use in hose is now being reconsidered because of its potential adverse effects.

4.39.14 Hose Identification Technology

Radio frequency identification (RFID) tags can identify, log, and track hose during manufacture [407]. Additionally, RFID can provide a complete history of all hose assemblies in a production facility directed toward hose management.

Articles initially made from Tracer Viton T-1 will fluoresce a light blue color until exposed to high temperature in a postcure oven [408]. High temperature changes the blue color to a permanent green color, except for exposure to certain strong acids, bases, and amines. The information obtained is useful for quality assurance purposes.

4.40 Expansion Joints

These are flexible connectors used with piping systems to relieve stress caused by temperature changes that occur in rigid piping systems [409]. Expansion joints also minimize vibration, sound, and transmission caused by vibrating equipment such as pumps and compressors.

4.41 Color

Specifying and agreeing upon a desired color is a major problem associated with colored compounds [410]. Color visualization software should aid in overcoming color problems. Color used for identification should be a readily recognizable shade to prevent recognition problems [411]. This is especially important for wire bundles where there may be a rainbow of colors.

Colored compounds should be mixed in a separate area remote from black-mixed compounds [412]. Where this is not possible, a clean-out batch can be used that can be incorporated later in less-critical compounds. Very low concentrations (about 5 phr) of a highly conductive carbon black can substantially improve the conductivity of a rubber compound without turning a colored compound black [413].

Use of blended colors can result in an unusual outcome [414]. EPDM roofing membrane in Oregon incorporated blue and yellow colorants to obtain a final green color in the membrane. After lengthy exposure to the sun the yellow faded and caused the membrane to turn blue. Ducks in the area saw the blue membrane as a pond and landed on it with interesting results.