Failure Analysis of a Grohe Snap Coupling

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Summary of Conclusions and Recommendations

This report is an analysis of a failed Grohe snap coupling, which is a simple plumbing fitting designed to quickly and securely connect a kitchen faucet to its supply line. The component that failed on the coupling is part of the housing, which is made of injection-molded PVC. The failure mode was brittle fracture caused by fatigue loading (most likely due to “water hammer” pressure spikes). Propagation of the fatigue crack was exacerbated by the design of the housing, which had thin walls and internal threads that acted as stress concentrators, and possibly by overtightening during installation. In order to prevent similar failures in the future, we recommend either changing the design of the threads or eliminating them entirely by molding the housing in one piece. A final alternative is to strengthen the housing material by reinforcing it with glass fiber.

Introduction

The failure of this particular coupling resulted in a leak that could have caused extensive damage if it had gone undetected. It is not known how long the coupling was in service. In order to prevent such failures in the future, we thoroughly analyzed the part to determine the most probable failure mechanisms as well as means of combating them. In addition to the failed coupling that is the subject of this report, we also obtained a newer, unused example of the same part for comparison purposes.

Visual examination

The snap coupling is approximately 2.4 inches long by 1 inch in diameter. The housing (black) is made from a hard thermoplastic and has prominent parting lines, indicating that it was formed by injection molding. There is a spring-loaded collar (yellow in photo 1, green in photo 2) at one end, which slides down to allow the coupling to snap onto a fitting on the underside of the faucet. The other end has a ½-inch-diameter female thread to screw onto the supply line. When installed, the coupling would be oriented vertically with the snap (faucet) end up and the screw (supply) end down. The supply line side of the coupling contains a ball valve to prevent the flow of water when the coupling is disconnected. This is visible on the right side of photo 3.
While the material of the coupling cannot be determined visually, it is almost certain to be either polyvinyl chloride (PVC) or acrylonitrile butadiene styrene (ABS) since these are by far the most commonly used types of plastic for plumbing parts.

The coupling can be seen to have failed by fracturing approximately halfway along its length, about 0.1 inches from the bottom of the collar. The crack had propagated almost all the way through the part by the time the failure was detected. The coupling then broke completely in half as it was being removed.

A close examination of the supply end of the coupling shows what may be tool marks on the outer surface of the part. There are two diametrically opposite gouges in the surface, each about ¼ inch in length. These marks appear to be consistent with the use of a wrench or pliers to tighten the part. One of the marks is shown up close in photo 2. The unused coupling we obtained at the plumbing supply store came with a sticker explicitly warning the user not to tighten it with a wrench.
Photo 1: General view of failed part and unused example of same part.

Photo 2: Possible tool mark on the exterior of the failed coupling.

Photo 3: Alternate view of failed part.
Sectioning the coupling along its center reveals the inner construction. The housing consists of two pieces which screw together as shown in photo 5; it is the piece on the snap side (colored silver in the photo) that fractured. All subsequent testing was done on this part, which we refer to in this report as the snap or faucet side of the coupling. The approximate location of the failure is shown in photo 5.

Photo 4: Section of intact coupling showing internal components.
The piece of the housing that fractured, the snap or faucet end, is shown in photo 6 alongside the unbroken specimen. The fracture location is clearly visible approximately 0.4 inches from the threaded end, at the bottom of the last thread. This is an unsurprising area for a fracture to occur, since the end of the threaded region acts as a severe stress concentrator and the wall of the coupling is thinnest at this point. It is unclear why the coupling housing was molded in two pieces and then assembled, instead of being molded in a single piece. This would eliminate all of the stress concentration issues and distribute stresses more evenly throughout the part.

It can be seen in photo 6 that the transition from the threaded area to the non-threaded area is more gradual on the newer, unbroken part, reducing the stress concentration caused by the end of the thread. The fully threaded portion of the failed part is 0.4 inches, but only 0.35 inches on the unbroken part. Since the crack initiated at the abrupt end of the thread, which the newer part lacks, it is unlikely that the newer coupling would fail in the same location. Therefore, it appears that the manufacturer of this part already discovered the problem and took steps to correct it.
Photo 6: Comparison of fractured and intact housing sections; approximate fracture location marked on intact specimen.

**Fracture Surface**

Upon visual inspection of the fracture surface, we drew several conclusions:

1. Brittle fracture was the mode of failure.
2. The crack initiated at the beginning of an internal thread.
3. The crack propagated along the thread.
4. Fatigue was the likely cause of crack propagation.

The most obvious observation made from the fracture surface is the location of the final fracture. Although not visible in the photos, a lip is present near the point labeled “final fracture surface” in photo 8 on the edge of the fracture surface that indicates this area was one of the last places to fracture. We worked backwards from the final fracture surface to determine where the crack initiated from. Because the fracture is located along the roots of the threads, we could determine that the thread roots were the medium through which the crack propagated. The only part that did not fracture along the thread root was the final fracture surface. The fracture can be traced back to the beginning of the thread, which is where the fracture must have initiated from. The
The beginning of the thread must have acted as a stress concentrator causing the crack to initially form. After the initial crack formation, the crack itself, as well as the thread roots acted as stress concentrators, causing the crack to propagate. Photos 7, the upper half of the coupling, and 9, the lower half, below are composite images of several photos taken of the fracture surface. Photos 8 and 10 are detail shots showing the final fracture surface and the supply-end thread which did not fracture.

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Photo 7: Composite image of upper half. (3x)

Photo 8: Detail of final fracture surface. (50x)

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Photo 9: Composite image of lower half. (3x)

Photo 10: Detail of fracture surface. (50x)
IR Spectroscopy

In order to learn more about the composition of the part, we performed an infrared spectroscopy test. This test measures the part’s transmittance across the infrared spectrum, producing a characteristic pattern of peaks which should allow the material to be identified. The results of this test are displayed in graph 1. Though the results of the test were not excellent, there were clearly observable peaks at 2920, 2850, 1740, 1470, 1240, 1090, and 892 cm\(^{-1}\). All of these except the 1470 cm\(^{-1}\) peak are a very good match for polyvinyl chloride (PVC), which has peaks at 2913, 2849, 1740, 1254, 1098, and 890 cm\(^{-1}\). The extra peak at 1470 cm\(^{-1}\) likely indicates the presence of a plasticizer in the part. Although the peaks we obtained are not nearly as pronounced as those on the reference spectrum (likely due to our specimen not being ideally suited for spectroscopy), the high degree of correlation between peaks indicates that the coupling housing is very likely plasticized PVC.

Graph 1: Infrared spectrum for the unknown plastic.
To determine whether any materials other than PVC (such as glass fiber) were present in the part, we performed a burnout test. Two samples of the material were held at 500°C for approximately three hours in order to burn all of the plastic. Afterwards, the samples were weighed to determine the amount of material remaining. The results of this test are displayed in Table 1.

**Burnout**

Graph 2: IR transmittance of PVC.\(^4\)

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\(^4\) This IR spectrum of PVC shows the characteristic peaks at 2970, 1740, 866, 935, 1420, 835, 1503, 715, 1494, 1199, and 1068 cm\(^{-1}\). These peaks correspond to the vibrational modes of the PVC molecular structure, which includes the stretching of the C=O group at 1740 cm\(^{-1}\), the in-plane bending of the C-H group at 1420 cm\(^{-1}\), and the rocking of the C-H group at 866 cm\(^{-1}\).

\(\text{C}_2\text{H}_4\text{Cl}\)

\(\text{CH}_2\text{CH}_2\text{CH}_2\text{Cl}\text{Cl}_n\)
<table>
<thead>
<tr>
<th>Sample</th>
<th>Before burnout</th>
<th>After burnout</th>
<th>Percent remaining</th>
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<td>11.0359</td>
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</table>

Table 1: Burnout results.

On average, about 0.75% of the material remained after the burnout. This is a very small amount, so it is unlikely that it was deliberately added. We can therefore conclude that the part is likely unreinforced PVC. However, if it were glass reinforced, it would be much stronger. This could potentially prevent this type of failure.

**Flame test**
As a check on our identification of the housing material as PVC, we performed a simple flame test. PVC should burn without dripping, produce a yellow flame with green edges and white smoke, and self-extinguish when removed from the flame. Our plastic sample, on the other hand, burned vigorously with a dripping blue-orange flame, no detectable smoke, and a very faint, somewhat sweet odor. When we turned off the light, we were able to detect flashes of green in the flame. This green color is indicative of PVC, even though the other flame characteristics are not. It is likely that the other flame characteristics we observed were due to the presence of the plasticizer, which could contribute entirely different characteristics.

**Finite Element Analysis**
In order to analyze the geometry of the snap coupling we created a dimensionally accurate model of the faucet side of the coupling in SolidWorks and analyzed it using ANSYS Workbench.
We ran tests for three scenarios. The first was for the case of abuse (e.g. using pliers or a wrench to tighten the fitting). A torque of 30 N-m (equivalent to applying 30 pounds at six inches, the length of a large pair of pliers or a wrench) was applied to the top of the part while the bottom half was fixed. The second test was for stresses caused by a typical household water pressure of 400 kPa (60 psi). Finally, we analyzed effect of water hammer, which is a pressure surge caused by sudden changes in momentum of the water in a pipe. The maximum pressure caused by a water hammer event can be roughly approximated in English units as

\[ P = \frac{0.07 \times v \times L}{t} + P_1 \]  

where \( P = \text{maximum pressure}, v = \text{flow velocity}, L = \text{upstream pipe length}, t = \text{time to close valve}, P_1 = \text{initial pressure}. \) We estimated \( v \) as 5 ft/s, \( L \) as 50 ft, and \( t \) as 0.1 s. \( P_1 \) is the same value of line pressure used above, 60 psi. The results are summarized in Table 2 and Figures 1 and 2 below.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Torque (N-m)</th>
<th>Pressure (kPa)</th>
<th>Max Stress (MPa)</th>
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<tr>
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<tr>
<td>3</td>
<td>0</td>
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</tr>
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Table 2: Results of finite element analysis.

The locations of the maximum stresses for the torque and water hammer simulations are shown below. Figure 1 shows that the maximum stresses were concentrated at the beginning and end of the thread for scenario 1. We would expect the stresses to be concentrated at the beginning of the
thread, because this is where the snap coupling fractured. For both pressure scenarios, the maximum stresses were located along the thread and again at the beginning of the thread. Scenario 2 had the same general results as 3, but with lower stresses.

Figure 1: Location of maximum stresses for torque scenario.

Figure 2: Location of maximum stresses for the water hammer scenario.
Matweb gives the ultimate strength of PVC as 4.00 to 59.0 MPa.² Therefore, it is unlikely that the coupling failed due to normal operating pressure alone, since this produces stresses under 3 MPa. Water hammer is more likely to cause a fatigue type of loading that would cause crack initiation or propagation, since it involves periodic, sudden applications of force to the component. We concluded from these analyses that water hammer is a probable fatigue mechanism, while normal operating pressures in the water line are unlikely to have caused much fatigue. Also, the forces generated in the part by tightening it with a wrench would likely be sufficient to cause a fracture.

Conclusions
1. The part is made from plasticized, unreinforced, injection-molded PVC.
2. The failure mode of the coupling was brittle fracture.
3. The coupling most likely failed due to fatigue, though abuse may also have been a factor.
4. Manufacturing defects were not a factor in the failure.
5. The most probable fatigue mechanism is internal pressure due to water hammer. Normal line pressures are unlikely to cause much fatigue.
6. The most likely type of abuse is over-tightening during installation, such as with a wrench or pliers. This could explain possible tool marks on the exterior of the coupling.

Recommendations
1. Redesign the thread profile so the stress concentration at the end of the threads is reduced. It looks as though this step has already been taken, as the newer version of the coupling has a less abrupt transition into the threaded region.
2. Mold the entire housing as a single piece. This would eliminate the need for threads and distribute stresses much more evenly throughout the part. With modern manufacturing techniques, the housing could probably be molded directly around the ball valve assembly.
3. The PVC could be reinforced with glass fiber to strengthen the housing. Although the raw material would cost more, this option would not require new tooling.
References


   MatGUID=29340c5df4bf4de0a511419ce86db27b&ckck=1

3. Course handbook

4. http://riodb01.ibase.aist.go.jp/sdbo/cgi-bin/direct_frame_top.cgi