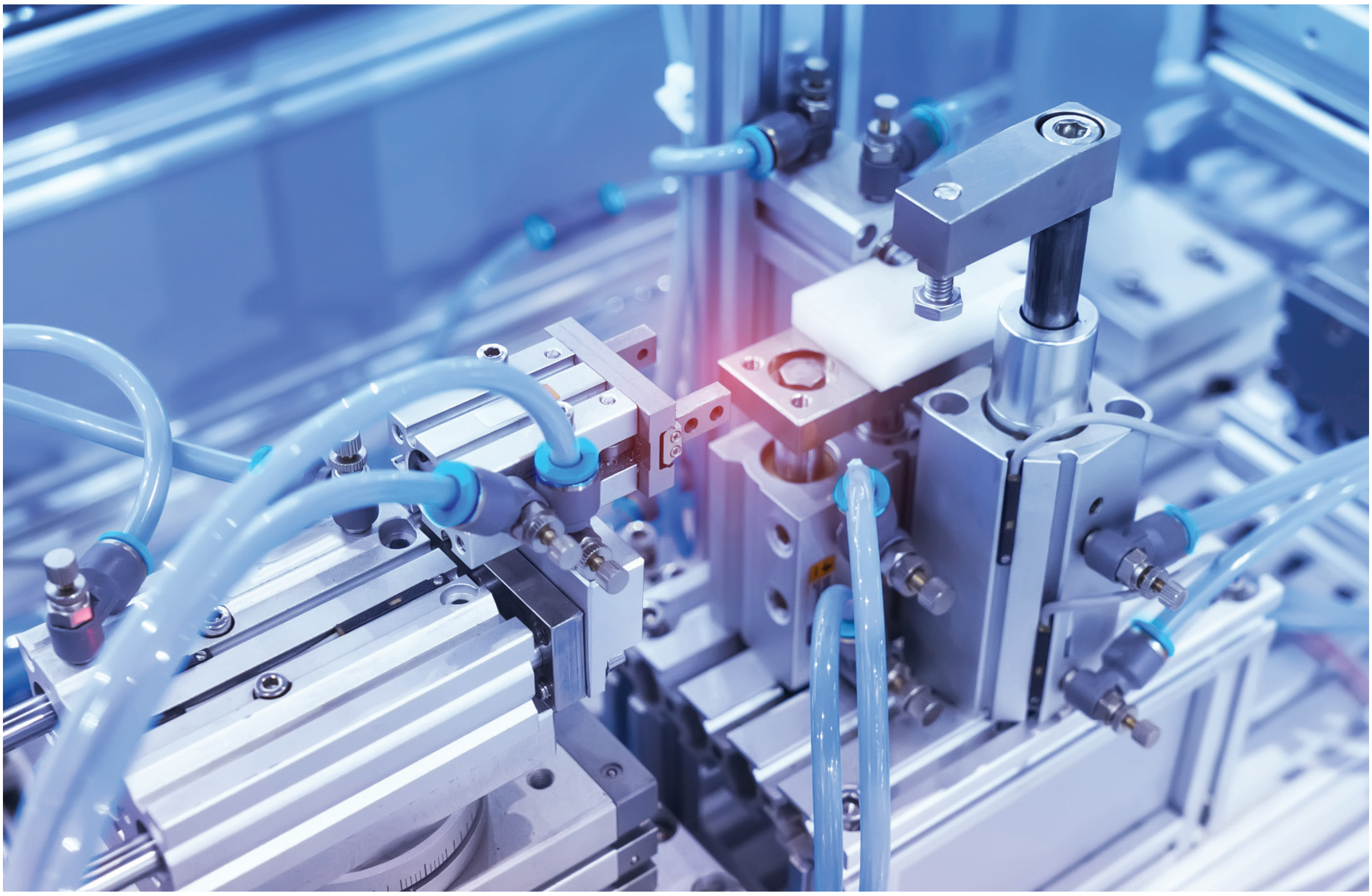
Keep Your Machines from Going Down the Tubes

This white paper explores the various environmental and mechanical causes of pneumatic tubing failure, which can cause downtime and costly production losses.



Because pneumatic tubing is a common component in machines, many designers don't give it the attention it deserves. But the reality is choosing the right tubing is a critical aspect of machine design, and your selection process must consider factors that extend beyond the more "obvious" operating conditions. For example, if your machine is located near welding equipment, then it's important to understand if and how the tubing can handle weld splatter. If it can't, due to thin wall thickness, for example, then odds are your tubing will fail prematurely.

Most of the time, tubing failure causes downtime for the equipment the tubing's attached to—leading to costly production losses, as well as extensive engineering effort to find and correct the cause of failure. Given what's at stake, it's important to ask the right questions about your machine's surroundings during the initial design process. Understanding both the obvious and less obvious conditions your tubing will be exposed to will enable you to make the right choice in polymer—whether polyurethane (PU), polyamide (PA), polyethylene (PE), among others.

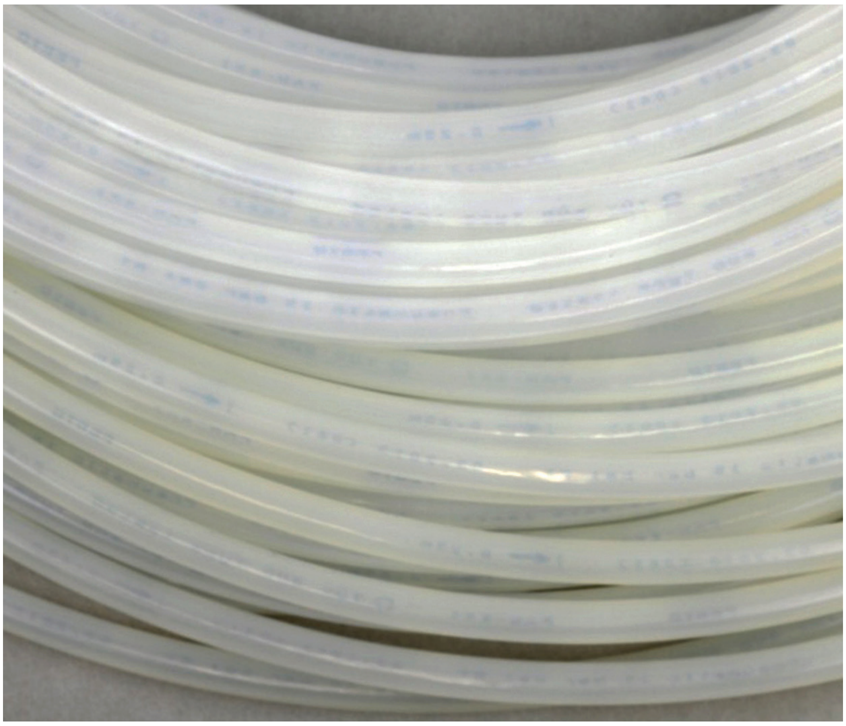
This white paper will explore several common causes of tubing failure—many of which can be easily overlooked during the design process. We will also discuss various scenarios that can lead to tubing failure, as well as the damage mechanism and failure mode of several mechanical and environmental factors. By the end, you should have a better understanding of the kinds of conditions to consider when designing your machine, minimizing the risk your tubing will fail.

Avoiding Degradation Due to UV Rays

When it comes to tubing failure, 90 percent of customer complaints falls under environmental damage—including physical, chemical and microbial damage—compared to mechanical factors like rubbing or crushing. The reason for this disparity is due to the unforeseen dangers of certain environmental factors on the tubing until it's already too late. For example, adding tubing to a machine located near windows can expose the tube to damaging UV rays from sunlight. High-energy radiation, whether ultraviolet, X-ray or gamma radiation, will cause the tube's macromolecules to split and lead to tubing deterioration. Such an oversight is completely accidental but can have long-lasting effects on not only the tubing's lifespan, but the performance of your machine.

UV energy excites photons in plastics, a process that creates free radicals. In the presence of oxygen, these free radicals form oxygen hydroperoxides that compromise the backbone chain and weaken the structure—a process called photooxidation. Photooxidation can also cause a color shift on the surface of the tubing.

While certain polymers, such as polytetrafluoroethylene (PTFE), have excellent natural UV resistance, adding certain stabilizers, absorbers or blockers to the plastic is an effective way to prevent UV degradation. For example, the addition of carbon black can provide sufficient protection for outdoor applications.



PA tubing with surface yellowing from UV light.

The Effects of Hydrolysis

In addition to UV rays, natural and artificial sources of water and moisture are other potential causes of environmental damage for tubing. In general, ester-based PU tubes are susceptible to hydrolysis reactions that cause tubing degradation, while ether-based PU tubes offer greater hydrolytic stability, especially in humid environments.

In general, it's important to ensure the tubing you use incorporates additives that resist UV radiation or hydrolysis, depending on your needs. For more information on which polymers can withstand these conditions, please see our "In-House Weathering Tests" sidebar.

Sample	Result	Description
PAN	Bad performance	Material gets porous when it's in contact with UV radiation.
PUN	Medium performance	Hydrolysis damages tubes while it's in outside environments long-term.
PUN-H	Good performance	No significant changes of technical characteristics. High hydrolysis resistance.
PLN	Best performance	No significant changes of technical characteristics. High hydrolysis and chemical resistance (e.g. acid rain).

Results of Festo's in-house weathering tests.

In-House Weathering Tests

At Festo, we conducted physical damage and weathering (UV rays and hydrolysis) tests on our tubing types, including our PAN (polyamide), PUN (ester-based polyurethane), PUN-H (ether-based polyurethane) and PLN (polyethylene) product lines. The conditions, which mimicked five years of outside operation, included the following:

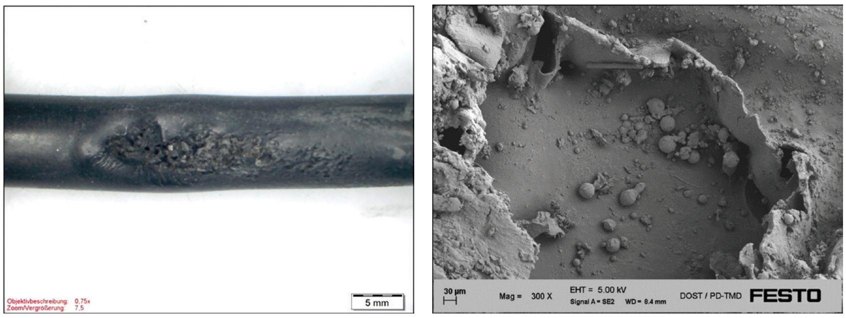
- UV radiation
- Rain simulation
- Lowest temperature: -20°C
- Highest temperature: +70°C
- Humidity at 35 percent
- Duration: 2,000 hours

Unintended Sources of Heat and Pressure Spikes

Heat can come from various sources, some of which may be more obvious than others. For example, perhaps you need to run tubing across a vehicle engine, in which certain components will become hotter than others. Throw a particular warm day into the mix, and the resulting high temperature may exceed what your tubing was initially designed to handle. Another common, though perhaps less obvious source of heat is simple friction. If tubing runs up against components in a machine with high cycle rates, for example, then the frictional heat can build and cause the tubing to fail over time.

Much like temperature, pressure is a variable that requires you to consider conditions that may exceed the tubing's normal range. For example, perhaps the machine you are designing incorporates a regulator that reduces a 200 PSI inlet pressure down to an acceptable operating pressure of 90 PSI. If the regulator fails, suddenly the whole system—your tubing included—will experience a damaging pressure spike.

In general, if you don't design around the maximum temperature or pressure the tubing can handle, then any spike in these conditions can cause fatal "ballooning." PA, also called nylon, tubes are ideal for standard applications with increased pressure and temperature ranges, and many can withstand pressure ranges over 290 PSI.



Examples of thermal damage to PAN tubing, including blistering (left) and melt craters and beads on the surface.

The Hidden Dangers of Chemical Interactions

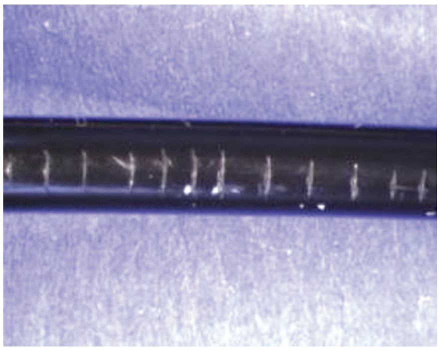
Acids and bases can trigger chemical reactions in a tube's polymer, causing its molecular structure to split and resulting in radial cracks. To avoid this structural deformation, it's important to select a polymer that can withstand chemical exposure—such as perfluoroalkoxy alkanes (PFA), which can handle even the most aggressive acids and lyes. Perhaps the most obvious industry where chemical interactions are a concern is food and beverage, which typically utilizes equipment that must endure washdown and other caustic cleaning chemicals.

But unfortunately, not every scenario is this obvious. For example, if you're running tubing near a machining tool that cuts metal, then it's important to take into account the fact that some coolant may settle on the tubing. If that's the case, chemicals within the coolant can react with the tubing material, leading to premature tubing failure.

Damage	Application
Chemical damage	Areas subject to cleaning; exposure to acidic or alkaline media—e.g. detergents, sanitizers and cleaning agents.
Stress cracks	Printing or standard environments; exposure to polar solvents, hydrocarbons, colors or lubricants.
Microbial damage	Outdoor or underground areas (manholes and wells) or dirty, humid environments—e.g. cable channels.
Physical damage	Outdoor areas or areas with artificial UV radiation, e.g. food applications.

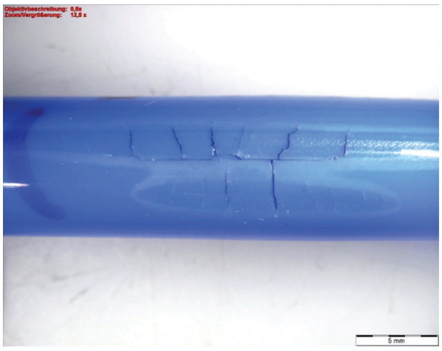
Critical zones for tubing.

In addition, standard PU tubing, if left in direct contact with electric wires or sensor cables in dark, humid environments, can experience chemical damage via phosphoric acid, which is found in phosphorus-based flame retardants. During this interaction, phosphorus esters diffuse out of the wires or cables, subsequently forming phosphoric acid on the tube's surface. This reaction often occurs in cable channels, where PU tubes make direct contact with wires and cables.



Stage 1:

- Single radial cracks
- Length of cracks ‹2mm
- Cracks located on one side of tube



Stage 2:

- Mostly longitudinal and transverse cracks form on the hose surface.

Stage 3:

- Blow-out of tubing segments

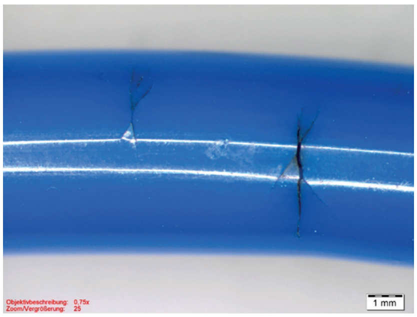
Chemical damage of PU tubing and electric wires/cables.

Microbial Damage and Stress Cracks

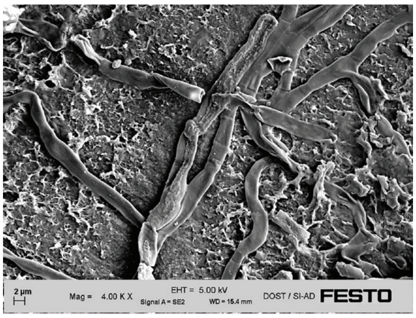
Outside of the food and beverage industry, many machine designers might not think about the dangers of microbes building up on the surface of tubing. But microorganisms and biofilms, such as bacteria and fungus, can inflict indirect damage on tubing—especially PU tubes— in the form of metabolic products:

- Acid attacks
- The enzymatic breakdown of plasticizers
- An increase in the level of water contained in the plastic (hydrolysis)
- Direct microbial degradation

In tubing, a polymer's constituents provide a source of carbon or nitrogen for the metabolic process, ultimately causing failure in the form of chemical damage or stress cracks. Stress cracks can also occur due to the presence of polar organic substances, including alcohol, ester and ketones. The resulting internal stress caused by these substances reduces the polymer's intermolecular forces due to the diffusion of the medium inside the tube. Making matters even more tricky, if tubing contact with the media that had initially caused the stress cracks suddenly stops, then the media diffuses out of the polymer—making it difficult to figure out the root cause of this damage.



An example of microbial damage. Oftentimes, cross-cracks with small, branched side cracks at the end will become macroscopically visible.



Microbial damage in the form of visible mycelium (fibrous cells) by actinobacteria (long, branched bacteria).

Dynamic Situations and Mechanical Damage

Although the majority of tubing damage is the result of environmental influences, you must still factor in possible sources of mechanical damage. For example, a common engineering mistake is to assume a tube can handle sharper corners than it can take, especially in confined areas. But if the tube's bend radius is reduced, even in static equipment, then the tube can easily kink, weaken and fail—especially if it's also pressurized. (To learn more about how we determine a tube's minimum bending radius, see our sidebar.)

From a design standpoint, it's important not to assume your tubing can handle corners—no matter how small—as it can cause the tubing to kink or come up short. In other instances, once a machine begins to cycle, the tubing can snag on or rub against another component or surface. For dynamic situations like this, you'll need to consider tubing materials that are more resistant to abrasion like PE tubing.

Determining a Tube's Bending Radius

To measure a tube's minimum bend radius, engineers will fix the tube to a base plate and then bend the tube until the deformation creates a kink. This measured value is the minimum bending radius, or Rmin. In general, PU tubes are highly flexible.

Application	Tubing Material	Description
Standard	PU	Excellent flexibility and weathering characteristics.
	PA (Nylon)	Ideal for higher pressure and temperature ranges. Can handle repeated flexing.
	PE	High levels of abrasion resistance in dynamic applications.
High pressures, temperatures	PA (Nylon)	Ideal for wider pressure (up to 20 bar) and temperature ranges. Excellent chemical and mechanical resistance—even in subfreezing temperatures.
Chemical and hydrolysis resistance; food-safe	PTFE	Ideal for food and beverage and laboratory applications. Resistant to chemicals and cleaning agents.
	PU	Hydrolysis-resistant and suitable for cleanrooms with the right fitting. Notable resistance to gasoline and oils.
	PFA / PTFE	Excellent temperature resistance (-200° to 500°F) and resistant to corrosion, solvents and aggressive acids and alkalis. PTFE has a low coefficient of friction, making it ideal for viscous and sticky materials.
Anti-static	PU	Anti-static when paired with a solid metal fitting. Provides maximum protection for electrical and electronic components.
Flame-retardant	PU	Safe for areas where there is a risk of fire.
Weld splatter	PU	Handles weld splatter with wall thicknesses of 2 millimeters.
	PA (Nylon)	Double-walled variants are safe for weld spatter when paired with special fitting.

Choosing the right tubing and connector combination can help you avoid almost every reason for tubing damage.

A Balancing Act

Each type of pneumatic tubing has its different strengths and weaknesses, all which must be balanced with the tube's environmental and/or mechanical conditions. Keep in mind, however, that not all of these conditions will be obvious—making it extremely important to ask yourself the right questions during the initial design process of your machine. Considering all aspects of your tube's operating environment will enable you to select the correct polymer and successfully avoid tubing damage, downtime and unnecessary costs.

You can learn more about pneumatic tubing by visiting www.festo.com.

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