Sticking Troubles of O-Rings and Countermeasures

1. Introduction

The rubber O-ring is a seal used for both static seal products (gaskets) and dynamic seal products (packings). It is made with soft elastomer, and so fits well to opposing faces and allows sealing with little tightening force. The O-ring also has the following other benefits:

- It can be used in various conditions, from high pressure to low pressure.
- It requires little space for mounting.
- The structure of the mounting section is simple, making mounting easy.
- It is standardized, readily available, and low cost.

Thanks to these benefits, the rubber O-ring is the most widely used general seal product in various equipment and devices in a wide range of industries including the automobile, hydro-pneumatic, machine-tool, food, semiconductor, and aerospace industries.

Rubber is an inherently elastic material and so recovers to its original shape. In addition to elasticity, rubber has non-slip, sticky properties. With these useful characteristics, rubber is used to produce tires, hoses, belts, and so on. On the other hand, these characteristics could cause malfunction cases when handling products, such as difficulties in mounting and dismounting. In the case of the rubber O-ring, these problems cause products to stick to each other and to stick to their opposing faces.

This report describes the causes of O-ring sticking and countermeasures, and introduces the products that Valqua has developed to reduce sticking troubles.

2. Sticking Phenomenon and its Causes

2-1) Sticking of O-rings

When a rubber O-ring contacts with its opposing face, such as a metal surface, under pressure, it sometimes sticks to the face. When the sticking strength of this phenomenon is small, the phenomenon is sometimes called adhesion. Depending on the usage condition, it may stick sufficiently strongly to cause material destruction of the rubber upon removal. In the case of static seal products, the sealing properties themselves rarely cause problems even if sticking occurs. However, sticking may result in a) a very large force required to open flanges at changing O-rings, and b) in the case of a large-bore O-ring, the flanges cannot be opened due to the large contact area with the opposing face, which creates substantial sticking force. Also, maintenance problems may occur, such as cleaning difficulties if the sticking rubber ruptures: the ruptured rubber sticks to the grooves and opposing faces when flanges are opened.

On the other hand, in the case of dynamic seal products, sticking may cause O-rings to detach from a groove and directly affects their sealing properties. In addition, sticking may cause equipment to malfunction, including operational delays, abnormal noise, and abnormal oscillation. Thus, sticking may directly result in equipment malfunctions.

2-2) Mechanism of Sticking

Sticking is considered to occur by the following process: when rubber contacts its opposing face, molecules of a rubber segment spread and stick to the

opposing face, forming an interface through secondary bonds (including hydrogen bonds and Van der Waals force). Thereafter, the initial sticking (physical sticking) occurs. There are no clear categories of sticking, and there are various theories about sticking. However, it is sometimes called adhesion when the degree of sticking is small. Also, the initial sticking may be affected by the anchor effect, vacuum effect, and so forth. It is considered that primary bonds (including chemical bonds) subsequently start to form at the interface and the sticking strength gradually increases, leading to strong sticking (chemical sticking + physical sticking).[1,2)]

2-3) Factors Affecting Sticking

The sticking strength varies depending on the type of rubber and the material of the opposing face. However, other major factors affecting sticking strength include the hardness of rubber, temperature and humidity conditions, and the surface roughness of the rubber and its opposing face. Other factors affecting sticking strength have been reported.[3)] Based on these reports, major factors are categorized as follows:[4)]

- Sticking strength decreases with increase of hardness of rubber.
- Sticking tends to occur with increasing temperature, although this is not always true.
- The effects of humidity vary depending on the combination of rubber and its counterpart material.
- Sticking strength decreases with increasing roughness of the surface of both rubber and metal. Contact area affects this phenomenon.

3. Sticking-prevention Methods

Simple methods of preventing sticking include greasing and lubrication. However, these processes can contaminate products and mounting sections. To shorten the operation time as well to as prevent contamination, O-rings which inherently prevent sticking are required.

Major methods of preventing the sticking of O-rings are categorized in Figure 1.

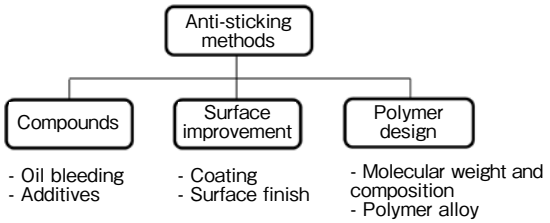


Figure1 Categorization of sticking-prevention methods

3-1) Sticking-prevention Using Material Combination

This method reduces sticking by mixing a combination of the following selected internal additives to rubber: solid lubricant including PTFE, lubricating components, releasing components, or other chemicals. Generally, these formulated chemicals affect the physical properties of rubber, compression set, and others, so the characteristics of each additive should be balanced.

3-2) Sticking-prevention Using Surface Modification

This method reduces sticking by making the surface of the rubber resistant to sticking. There are two approaches for doing this: coating to form a sticking-resistant thin film on the surface of rubber, and surface treatment using chemical immersion or plasma/radio irradiation. The types of coating include the following: a coating that physically adheres to the surface and a coating that forms a thin film through reaction with the surface of the rubber to enhance adhesion to the base rubber. The thin film should exhibit chemical affinity with the base rubber. A typical surface treatment is surface hardening: rubber is immersed in chemical solution containing a vulcanizing agent and then heat is applied for hardening. However, the area modified by this approach is limited to the area close to the top surface, and frictional wear of the modified layer results in the loss of this preventive effect. This approach should be used with care when applied to dynamic seal products.

3-3) Sticking-prevention Using Polymer Design

This method reduces sticking by improving the

material polymer of the O-ring itself. Generally, polymers with high molecular weight are considered to stick less, as well as polymers with fewer side chains and end groups (including -COOH, -OH, and >CO) .

Also, this method can be performed by giving a polymer a structure which inhibits molecular-chain motion (e.g. a structure with a high glass transition point) . However, it is difficult to develop a polymer which has a structure to reduce sticking while retaining the elasticity of rubber. Further molecular-design investigations are expected by new polymer design and polymer alloys with new structures.

Valqua has developed various methods to prevent and reduce sticking in its products. Some of our key products are outlined below.

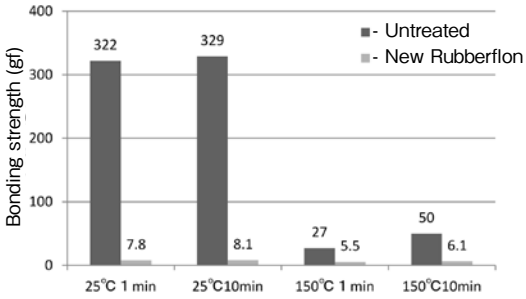
4. New Rubberflon

New Rubberflon (Rubberflon is our registered trademark) is an example of our products that are designed to prevent sticking.

New Rubberflon is produced using the surface-modification method, not just a coating. Because of reactive treatment, the treated surface layer adhere with matrix rubber, thus not easy to remove. Moreover, the method does not affect the physical properties of the base rubber, so most rubber materials such as nitrile rubber and fluororubber except for silicone rubber can be processed with this method. New Rubberflon offers both low sticking and friction. Thus, the product not only prevents sticking between products or to the opposing face, but also reduces insertion friction when mounting O-rings including cylindrical-surface seals.[5,6] Figure2 showed values obtained by experiment to measure New Rubberflon's sticking strength. Figure3 showed values obtained by experiment to measure friction coefficient.

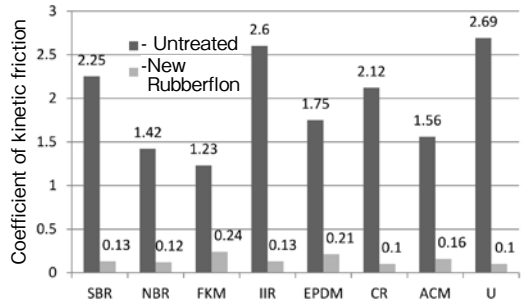
The treatment of O-rings with New Rubberflon is expected to provide the following benefits:

- Prevention of sticking between O-rings
- Prevention of sticking to the opposing face
- Improvement in fit of O-rings (greaseless)
- Prevention of twisting and damage in O-rings



Test method: tack testing device
The strength required to detach the probe from the test pieces, after being in contact under certain conditions, is measured.
Test piece: acrylic rubber sheet of 2 mm thickness; weight: 100 gf; probe: stainless probe, Φ 5 mm; velocity of probe removal: 600 mm/min

Figure2 Sticking strength of a rubber treated with New Rubberflon



Test method: ball indenter test, testing velocity: 60 mm/min
Test piece: rubber sheet of 2 mm thickness, weight: 200 gf, ball indenter: SUS Φ 6
SBR: styrene-butadiene rubber; NBR: nitrile rubber;
FKM: fluorocarbon rubber; IIR: isobutylene-isoprene rubber;
EPDM: ethylene propylene rubber; CR: polychloroprene rubber;
ACM: acrylic rubber; U: polyurethane rubber

Figure3 Coefficient of dynamic friction of a rubber treated with New Rubberflon

5. D2370, a Non-adhesive Fluororubber

Fluororubber has excellent heat and chemical resistance, and so is used in a broad range of industries. Generally, fluorine is considered to be an adhesion-resistant, slippery material. However, contrary to expectations, fluororubber often sticks to the opposing face, and so is not an adhesion-resistant material.

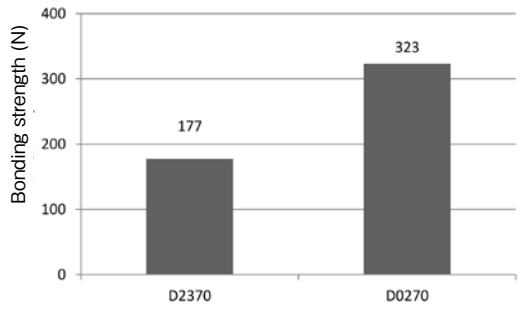
D2370 was developed using our unique compounding technique. The product reduces sticking while maintaining the characteristics of conventional fluororubbers including heat resistance and physical properties.

Table1 showed the physical properties of D2370, and Figure4 showed its sticking strength measured by experiment.

Table1 List of physical properties of D2370 (a non-adhesive fluororubber)

	D2370 Non-adhesive fluorocarbon rubber	D0270 Standard Valqua fluorocarbon rubber
Hardness (Shore A)	70	71
Tensile strength (MPa)	14.0	13.9
Stretch (%)	190	230
Compressed permanent deformation rate (%)*)	14	16

*) 200° C/70 hours, 25% compression, Φ 29 mm disc
The values in the table are observed values, not standard values.



Test method: The test piece was placed in contact with the counterpart under certain conditions and cooled in an ambient environment for 4 hours, then the strength required to detach the counterpart from the test pieces is measured.
Test piece: rubber sheet of 2 mm thickness; contact pressure: 5.88 MPa; heating conditions: at 120℃ for 20 hours
Counterpart: ring-shaped SUS 304 of Φ 25 x Φ 19; detaching velocity: 50 mm/min

Figure4 Sticking strength of D2370 measured by experiment

D2370 can be used as an alternative to common fluororubber in various valves which use a common fluororubber O-ring including for door seals and gate valve seals. We consider that D2370 can reduce operational malfunctions at opening and closing points by decreasing sticking strength of seal materials. In addition, the product is expected to prevent sticking to the opposing face including flanges.

6. Conclusion

This report explained sticking factors and methods for preventing the sticking of O-rings, and introduced our sticking-prevention products.

In the case of static seal products, sticking is one of important factor which affects maintenance seriously. However, there also are cases where sealing properties are sometimes retained and extended because of the sticking characteristics of O-rings in site of beyond limitation for sealing by permanent deformation of O-ring. In such cases, prevention sticking might not an only way to solve problems but also prevention methods while considering various operating conditions were required.

Also, various factors including the usage environment and conditions affect sticking, so it is difficult to solve sticking problems only with seal materials. Therefore, it is important to precisely identify the conditions in which O-rings are used.

We welcome feedback and honest opinions from users, to help us make full use of the characteristics of rubber materials, develop high-value-added products, and introduce new products.

7. References

1) Mori, K. et al., *Journal of the Society of Rubber Science and Technology*, Vol. 60, 7th issue, 1987
2) *Handbook for the Rubber Industry*, 4th ed., Society of Rubber Science and Technology, Japan, 1994
3) Mori, K. et al., *Journal of the Society of Rubber Science and Technology*, Vol. 60, 4th issue, 1987
4) Sagan I., *Valqua Review*, Vol. 38, 8th issue, 1994
5) Sagan I., Okazaki, M., *Valqua Review*, Vol. 41, 1st issue, 1997
6) Sagan I., *Tribology*, March 1998

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