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Flexible Water Hose Failures: A Case Study and General Design Considerations

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Abstract

Flexible water hoses (or flexible hose connectors) have become commonplace in recent years and provide a low-cost and convenient alternative to rigid pipe. Unfortunately, inadequate designs, particularly with regard to the selection of materials and material parameters, have made some hoses prone to failure. Such failures are often initiated by incidental exposure to corrosive substances commonly found in homes (including chlorides in tap water) that attack and corrode the stainless steel metal braid. A failure of the braid then leads to a rupture of the water-carrying tube. We evaluate the design considerations pertinent to flexible water hose failure and consider a recent failure scenario that illustrates some key points.

Keywords: austenitic stainless steel, corrosion, failure analysis, pipe burst, plastics, SEM, stress corrosion cracking

Introduction

Failures involving flexible water hoses have become more common as their use has proliferated in residential settings. Flexible water hoses connect household plumbing to fixtures such as sinks and appliances. Their popularity is due to ease of installation as a consequence of the hoses' flexibility and quick connections that eliminate the need for soldering or threading.

In many cases failure of the hose can be traced to simple design considerations, specifically, to the grade of stainless steel selected for the metal braiding as well as the thickness and material of the elastomeric tube. Manufacturers, distributors, and tradespeople should consider the foreseeable use and environment of flexible hoses in light of these facts and familiarize themselves with alternatives less prone to failure.

A Case History

A recent case demonstrates many of the key design considerations. The incident in question involved a flexible water hose connected to a faucet (Figure 1). The metal braiding on the hot water side was compromised and a rupture occurred in the elastomeric tube, which caused flooding and considerable property damage.

Upon examination of the hose it was found that the tube braiding was heavily frayed with large portions missing, displaced or loose (Figure 2). The rupture in the rubber hose was consistent with a failure from hoop stresses on the tube, having formed longitudinally along the length of the tube.

The hoop stress on a thin walled tube can be calculated with the Barlow formula as follows (Morton, 1999):

$$\text{Hoop stress, psi} = \frac{\text{Pressure (psi)} \times \text{outside diameter (in.)}}{2 \times \text{wall thickness (in.)}}$$

For a household water pressure of 80 psi, an outside tube diameter of 0.50 inches, and a wall thickness of 0.050 inches, the hoop stress is calculated to be 400 psi (2.8 MPa). This stress is within the range of breaking stress for silicone rubber (Gent, 2001) and is approximately 30% of the minimum breaking strength of polychloroprene (Neoprene). The hoop stress will continue to exceed 290 psi (2 MPa) at pressures of approximately 60 psi and higher. At elevated temperatures and at slow strain rates, the strength of the rubber material is diminished (Schweitzer, 1990). Stated more simply, without mechanical support from the braided steel sheath, the rubber hose is likely to fail at normal water pressures.

It should be noted that tube failure also occurs at stresses well below the breaking stress by a process known as creep. Creep is a process whereby continuous stresses and elevated temperatures cause progressive, time-dependent deformation of the material. The permanent thinning of the tube walls by slippage between molecular chains and chemical breakdown of the molecular chains increases the hoop stress on the tube, so that a decrease in tube thickness by 20% results in an increase in hoop stress by 25%. At the elevated temperatures and stresses of normal use, creep failure is likely even when the stress is below the breaking strength of the material, if the braided metal sheath is compromised. The creep rupture curves of polymeric materials found in the literature illustrate this point [see for example, (Osswald, 2010)].

To understand the cause of the braiding failure, the hose was examined with a digital scanning microscope (DSM) and a scanning electron microscope (SEM). Intergranular and pitting corrosion damage was observed on the individual braid wires (Figure 3). The composition of the braid wires was analyzed using EDS indicating manganese in the base metal of a percentage approximately equal to the percentage of nickel. The compositional analysis of the braids revealed a chromium-manganese (CrMn) steel with a chromium content of approximately 16% and nickel and manganese of approximately 6% (Table 1).

Although austenitic manganese steels were invented in the 19th century by Sir Robert Hadfield, it wasn't until the 1930s that the stainless varieties of CrMn steels were investigated. A shortage of nickel during WWII led investigators to pursue manganese as an austenite-forming replacement in stainless steels. Work on CrMn steels continued through the 1950s due to a continued shortage of nickel and resulted in the development of the 200 series stainless grades. As world nickel prices have risen over the past decade, the production of 200 series (or related) grades have increased, particularly in China and India.

The low percentage of chromium and nickel in many CrMn steels as compared to the 300 series stainless grades increases their susceptibility to corrosion[1]. The reduction in chromium (in part to facilitate the austenite phase) and nickel of the CrMn steels leads to problems with chloride stress corrosion cracking and pitting. Corrosion product on the incident braid wires, analyzed using EDS, contained chlorides at a concentration of approximately 1% (10,000 PPM). The susceptibility to failure by chloride attack was worsened by an inappropriate choice of braid metal material.

Chlorine and chlorine containing compounds are common disinfectants added to public water supplies. While the concentration of chlorides in water is too low under normal circumstances to cause stress corrosion cracking or pitting, the presence of a slow leak in the connection allows the gradual accrual of chlorides on metal surfaces as water evaporates and concentrates the compounds. This process is accelerated on the hot water side, as the accumulation of chlorides (and the aggressiveness of the corrosion process) is worsened by the warmer water and metal.

The locations of the most pronounced damage on the hot water side of the incident hose and the rupture of the hose near the hose connections point to a slow leak as a likely source of chlorides. It should also be noted that chlorine compounds are common in household cleaners (e.g., bleach and bleach containing products). The proximity and use of such cleaners must be considered a possible contributor to a corrosion failure. Regular cleaning with chloride containing agents can serve to deposit chlorides in much the same way as a slow leak.

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[1] It should be noted that some of the 300 series steels may also be inadequate for use in flexible water hoses (Allwin, 2005).

Conclusion

The grade of stainless steel used in the fabrication of the braid of flexible water hoses is critical given the foreseeable environment of such hoses. Under-sink cabinets are commonly used to store cleaning agents, which often contain chlorides and other corrosive compounds. Bathrooms and kitchens are commonly treated with disinfectant sprays, wipes, and powders to clean and disinfect. It is therefore likely that the flexible connections between the household plumbing and appliances or fixtures will be directly or incidentally exposed to such chemicals.

As a result of the expected environment of flexible water hoses it is important that the metal braid be fabricated from a grade of stainless steel that is sufficiently resistant to chlorides and other forms of household chemicals. Inexpensive hoses with steel braids manufactured in China and India should be avoided (or cautiously considered), as the use of CrMn steels (200 series and related) has increased due to lower material cost. The fact that distributors and retailers seldom report the grade of the stainless steel is problematic, but barring any other information cost may be a reasonable indicator of quality. Alternatives to stainless steel braids (e.g., polymer coated fibers) should also be considered.

The material and dimensions of the elastomeric tube is likewise an important design consideration. As the tube wall thickness is increased and as the diameter of the tube goes down, the stress on the tube is reduced. The specific polymer selected, its hardness at elevated temperature, creep properties, breaking strength, etc., should be considered. Although the combined pressure rating of the inner hose and metal sheath are typically hundreds of PSI, the pressure rating of the inner hose may be inadequate to meet the desired robustness. Some manufacturers offer fiber reinforced polymer tubes that will withstand higher stresses.

Poorly designed flexible water hose connections have been used for some time and will undoubtedly continue to be used. As a result, failures will continue to occur with their accompanying cost and damage to property. Fortunately, the reasons and remedies for these failures are often simple; making the appropriate design modifications requires understanding the basic engineering principles behind the failure and a consideration of the foreseeable environment and exposure of the hoses.

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Table 1 Results of semi-quantitative elemental analysis of wire surface using electron dispersive spectroscopy (EDS).

Chromium (Cr)	Manganese (Mn)	Iron (Fe)	Nickel (Ni)	Carbon (C)
16.3 wt.%	5.6 wt.%	72.5 wt.%	5.7 wt.%	3.3 wt.%

Fig 1: Flexible water hose failure. The hoses supplied water from the household plumbing to a faucet. The background grid shows one-inch squares.

Fig 2: Hose with fraying, missing, or loose braiding. The background grid shows one-inch squares.

Fig 3: SEM image of individual braid wire. A fracture in progress is visible. Pitting and corrosion deposits are also seen on the surface of the wire.

Fig 4: Fractured individual braid wire with intergranular attack.