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Analysis of acetal toilet fill valve supply line nut failure

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ABSTRACT

In recent years, there has been a rise in the number of product liability cases involving the failure of toilet water supply line acetal plastic nuts. These nuts can fail in service, causing water leaks that result in significant property and financial losses. This study examines three possible failure modes of acetal plastic toilet water supply nuts. The three failure modes tested were all due to over load failure of the acetal nut and are as follows: (1) Overtightening of the supply line acetal nut, (2) Supply line lateral pull and, (3) Embrittled supply line lateral pull. Additionally, a "hand-tight" torque survey was conducted. The fracture surfaces and characteristics of these failure tests were examined with Stereo Microscopy and Scanning Electron Microscopy (SEM). The failure modes were compared and contrasted to provide guidance in determination of cause in these investigations.

1. Introduction

This research examined the possible failure modes of acetal (polyoxymethylene, polyacetal, polyformaldehyde) plastic toilet fill valve (ballcock) supply line nuts, a connector commonly used to connect a water supply line to toilet fill valves. It has been reported that ballcock supply line nuts have failed causing flooding and associated property damage. These failures have demonstrated several different failure modes. This paper focuses on the failure of the acetal components due to mechanical overtightening of the nuts and lateral pulling on the supply line. By comparing and contrasting the characteristics of these distinct failure modes, a comparison to failures in service can be made, and guidance on cause of failure can be provided.

Acetal ballcock supply line nuts are mostly manufactured through injection molding followed by machining of the threads into the inside surface. The nut itself has a hole in the bottom through which the supply line extends. The annulus around the supply line is used to hold a plastimer cone gasket to the actual bottom of the ballcock tube that protrudes though the toilet tank, which is used to fill the tank. Ballcocks and their mating supply line nuts have their own thread dimensions known as 7/8 inch B.C, or 7/8 B.C. This ballcock thread is a straight thread and is used solely to make a tight seal between the rubber cone gasket and the bottom of the ballcock tube [1]. Because the seal isn't made by an interference fit of the threads, the ballcock nut does not need any additional sealant, such as plumbing thread sealant (pipe dope) or Teflon tape. In a proper installation, the ballcock supply line nut should only be hand-tightened [1].

Ballcock nuts and other plastics parts used in toilets should not be exposed to harsh chemical agents, specifically those containing chlorine. Chlorides, Chlorine, and Chloramines, which are used to treat water, are known to attack the plastics used in toilets [2]. These chlorides make the plastic susceptible to cracking from stress [2]. The effect of chlorides on the plastic make the use of acetal ballcock supply line nuts questionable since nearly all commercially available bathroom cleaners contain chlorine. Further, urban water supplies are generally chlorinated, containing up to 3 ppm of chlorides [2,3,4]. Though the ballcock nuts do not directly have

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contact with supply line water, the atmosphere in bathrooms may contain the chlorinated water vapors. External contact with domestic water and chlorine containing cleaning products provide numerous opportunities for exposure.

Additionally, some possible issues that could lead to failure of an acetal ballcock supply line nut include internal stresses from manufacturing and material flaws like voids, blushing (striations from plastic flow), etc., in the injection molding process. Manufacturing defects such as these can be caused by using an excessive injection rate and/or inadequate mold temperature [5]. It follows that blushing would be present if the manufacturer is attempting to increase their production; however, this could be an indicator of other potential manufacturing defects leading to inconsistencies in the injection process and a weakened part. In an effort to increase production, over/under heating the plastic melt, using an unusually high injection rate, under heating the molds, premature release of the parts before proper cooling, etc., are all possible. These parameters could potentially alter the structural properties of the part, the material properties of the acetal plastic, and ultimately the service life of the ballcock supply line nut.

1.1. Acetal plastic (Polyoxymethylene)

Acetal plastic or Polyoxymethylene (POM) is a semi-crystalline polymerized chain of formaldehyde (CH_2O) molecules that is produced by a variety of polymerization techniques on formaldehyde or trioxane [6–9]. POM is found in two main forms, as a homopolymer or a copolymer [7,8]. Copolymer is a polymerized chain of formaldehyde broken up by other monomer units inserted in the chain, where Homopolymer consists of an unbroken chain of a single monomer [7,8]. To induce stability of the polymer chain, the ends are capped with, most commonly, acetic anhydride or a long-chain alkyl group [7]. Additional additives can be used to alter properties of the bulk polymer including antioxidizer/heat stabilizer, formic acid trapping agents, lubricants, molding assistants, UV stabilizers, impact modifiers, nucleating agents, colorants, flame retardants, antistatic agents, and/or fillers [7].

POM homopolymer can have a crystallinity between 50% and 80%, producing attributes of relatively high strength, high stiffness, high toughness, resistance to creep, fatigue endurance, resistance to solvents, and low coefficient of friction [7]. The melting temperature of POM is 164–180 °C, deflection temperature is reported to be 97–180 °C, and a glass transition temperature of −80–0 °C [5,7,9–13].

Chains of POM are susceptible to attacks from acidic (low pH) and basic (high pH) chemicals and degradation when exposed to elevated temperatures [14,15]. Acidic/basic attacks cause a catalytic degradation into formaldehyde monomer [14,15]. When POM is exposed to high temperatures, the polymer chain unzips (depolymerization) into formaldehyde which then oxidizes into formic acid, this in turn acts as a catalyst and increases the rate that the polymer chain unzips [14,15]. These degradation effects are lessened by the introduction of capping the ends of the polymer chain and/or form a copolymer POM by copolymerizing with a different monomer [13–16]. Additionally, Zinc ions can cause similar degradation. In a study by Wright, analysis of a failed acetal compression fitting involved in a water loss showed a “viscous deposit” and demonstrated degradation as discussed above [14]. The deposit was found to have high concentrations of zinc chloride ions consistent with the composition of plumber’s flux.

2. Experimental setup and procedure

For this study, three possible failure modes were tested for the acetal ballcock supply line nuts. The first failure mode tested was overtightening of the nut on the toilet fill valve. The second failure mode tested was mechanical failure of the nut when a moment was applied to the nut and fitting via the supply line. The third failure mode was mechanical failure of the nut when a moment was applied to an embrittled acetal nut. Prior to testing of the suggested failure modes, a survey was conducted to quantify “hand-tight” torque. The toilet connectors used in all tests were Watts® FST2-12 toilet connector as shown below in Fig. 1.

2.1. Hand-Tight survey

These nuts are designed to be installed “hand-tight”. Since there is no exact torque associated with “hand-tight”, a survey of ten people was conducted in order to quantify a “hand-tight” torque.

To obtain each participant’s “hand-tight” torque, a calibrated Sturtevant Richmont Model MD300I torque wrench and a custom fabricated 7/8 B.C. threaded pipe socket was used. With the torque wrench secured in a table vice, each participant applied their own “hand-tight” torque to one of the toilet connectors. Each participant’s “hand-tight” torque was recorded and repeated three times. This test was conducted in order to obtain quantitative data for typical “hand-tightness”. A schematic of the test can be found in Fig. 2.

2.2. Overtightening

One suggested failure mode of acetal ballcock nuts is the nut is overtightened to the point of failure. In this study, six identical Watts toilet connectors were tested by applying steadily increasing toque until failure of the acetal ballcock supply line nut. A custom apparatus was used to hold each toilet connector by the acetal ballcock nut only; this ensured that each nut was secured in the same manner while torque was applied. The torque wrench and the custom socket used for the “hand-tight” survey were also used to apply the torque in each of the overtightening failure tests. Maximum torque at failure was recorded for each test.

Once each ballcock supply line nut failed, the fracture surfaces of the broken remains were photographed and examined under a stereo microscope. The fracture surfaces were then sputter coated and examined with a Scanning Electron Microscope (SEM).