



O-Rings: An Effective, Simple and Versatile Sealing Solution

Jeffrey A. Jansen

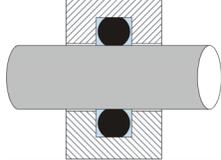
“With the substantial changes that have taken place in engineering, design, and manufacturing over the past 120 years, O-rings have essentially remained unchanged in form and function.”



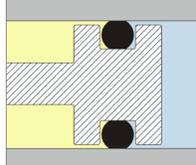
Function

O-rings function as a means of sealing, essentially closing off a passageway to prevent the escape or loss of a fluid, either a liquid or a gas. An O-ring is a circular ring, typically manufactured from an elastomeric material, with a circular cross-section. The seal is established by placing the O-ring into a cavity, known as a gland. The gland acts to compress the O-ring, and produces a zero-clearance condition, which effectively blocks the flow of the fluid. The sealing effect is produced through axial or radial compression of

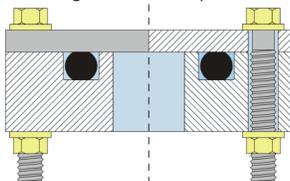
Rod Seal: Female gland
O-ring with radial compression



Piston Seal: Male gland
O-ring with radial compression



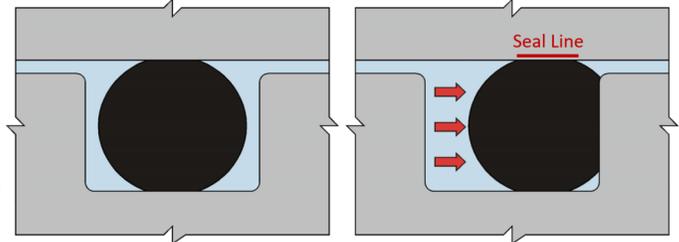
Face Seal:
O-ring with axial compression



Schematics showing the three fundamental types of seal designs, based upon sealing force direction and gland orientation.

radial compression, it is considered a rod seal. When a male gland is cut in the inside of the machine part such that the O-ring is an outer diameter seal using radial compression, it is categorized as a piston seal. When the seal utilizes

the O-ring. In order to seal reliably, a continuous “seal line” must be formed at the interface between the O-ring and the mating gland surface. The creation of this “seal line” is a result of a



Schematic showing how an O-ring seals in the gland. The O-ring deforms as a response to pressure to create the seal line.

combination of the gland design, the O-ring cross-section, and the proper level of compression of the elastomeric material. Elastomeric O-rings function unlike most of the material systems that engineers work with; in that it must deform significantly to achieve proper function.

The use of O-rings affords designers a wide variety of sealing design options. O-rings can be utilized in both static situations in which there is no movement between the mating parts, and in dynamic applications where the machine parts move relative to one another.

There are three basic sealing designs used that utilize O-rings: a rod seal, a piston seal, and a face seal. When a female gland is cut in the inside of the machine part such that the O-ring is an inner diameter seal using

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axial compression, it is regarded as a face seal. Within each of these designs, considering both static and dynamic applications, there are numerous design alternatives to affect the optimum seal for the application.

Failure of an O-ring is typically manifested as leakage of the fluid that was designed to be sealed. In order to achieve an adequate O-ring seal initially, as well as maintain that seal effectively over a satisfactory service life, it is important to:

- Follow proper gland design principles which allow for proper displacement under compression and a suitable tolerance stack up.
- Utilize the proper size O-ring for the application and design.
- Select the appropriate O-ring material based upon anticipated mechanical, thermal, and chemical exposure.
- Perform pre-production simulation and actual testing to verify performance.
- Follow accepted assembly practices for the installation of the O-ring.

Failure Modes

In general, O-ring seals are considered to be particularly reliable due to the simplicity of the O-ring/gland design and overall material resilience. However, under a number of circumstances failure can occur. O-ring failure can range from minor leakage to catastrophic equipment breakdown. Regardless of the magnitude, an O-ring failure can be diagnosed through proper visual and analytical techniques. Common O-ring failure modes include:

- Excessive Compression Set
- Explosive Decompression
- Installation Damage
- Abrasion
- Spiral Twisting
- Thermal Degradation
- Chemical Effects
- Over Compression

When an O-ring fails prematurely it is usually the result of a combination of factors, and not attributable to a single cause. As with any failure, there are factors that govern performance. Specific to O-rings, there are a number of potential issues under each of these factors:

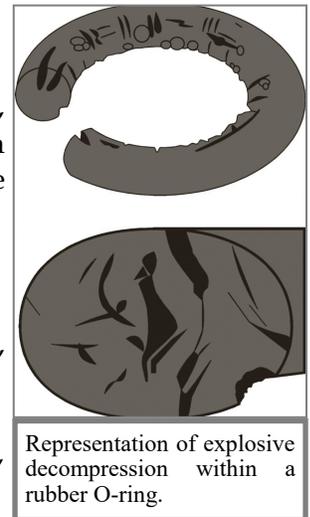
Design: Inadequate gland design, improperly sized O-ring

Material: Poor O-ring material selection based upon anticipated service conditions

Manufacturing: O-ring rubber undercure, premature cure, excessive parting line, material voids or inclusions

Assembly: Insertion resulting in O-ring twisting or tearing

Service Conditions: Excessive thermal exposure, extreme applied stress or pressure, unanticipated exposure to aggressive chemical agents



There are a number of key attributes that will significantly affect the performance of an O-ring seal application. The quality of the short-term sealing properties and the long-term durability and failure avoidance of an O-ring system is based upon these elements.

Stretch

To provide an effective seal, the O-ring's inside diameter must be smaller than the mating component's diameter, so that the O-ring is slightly stretched and fits snugly. The stretch should be between 1% and 5%, with 2% to 3% as the ideal in most applications. When an O-ring is stretched, its cross-section is reduced and flattened. An assembled stretch greater than 5% is not recommended because the internal stress on the O-ring causes more rapid aging and shorten the life of most O-ring materials. On the other hand, insufficient stretch

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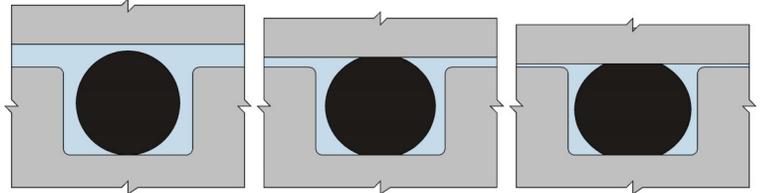
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Stretch (cont.)

will result in a loose fit and in an increased likelihood of leakage.

Squeeze

The squeeze of an O-ring is defined as the compressive reduction in cross-sectional thickness as a result of deflection caused by the gland configuration. The tendency of an O-ring to attempt to return to its original uncompressed shape when the cross-section is deflected is the basic reason why O-rings make such excellent seals. Because of this, squeeze is a major consideration in O-ring seal design. The squeeze is determined by the geometry of the gland and the O-ring cross-section. This represents the cross-section diametral compression of the O-ring between the surface of the groove bottom and the surface of the other mating part in the gland assembly.



When used as a static seal, the maximum recommended squeeze for most elastomers is 30%. There is a danger in squeezing more than 30% since the extra stress induced may contribute to premature seal deterioration. The minimum squeeze for all seals, regardless of cross-section should be about 0.2 mm. Insufficient squeeze may cause O-ring leakage, so most applications cannot perform acceptably at a “no” or zero squeeze condition.

Gland Fill

Gland fill is the percentage of the gland volume that an O-ring cross-section displaces as confined inside the gland in the installed state. Together, the cross-section of the O-ring and the size of the gland determine the gland fill. Most O-ring seal applications call for a gland fill of between 60% to 85% of the available volume, with the optimal fill typically being 75%, representing 25% void space. It is essential to allow at least a 10% void in any elastomer sealing gland. This ensures the O-ring will not be over-stressed, and will conform to the shape needed to create a seal.

Surface Finish

It is generally recommended that a surface roughness value not exceed 32 micro-inches (32 rms) on sealing surfaces for static seals. This would mean the surface of the interior of the gland. Also important, is the type of roughness and the presence of continuous irregularities. Scratches and ridges that cut across the O-ring can cause a leak path, as the O-ring may not adequately penetrate and seal these surface irregularities.

Assembly

Assembly must be done with great care so that the O-ring is properly placed in the groove, and is not damaged as the gland assembly is closed. One important aspect of this is the inner diameter expansion needed to reach the groove during the assembly. This expansion should not exceed 50% of the ultimate elongation of the chosen O-ring rubber compound.

Also, it is important that the O-ring should not be twisted during assembly. This can produce excessive stress on the O-ring elastomer. Further, the O-rings should never be forced over unprotected sharp corners, threads, slots, splines, ports, or other sharp edges. Closure of the gland assembly should not result in pinching of the O-ring at the groove corners. Gland closure should be accomplished by straight longitudinal movement. Rotary or oscillatory motion is undesirable since it may cause bunching, misalignment, and pinching or cutting of the seal.

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O-Ring Material

In choosing an O-ring material it is important to consider several factors, primarily the applied pressure, the temperature range over which the seal will operate, and the chemical fluid to be sealed. Typically, balancing the numerous requirements placed on an O-ring can be difficult and result in a best-case compromise. Most of the materials used for O-ring applications are elastomeric, with thermoset rubber compounds and thermoplastic elastomers based on block copolymers being most common. One of the advantages of designing with O-rings is that they can be manufactured from a wide range of elastomeric materials to provide a functional and durable sealing system. Often, the number and variety of material selection criteria are often overlooked by system designers, which can lead to premature failure. In choosing the proper O-ring material, attention must be paid to the following considerations and material characteristics:

- Chemical compatibility
- Thermal resistance and degradation
- Cold temperature resilience
- Abrasion and wear resistance
- Compression set and tension set
- Stress relaxation
- Tear resistance
- Coefficient of thermal expansion
- Compressibility and compression modulus

Too often, O-ring material selection is made based upon durometer hardness alone, which can be a poor predictor of the short-term and long-term mechanical properties of elastomeric material.

Another area of potential concern is when O-rings are used in conjunction with plastic components. Elastomeric materials, especially rubbers, are often compounded with a significant amount of plasticizer and oil. Such oils, particularly ester-based oils including phthalates, adipates, trimellitates, can act as particularly aggressive environmental stress crack (ESC) agents.

O-Ring Quality

The quality of the O-ring will have a relatively large effect on the overall performance of the sealing system. This includes the proper mixing of the rubber compound and the consistent molding of the O-ring. Rubber properties, such as compression set, modulus, hardness, and tensile strength will all be directly affected by the mixing and molding operations. It is important that good consistency be achieved. Additionally, there are recommendations on the acceptable level of flash at the parting line. This is typically 0.005 in. wide and 0.003 in. tall. Additionally, the O-ring should exhibit a maximum eccentricity of 0.05 mm.

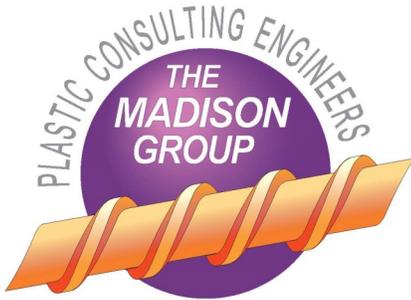


Conclusion

O-rings can be considered to be old technology in regard to the design and manufacturing of components and assemblies. Their design and function are relatively simple, and they have been utilized as seals since the early 19th century. However, it is their simplicity that accounts for the efficient way in which they function in sealing applications. With the substantial changes that have taken place in engineering, design, and manufacturing over the past 120 years, O-rings have essentially remained unchanged in form and function. O-rings have been and remain to be a simple, yet effective and versatile sealing solution.

Additional case studies can also be found at:
<https://www.madisongroup.com/case-studies.html>

COVID-19



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March 27, 2020

Dear Valued Clients and Partners,

With the global challenges we are all experiencing with the COVID-19 pandemic, The Madison Group remains committed to the health, safety and well-being of our employees, clients and partners. Our thoughts and prayers are with those affected by the pandemic and especially those working on the front lines to provide critical care and support to the victims.

During this unprecedented series of events, **our facilities remain open** to assist in the battle against this global pandemic. We have taken internal measures to ensure the health and safety of our employees as we continue to provide the same high-quality and responsive services our customers and partners have come to expect. We also have a host of virtual capabilities that allow our employees to conduct work remotely and have procedures in place to enhance cleaning procedures and comply with social distancing requirements while in our facilities.

The Madison Group has the unique privilege and responsibility to help make an impact in the global fight against the COVID-19 pandemic. We will continue to provide the high-quality material testing, manufacturing services and design/failure analyses as supply-chain partners with the key healthcare, pharmaceutical, medical, transportation, energy, communications, food and agriculture, chemical manufacturing and defense base industries in the continuation of critical infrastructure endeavors. Rest assured, The Madison Group remains committed to serving our valued clients in a safe and responsive manner during these trying times.

During this critical time, The Madison Group also pledges it will strive to expedite its supply-chain products and services for these critical industries with no additional fees or surcharges. The global challenges we all face demand cooperation to make a difference in winning the battle against this pandemic.

Thank you for your continued partnership with The Madison Group and please contact either of us if you have any questions or concerns.

Best Regards,

Paul Gramann, Ph.D.
President

Bruce Davis, Ph.D.
CEO

Announcements

Welcome – New Addition to The Madison Group Team

Paul J. Gramann

The Madison Group is proud to announce the hiring of **Melissa Kurtz**, M.S., as a Managing Engineer. She brings 20+ years of experience in material science and engineering that are deeply rooted in product development, advanced testing, and manufacturing support. She has performed hundreds of failure analysis investigations on a wide variety of products and applications across multiple industries including, transportation, medical, and consumer. These learnings compiled over many years have revealed vulnerable areas within the product development cycle including identifying part requirements, performing material selection along with developing part validation testing. Melissa has extensive experience with supporting clients in their relationships with manufacturing partners. This support includes, but is not limited to, root cause analysis of processing issues, development of quality assurance tests, along with cost saving initiatives.



Melissa received her M.S. in Material Science and Engineering from Wayne State University and her B.S. in Material Science and Engineering from the University of Minnesota - Twin Cities. She is a long-standing member of Society of Plastics Engineers and Society of Women in Engineering as well as a leader of her daughter's Girl Scout Troop.

Training



Training Topics

- Failure Analysis
- Plastic Material Selection
- Plastic Part Design
- Moldflow
- Other



If you are interested to have **The Madison Group** provide training to your team, please feel free to contact us at info@madisongroup.com.

Upcoming Educational Webinars

Webinars provide a cost-effective way to expand your knowledge of plastics.

Below is a list of the upcoming webinars presented by TMG Engineers:

Thursday, May 14, 2020 - Jeffrey A. Jansen – Society of Plastics Engineers



Plastic Failures Associated With Metal Fasteners

10:00 AM (CST)

The need to secure plastic components is prevalent in the manufacture of assemblies in many industries. Joining plastic components to other plastic parts or metal parts often involves the use of mechanical fasteners, such as screws, inserts, or rivets. The joining of plastic parts is inherently more complicated than assembling two metal components because of the fundamental differences in physical properties, including strength, chemical resistance and susceptibility to creep and stress relaxation. Case Studies will be presented to illustrate failures associated with the interaction between plastic components and metal fasteners. The presented cases will illustrate how the failure analysis process was used to identify the failure mechanism as well as the primary factors responsible for the failures. The cases depict representative failures involving varied designs and service conditions.

Click [here](#) to register.

Thursday, June 11, 2020 – Jeffrey A. Jansen – Society of Plastics Engineers



The Effects of Impact Loading Mechanisms on Plastics

10:00 AM (CST)

While in service, plastic materials are subjected to many different types of mechanical stress. One common type of stress that is typically severe on plastics is rapid impact loading. The rate at which loading is applied, otherwise known as the strain rate, is a very important factor in the performance of a plastic component. Impact, together with snap fit assembly, and rapid pressurization are the most common forms of rapid loading or high strain rate mechanisms.

The response of plastics to impact and the ability of a plastic part to withstand the stress through absorption of the applied energy is dependent on many aspects, including the material, design, processing and the service conditions.

Topics covered as part of this presentation will include:

- Failure Mechanism of Plastics
- Strain Rate as a Ductile-to-Brittle Transition
- Impact Failure
- Factors Effecting Impact Resistance
- Impact Testing
- Case Studies

Impact loads are among the most challenging stresses that plastic component designers and manufacturers must deal with. In many cases impact stress is not adequately accounted for. In many cases this leads to unnecessary, premature or unexpected failures.

Click [here](#) to register.

Information regarding upcoming educational opportunities can also be found at:

<http://www.madisongroup.com/events.html>

Upcoming Educational Webinars (cont.)

Wednesday, June 17, 2020 – Jeffrey A. Jansen - SpecialChem
Using FTIR for Identification and Evaluation of Plastics
 9:00 AM (CST)



Possessing an understanding of FTIR will allow participants to more efficiently and effectively use the technique in the analysis of polymeric materials, whether directly or through testing laboratories. The course will cover the applications of FTIR and explain the strengths and weaknesses of this analytical method.

The course will focus on:

- Understanding what information FTIR can provide in the analysis of polymeric materials in order to maximize polymer problem solving evaluations.
- Appreciating what other analytical techniques provide complementary information to get the most out of polymer analysis.
- Recognizing the challenges of sample preparation and how to overcome these obstacles to get optimal results.
- Comprehending how to interpret the spectral data generated through FTIR analysis to get the most out of the results.
- Presenting the basic theory behind FTIR analysis so that the obtained results can be better understood.

Having a thorough knowledge of FTIR analysis will allow scientists and engineers using FTIR spectral data, to better understand the results and apply the data to problem solving and material investigations. This includes quality control material analysis, failure analysis, and reverse engineering material characterization.

Friday, August 28, 2020 – Jeffrey A. Jansen - SpecialChem
Nylon Selection in Demanding Applications: How to Avoid Failure
 9:00 AM (CST)



Polyamide (nylon) is a generic designation for a family of synthetic thermoplastics, based on aliphatic or semi-aromatic polymers with amide functionality. Polyamides can be mixed with a wide variety of additives, fillers, and reinforcers to achieve many different properties. Many different types of polyamide resins are available commercially based upon the monomers used in the polymerization process. **These include:**

- Nylon 6
- Nylon 6/6
- Nylon 11
- Nylon 12
- Nylon 4/6
- Nylon 6/12
- Polyphthalamide
- Polyarylamide

Attendees will gain an understanding of the performance properties of polyamide resins, including how and where they can be used effectively. By understanding the critical performance characteristics of polyamides, attendees can make smart decisions on when polyamides are suitable for an application, and which type would be most appropriate. Recognizing the strengths and weaknesses of this important class of material will help to avoid failures.

In order to effectively design, produce, and utilize products made from polyamides, it is essential to thoroughly understand the nature of this material, including the mechanical, thermal, and chemical properties. This webinar will differentiate between the various types of polyamides, illustrating the advantages and disadvantages over other materials. Information will be discussed to allow the attendees to select between the various types, and which type may be the most beneficial for a particular application.

While the structure of polyamide is relatively straightforward, and it is often viewed as a basic resin, polyamides are used in many highly engineered and demanding applications. In order to do this, however, there must be a thorough understanding of the material.

Information regarding upcoming educational opportunities can also be found at:

<http://www.madisongroup.com/events.html>

Announcements

TMG – Industry News



New Moldflow Training Courses

Learn ways to utilize Moldflow technology in your manufacturing processes.

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PLASTIC CONSULTING ENGINEERS
THE MADISON GROUP

DS TECHNOLOGIES

The Madison Group is excited to offer our training for all Autodesk Moldflow products, both Insight and Advisor.

The need for optimizing our plastic part designs, processes and mold designs prior to first shots, is more critical than ever. Autodesk Moldflow has multiple products to help assist and optimize your project at any stage. Whether you are a part designer that is interested in better understanding your externally provided Moldflow reports, a user that is looking to take full advantage of the tools you already have, or explore what additional tools are available to take you to the next level, we have a training package that can help you accomplish just that.

The Madison Group has a training plan option for any circumstance and budget. **Choose any of the following options:**

- **On-site Training**
- **Remote Instructor-Led Training**
- **Private Training**

Benefits of Virtual Training Sessions:

- Allow any of your employees to gain the training without being out of the office.
- Eliminate travel costs so you can have more employees trained.
- Choose interactive, live, instructor-led classes for one-on-one assistance with solver set-up and results interpretation.
- Installation of software not needed prior to training opportunities.

Benefits of Investing in Moldflow Training

- Keep up to date on the newest solvers and simulation tools for all the Autodesk Moldflow Products designed to save you time.
- Improve your results interpretation skills and help optimize your design.
- Increase your internal knowledge quickly and economically to improve communication and create a culture of innovation.
- Explore additional simulation capabilities to improve overall customer satisfaction.

Find a listing of all of our Upcoming Training Sessions [here](#).