

An Experimental Investigation of Silicone-to-Metal Bond Strength in Composite Space Docking System Seals

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Abstract

The National Aeronautics and Space Administration (NASA) is currently developing a new universal docking mechanism for future space exploration missions called the Low Impact Docking System (LIDS). A candidate LIDS main interface seal design is a composite assembly of silicone elastomer seals vacuum molded into grooves in an electroless nickel plated aluminum retainer. The strength of the silicone-to-metal bond is a critical consideration for the new system, especially due to the presence of small areas of disbond created during the molding process. In the work presented herein, seal-to-retainer bonds of subscale seal specimens with different sizes of intentional disbond were destructively tensile tested. Nominal specimens without intentional disbonds were also tested. Tension was applied either uniformly on the entire seal circumference or locally in one short circumferential length. Bond failure due to uniform tension produced a wide scatter of observable failure modes and measured load-displacement behaviors. Although the preferable failure mode for the seal-to-retainer bond is cohesive failure of the elastomer material, the dominant observed failure mode under the uniform loading condition was found to be the less desirable adhesive failure of the bond in question. The uniform tension case results did not show a correlation between disbond size and bond strength. Localized tension was found to produce failure either as immediate tearing of the elastomer material outside the bond region or as complete peel-out of the seal in one piece. The obtained results represent a valuable benchmark for comparison in the future between adhesion loads under various separation conditions and composite seal bond strength.

Nomenclature

<i>CEV</i>	Crew Exploration Vehicle
<i>GRC</i>	Glenn Research Center
<i>LIDS</i>	Low Impact Docking System
<i>LSAM</i>	Lunar Surface Access Module
<i>NASA</i>	National Aeronautics and Space Administration
<i>AS</i>	Adhesive failure at Seal-to-retainer bond
<i>CS</i>	Cohesive failure in Seal at seal-to-retainer bond
<i>M</i>	Material failure
<i>CRR</i>	Cohesive failure at RTV-to-seal bond in RTV
<i>CRS</i>	Cohesive failure at RTV-to-seal bond in Seal

I. Introduction

The National Aeronautics and Space Administration (NASA) is currently developing a universal next-generation docking system to meet the demands of the Constellation program. The Low Impact Docking System (LIDS)¹ design, shown in Figure 1, uses an extendable load-sensing electromagnetic capture ring and closed-loop feedback control to join two round docking interfaces at the periphery, allowing cargo and crew passage through the tunnel that is formed. During the mating of two vehicles, each equipped with a LIDS interface, one side assumes an active role and the other a passive role. The active LIDS extends its capture ring and attaches to the opposing passive unit. After a “soft” electromagnetic capture is achieved, the interface is aligned with a system of actuator arms, and then is retracted. At this point, the pressure seals are compressed, structural attachments are made, and the docking process is completed. This sequence decreases the necessary contact velocity as compared to other docking systems currently in use² and thus decreases the risk of collision, undesired vibrations to sensitive onboard equipment, and vehicle course alterations.

The LIDS must be able to withstand multiple docking and undocking cycles on orbit in order to support the exploration mission scenarios planned for the Constellation program. For example, the lunar mission scenario requires docking the Orion Crew Exploration Vehicle (CEV) with the Lunar Surface Access Module (LSAM) in Earth orbit, undocking the crafts in lunar orbit to allow descent and landing with the LSAM, and finally, re-docking in lunar orbit to allow crew return to Earth in the CEV.³ The operational requirements of the LIDS introduce the need for sophisticated components at all levels of the system.

The successful operation of the LIDS requires an advanced sealing system at the mating interface to prevent the loss of breathable cabin air to vacuum. The LIDS main interface seal is being developed at NASA Glenn Research Center (GRC) in Cleveland, OH. A key design challenge for the main interface seal is its operating environment, which includes prolonged exposure to atomic oxygen, ultraviolet and ionizing radiation, vacuum pressure, and potential micrometeoroid and orbital debris impact damage, as well as an expected exposure temperature range of -100°C to 125°C . In addition, NASA requires that all spacecraft materials exposed to hard vacuum meet low-outgas requirements,⁴ as liberated material can condense on other external objects and affect their functionality. The operating environment and the low-outgas requirements have led to the selection of the silicone elastomer S0383-70 manufactured by Parker Haniffin Corporation as a candidate material for use in the LIDS main interface seal. This particular material has been found to meet the low-outgas requirements, as well as exhibit desired behaviors when tested in subscale seal configurations exposed to simulated space environment conditions.⁵⁻⁸

Upon undocking, the rigid latches securing the interface are released and spring-loaded mechanisms provide a separation force. It is critical that the seal material is not dislodged during this maneuver, as this could liberate orbital debris and damage the seal, potentially impairing sealing ability and redundancy. Seal fragments could also be left behind on the mating flange, disabling the docking port. Quantifying the amount of separation force required to undock the seal from its flat metal mating surface is a part of ongoing research.⁶ The S0383-70 compound has been found to develop considerable adhesion when compressed against a flat metal surface,^{7,8} thus introducing the possibility that the seal-to-retainer bond of the composite seal might fail before the seal detaches from the flat metal mating surface at the interface.

The objective of the work presented herein was to quantify the strength of the silicone-to-metal bond in the candidate composite seal assembly design. In particular, the objective of this work was to determine the amount of force required to extract molded-in-place silicone elastomer seals from their grooves in the retainer. Moreover, the observed bond failure modes were examined to provide a thorough understanding of the extraction behavior. The presented data was acquired from tests on individual seals of subscale (12 inch diameter) seal assemblies at ambient conditions. Results of tests on seal assembly specimens fabricated using nominal procedures, as well as specimens fabricated with three levels of intentional flaw (i.e. disbond) are reported.

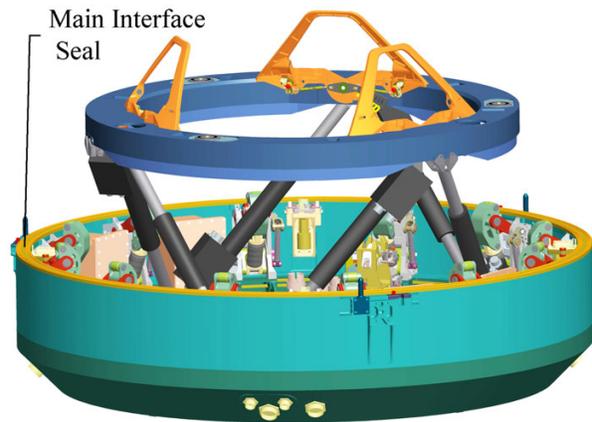


Figure 1. Illustration of the active LIDS

II. Description and Methodology of the Experiments

A. Test Specimens

The test specimens were custom designed seal assemblies manufactured by the Composite Sealing Systems Division at Parker Hannifin Corporation. The test specimens considered herein were manufactured according to a candidate Gask-O-SealTM design with multiple elastomer seals molded into an aluminum retainer, as shown in Figure 2. The upper portion of the seal assembly consists of a primary (inner) seal and a redundant (outer) seal, providing single fault tolerance.

The seals were made of S0383-70 silicone elastomer compound. The 6061-T651 aluminum retainer of the seal assembly had an outside diameter of 12.0 inches. The expected outside diameter of the full-scale LIDS interface seal is currently 58 inches.

In the nominal fabrication process for the seal assembly, the metal retainer is machined and electroless nickel plated, after which a priming agent is applied to the groove surfaces prior to silicone vacuum-molding. Once the silicone cures in place in the grooves, it is permanently bonded to the retainer. Unintentional localized disbond occurs where the silicone separates from the metal, as seen in Figures 3 and 4.

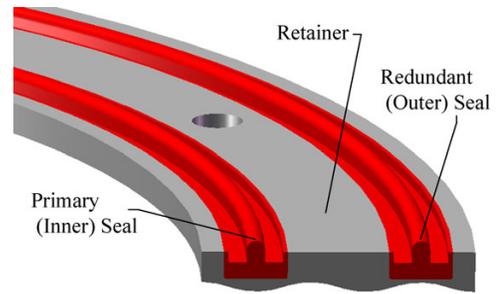


Figure 2. Illustration of the upper portion of a test specimen cross section showing two elastomer seals in grooves in an electroless nickel plated aluminum retainer.

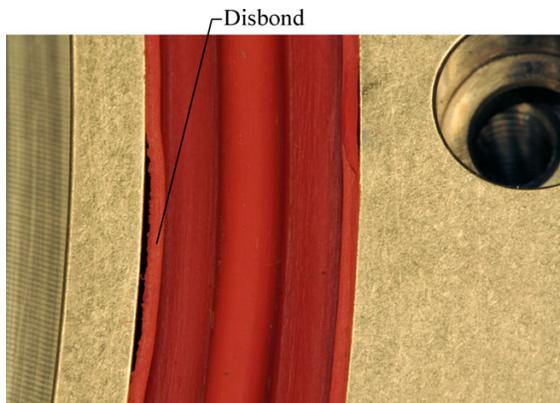


Figure 3. Photograph of unintentional localized disbond at an arbitrary location.

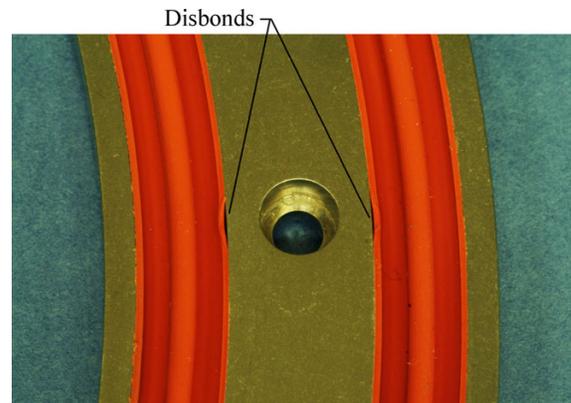


Figure 4. Photograph of unintentional disbond occurring at bolt hole locations due to molding process.

Two different kinds of test specimens were fabricated for this study: nominal and intentionally flawed. The nominal test specimens were manufactured using standard processes expected to take place during the full-scale seal assembly fabrication. The intentionally flawed test specimens were fabricated with a controlled flaw (i.e. disbond) in the seal-to-retainer bond of both seals by masking a specified length of the retainer grooves when applying the priming agent prior to the molding process. Three levels of intentional flaw, along with the nominal configuration, were considered. The lengths of the intentional disbands in the received test specimens are summarized in Table 1. It should be noted that the molding process typically produces some level of disbond visible at the edge of the groove on the side wall, as was shown in Figure 4. Although unintentional disbond could occur at the bottom of the groove, it is very unlikely that a seal produced with the standard process would have both side walls and the entire groove bottom completely disbonded at the same circumferential location. For that reason, the test specimens manufactured with the intentional disbands represent a worst-case scenario of what might occur during seal assembly fabrication. In addition,

Table 1. Seal Specimen Types and Corresponding Circumferential Flaw Lengths

Specimen Type	Fabrication Process	Flaw Length, inch
A	Nominal	0
B1	Flawed	0.25
B2	Flawed	0.50
B3	Flawed	1.0

the disbond lengths in Table 1 have been shown to be detectable by nondestructive inspection techniques, with the maximum disbond length (1.0 inch) representing an extreme case that would most likely lead to part rejection.

B. Test Fixture Assembly

Custom steel rings were designed to allow “gripping” of the seals without actually pinching or squeezing the S0383-70 material. Different ring sizes were made so that only one seal, inner or outer, would be tested at a time. These rings were bonded to the top surface of the seal using a room temperature vulcanizing (RTV) silicone adhesive. The rings were designed to match the seal surface profile in order to maximize the area available for bonding with the RTV, as shown in Figure 5. The RTV was applied to the elastomer surface and the rings were placed onto the seals. The rings and the seal assembly were then fastened to identical 1.0 inch thick stainless steel platens and the RTV was cured for a period of approximately five days. A schematic of the resulting test fixture assembly is shown in Figure 6.

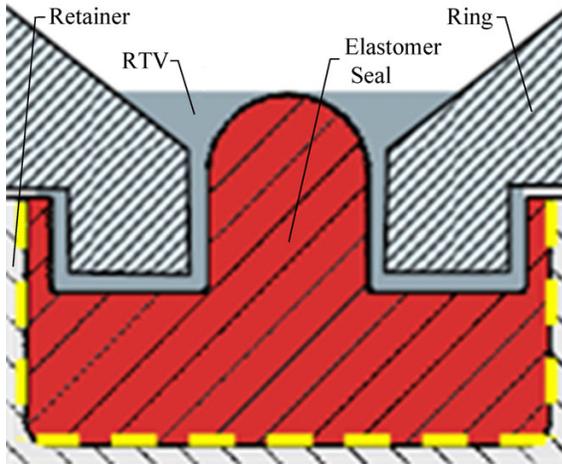


Figure 5. Section view of the test fixture used to maximize adhesive bonding area by matching the seal profile. The seal-to-retainer bond being tested is shown in dashed yellow lines.

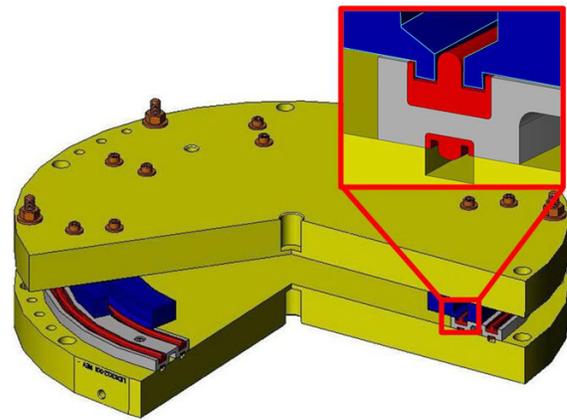


Figure 6. Illustration of the test fixture showing the seal specimen, rings (blue), and platens (yellow) with an inset view of the RTV interface.

The specimens were tested under two different loading scenarios: uniform tension and localized tension. In the uniform tension case, the RTV adhesive was applied to the entire seal circumference, therefore stressing the entire seal-to-retainer bond simultaneously. The localized tension case was considered to represent the worst-case scenario for the seal-to-retainer bond, where the RTV adhesive was applied only over a 1.0 inch circumferential length of the seal. For intentionally flawed specimens, the adhesive area coincided with the intentional disbond area.

C. Bond Strength Tensile Test System

The bond strength tensile tests were performed using an Instron 5584 electromechanical load frame. The frame was equipped with an alignment fixture for both angular and concentricity adjustments of the upper actuator rod with respect to the lower actuator rod. Load during separation was measured using a 33700 lbf capacity Instron 2525 – 171 load cell with an accuracy of 0.30% of the full range. A position encoder within the load frame was used to measure displacement of the crosshead to an accuracy of 0.001 inch. Sources for measurement uncertainty include linearity, repeatability, and hysteresis, as well as the off-axis nature of loading the circumference of the seal. The speed at which the platens were separated was a function of time simulating the expected LIDS undocking rate. The test fixture assembly was mounted in the load frame as shown in Figure 7.

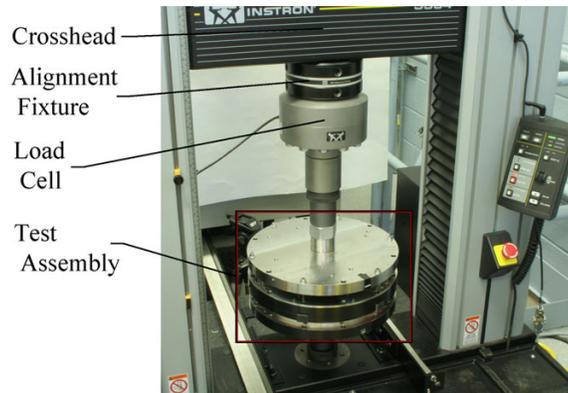


Figure 7. Photograph of the test specimen assembly mounted in the load frame.

D. Failure Mode Identification

Adhesion is defined as the attraction between two different substances because of the intermolecular forces between the materials.⁹ Cohesion, on the other hand, describes the attractive forces between molecules within a single substance.⁹ At a bonded interface of two different materials (in this case silicone elastomer and aluminum retainer), bond failure can occur in two distinct ways differentiated by location. Adhesive failure occurs in the interfacial layer between the bonded materials, indicating that the bond is the weaker intermolecular force. Cohesive failure occurs within one of the two materials but not at the interface itself. Cohesive failure is the desirable failure mode for an engineered bonded joint because it indicates that the bond achieved with a material is stronger than the material itself. Both cohesion and adhesion are dependant on local conditions, meaning some areas can fail cohesively and others adhesively on the same test specimen.

Five failure modes were defined in this study:

1. Adhesive failure at the molded seal-to-retainer bond (AS),
2. Cohesive failure in the S0383-70 at the molded seal-to-retainer bond (CS),
3. Material failure in the S0383-70 away from the surfaces (M),
4. Cohesive failure in the RTV adhesive at the top surface of the seal (CRR),
5. Cohesive failure in the S0383-70 at the top surface of the seal (CRS).

The adopted nomenclature is also shown in Figure 8 along with a schematic of a seal molded into a retainer at the bottom and attached to two rings at the top using RTV. All of the defined failure modes represented either adhesive or cohesive failure in a general sense. However, the area of failure had different implications for the LIDS main interface seal and thus they were differentiated for clarity. Careful selection of the RTV adhesive successfully eliminated two other possible failure modes: adhesive failure at the top surface of the seal and adhesive failure at the RTV-to-retainer bond. The relative strengths of the materials precluded any cohesive failure within the metal components.

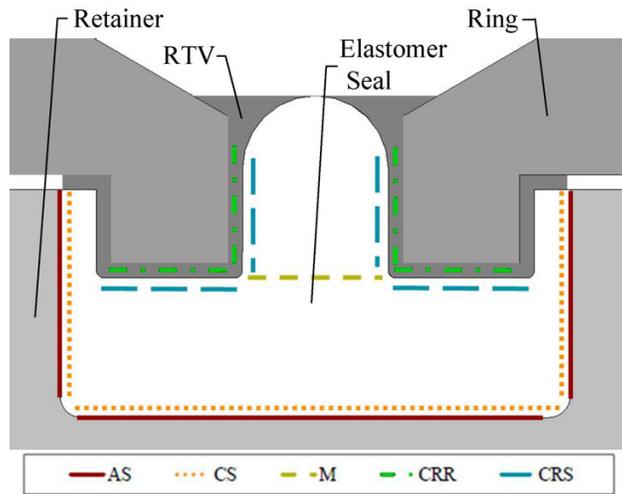


Figure 8. Schematic showing the location of the five failure modes observed.

III. Results and Discussion

Results of the seal-to-retainer bond strength tests are reported from quantitative and qualitative perspectives. The results are divided into the two loading cases: uniform tension and localized tension. Analysis of each of the cases includes both acquired data quantifying the bond strength and observations of the failure surfaces to determine the failure modes.

A. Uniform Tension Case

The uniform tension case was a simulation of an extreme adhesion load during separation due to prolonged contact between the S0383-70 material and a metal surface in the compressed (i.e. docked) state. In this case, as previously mentioned, the RTV adhesive was applied on the entire seal circumference, therefore stressing the entire seal-to-retainer bond simultaneously.

1. Failure Mode Characterization

Failure in the specimens tested in the uniform tension case occurred primarily at the seal-to-retainer bond, with the exception of one test where a majority of the RTV failed. In the event of RTV failure the information produced was the strength of the test adhesive, not the seal-to-retainer bond performance, and thus was treated as a minimum strength value of the seal-to-retainer bond.

Bonds are commonly given bond ratings which represent the percentage of bond area exhibiting each failure mode. A summary of bond ratings using the failure modes defined above is shown in Figure 9 for the uniform tension case specimens. The most dominant failure mode observed was adhesive failure of the seal-to-retainer bond (AS), notably on specimens which exhibited greater than 99% adhesive failure (Type B1 specimens). A representative area of the groove surface exhibiting adhesive failure (AS) is shown in Figure 10, where the retainer surface was clear of any seal residue. In addition to adhesive failure, all of the other failure modes were observed. During the Type A Inner 2 seal test, a majority of the RTV failed (CRR) and the specimen exhibited all five of the failure modes to some extent. This result highlighted the variability that is possible of the seal-to-retainer bond, even within a single seal specimen.

A representative image of significant cohesive failure (CS) in the bottom of the groove of a Type A specimen is shown in Figure 11. For this particular section of the seal, it was not immediately clear whether cohesive or adhesive failure was the dominant failure mode. The groove bottom was covered in S0383-70 residue in patterns along the circumference, possibly indicating that priming agent was brushed in this direction, leading to distributed spots of superior bond formation and resulting in cohesive failure. This observation suggests the sensitivity of bond quality to fabrication processes. To explore this failure in more detail, the surface was examined with an optical microscope. Under 63X magnification, areas which appeared to the naked eye as sparse spots of residue, were actually interspersed with fields of much smaller residue

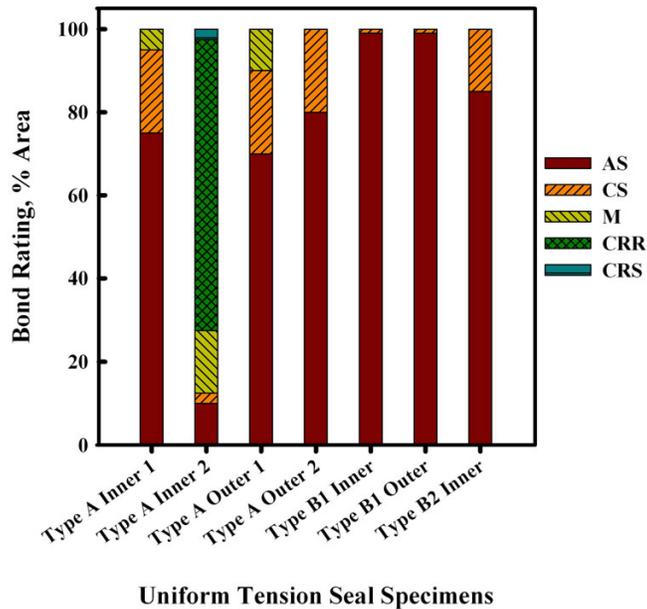


Figure 9. Bar chart summarizing the bond ratings of uniform tension case test specimens.

spots with size on the order of $100\mu\text{m}$ (Figure 12). This led to the observation that cohesive failure may be more prevalent than is visible with the naked eye. Specimens that failed in the adhesive (AS) were also examined under magnification to confirm the visual assessment as shown in Figure 10.



Figure 10. Photograph of a representative area showing exclusively adhesive failure i.e. the seal material is completely removed.



Figure 11. Photograph of a fracture surface showing significant cohesive failure, along with adhesive failure.

2. Failure Load Measurements

Representative load-displacement results of an inner and outer seal of a Type A specimen are shown in Figure 13. These particular test results produced the highest measured failure loads of the uniform tension test series, with the peak load of 4576 lbf for the outer seal and 3842 lbf for the inner seal. As seen in Figure 13, the load-displacement curves of the inner and outer seal tests agree closely until the point of failure in the inner seal test. In the first stage of the separation (approximately 0.030 inch) a linear relationship between load and deflection was observed. At the initiation of failure, a flattening of the curve is noted as small areas began to fail and could no longer carry the load. The first steep drop in load represents the initial bond failure in part of the seal and this peak load was the parameter of interest. A chart summarizing the peak measured load divided by the seal circumference for all specimens in the uniform tension case is shown in

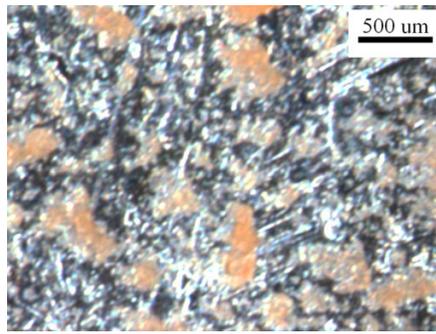


Figure 12. Optical micrograph of fracture surface under 63X magnification showing small spots of cohesive failure invisible to the naked eye.

Figure 14. The second steep drop indicates that most of the remaining bonded area had failed. The slightly downward slope in the final region indicates that the last remaining bonded section of the elastomer was stretching and/or tearing away from the retainer. The failure surface image shown in Figure 11 corresponds to the outer seal data shown in Figure 13.

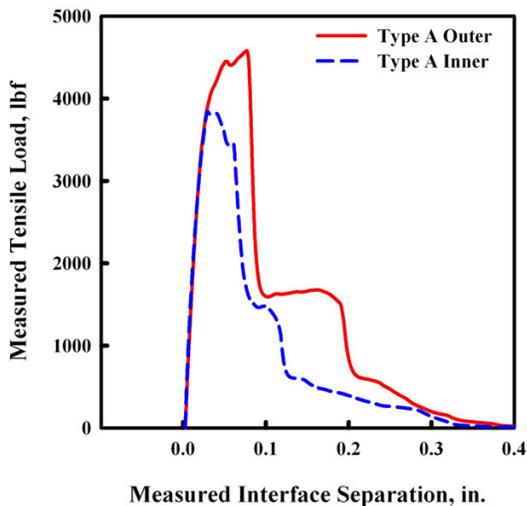


Figure 13. Graph of measured results for uniform tension case exhibiting significant cohesive failure.

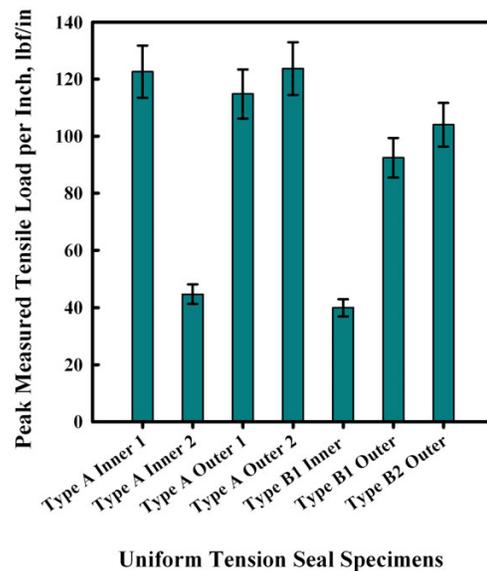


Figure 14. Bar chart representing failure load per circumferential inch of a single seal. The error bars indicate load measurement uncertainty.

Based on the peak measured tensile load values shown in Figure 14, there was no clear correlation between intentional flaw length and failure load. The two significantly lower values of Figure 14 can be explained by failure mode observations. The second Type A inner seal exhibited mostly RTV failure (CRR), and thus the seal-to-retainer bond had at least that level of strength. In the Type B1 Inner seal test a portion of the circumference initially failed at the RTV-to-seal interface (CRR and CRS), as shown in Figure 15, while most of the seal failed adhesively at the seal-to-retainer bond (AS). The subsequent separation removed the rest of the seal circumference in adhesive failure (AS). This partial RTV failure is characterized by a lower peak load measured, followed by a long and slow decline in the measured load as the remaining length of the seal peeled out. Aside from these lower values, there was no clear relationship between the failure load and the failure modes exhibited. The Type A seal specimens exhibited slightly higher load measurements and more cohesive failure (CS and M). However, the load to failure was not significantly different for seals with intentional flaws, though they exhibited more adhesive (AS) failure. It was originally anticipated that the intentional disbond location would be the initiation point of rapid peel-out of the seal.

It was assumed that, considering the mechanics of separation, the short section of disbanded seal would arc upward and begins to stretch as the interface separated until enough of the tension in the seal concentrated at the seal-to-retainer bond line to commence peel-out.

However, this behavior was not observed in the tests because failure initiated at a displacement less than that required for lifting and stretching the unbonded section of the seal. As a result, the initial bond failure occurred at an arbitrary location and not necessarily at the disbond. Therefore, there was not a stark difference in failure load values or bond ratings between Type A and Type B seals.

The uniform tension case led to the important observation that a bond which eventually fails adhesively can still be strong in terms of the load it can withstand before failure. This suggested that although the bond strength may be acceptable for the loads generated by the LIDS system, the dominant observed mode of failure may not be desirable.



Figure 15. Video frame of the initial partial RTV failure in a uniform tension case test leading to an altered load-displacement curve. The remaining bonded section was peeled out adhesively.

B. Localized Tension Case

The localized tension case can be viewed as the worst-case scenario for the seal-to-retainer bond as it represents increased localized seal adhesion coinciding precisely with an area of complete disbond. The potential for increased localized adhesion stems from surface contamination of the interface and material variation in the elastomer, which likely would be non-uniform on the surface. This introduces the possibility that some areas would be preferentially adhesive with the S0383-70 and therefore develop isolated higher adhesion loads.

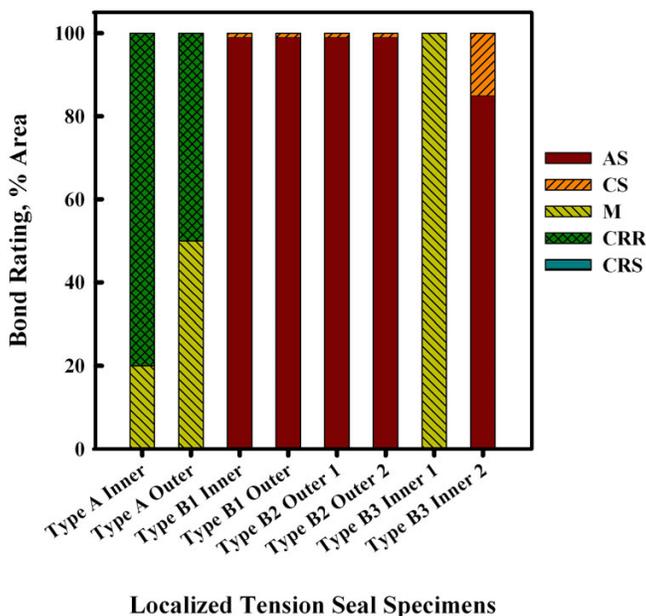


Figure 16. Bar chart summarizing the bond rating of localized tension case test specimens.

1. Failure Mode Characterization

A summary of the bond ratings for the localized tension case is presented in Figure 16. Five of the eight seals tested in this case produced predominantly adhesive failure (AS). The seals in this category detached

from the retainer by way of slow, steady peel-out (Figure 17) along the entire circumference, resulting in the complete removal of the seal in one piece as shown in Figure 18. The bottom of the grooves in these tests exhibited the same conditions as the adhesive failure mode exhibited by tests of the uniform tension case. Inspection of the groove side walls on several tests revealed small spots of apparent cohesive failure (CS) as well. The remaining three tests failed significantly within the S0383-70 material (M) rather than at

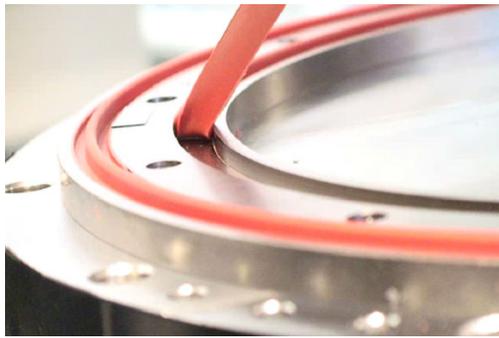


Figure 17. Video frame of an inner seal pull-out and peel from the retainer groove.



Figure 18. Photograph of the complete removal of the seal in one piece due to localized tension.

the seal-to-retainer bond. This was a more desirable failure mode than adhesive failure in the LIDS main interface seal as it prevents the seal from being loosely attached at only one point. The distinction between the material (M) and adhesive (AS) failure modes has important implications for the LIDS application. In a localized material failure, some fragments could be left behind on the mating surface after the failure. Upon a subsequent docking operation, it would be possible to achieve some level of seal, although the redundancy provided by the two seals would be lost. In a completely adhesive failure, where the entire seal peeled out of the groove (as was shown in Figure 18), it would most likely lie across the interface, preventing any kind of seal from being attainable.

Material failure in the localized tension case progressed along the top of the seal for a distance before release. A sequence of photographs detailing the material failure process is outlined in Figure 19. The failure shown in Figure 19 is analogous to the propagation of peel around the circumference, except that the failure occurred within the S0383-70 elastomer.

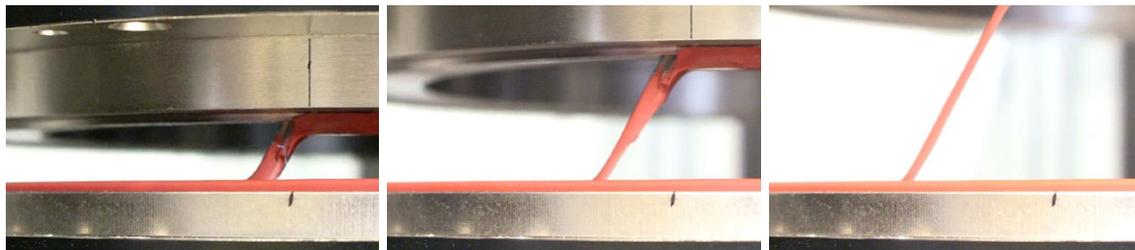


Figure 19. Video frame sequence showing the progressive material failure along the top of an inner seal. The reference mark on the lower platen shows the edge of the 1.0 inch disbond.

2. Failure Load Measurements

Representative load-displacement curves for Type B1 localized tension case specimens which failed adhesively (AS) are shown in Figure 20. Peel out of the seal began at a displacement of about 0.06 inches and continued at negligible peel loads until the entire seal circumference was extracted from the retainer groove. Complete extraction required nearly 15 inches of total displacement, but only the first inch is shown in Figure 20 for visual clarity. These results suggested that once peel had initiated, the seal was likely to be completely extracted from the groove.

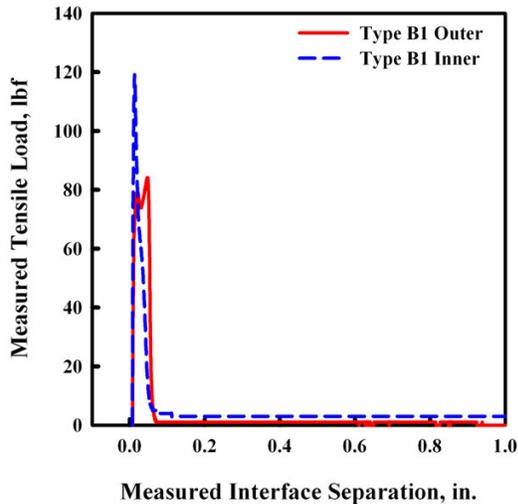


Figure 20. Graph of measured results for a localized tension case specimen exhibiting adhesive failure.

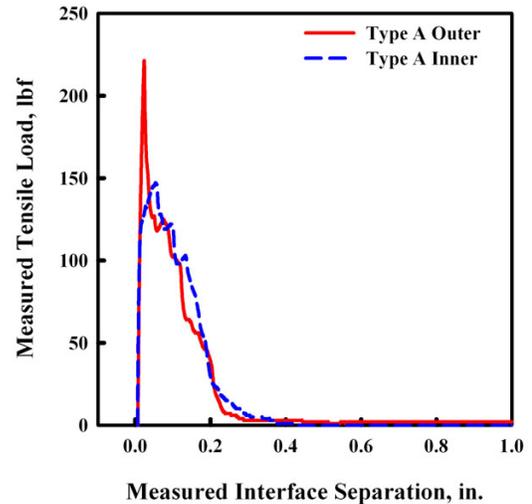


Figure 21. Graph of measured results for a localized tension case specimen exhibiting material failure.

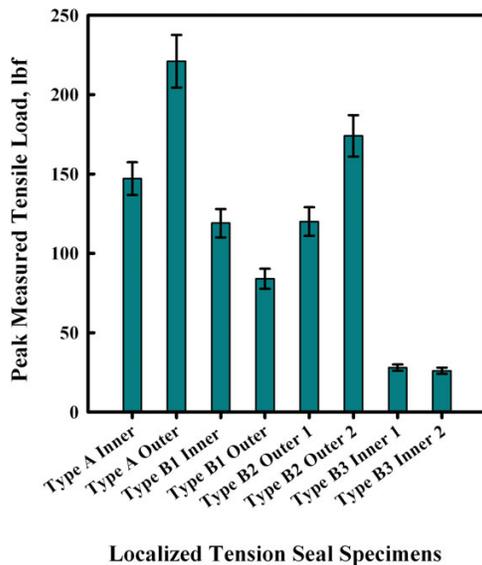


Figure 22. Bar chart representing failure loads measured during localized tension tests using 1.0 inch of RTV adhesive. The error bars indicate load measurement uncertainty.



Figure 23. Photograph of material failure of a test specimen with a 1.0 inch intentional flaw.

Results from two localized tension cases which demonstrated failure in the seal material (M) are plotted in Figure 21. The “sawtooth” pattern evident in both the inner and outer seal curves indicates start-stop failure. In other words, the failure progressed for a distance, then stalled until enough stress built up again to recommence the failure propagation. Figure 22 shows a summary of the peak loads measured in the localized tension case. An image of the surface of material failure is shown in Figure 23.

The Type A, B1, and B2 specimens resulted in peak measured load between approximately 75 and 225 lbf, but there is not a clear correlation between disbond length and peak measured load. However, the Type B3 specimens are both less than 30 lbf due to the fact that only the 1.0 inch disbond was pulled with RTV adhesive. Therefore, the seal-to-retainer bond was stressed in peel almost immediately, leading to material failure or peel progression.

IV. Summary

The experiments presented in this paper were part of the Low Impact Docking System (LIDS) main interface seal development. The key concern addressed in this work was whether the seal-to-retainer bond in a composite seal assembly can be relied on for elastomer seal retention during interface separation. The bond strength between the elastomer and retainer was quantified on both nominal and intentionally flawed specimens by simulating high adhesion loads during LIDS separation. The measured failure load and observed manner of failure were used to characterize the bond strength.

The seal assemblies were tested under both uniform and localized tensile loads. The uniform case represented the normal LIDS separation scenario where the S0383-70 develops nearly uniform adhesion to the mating surface. The localized case represented a worst-case scenario, where an area of increased localized adhesion coincides precisely with a disbond. In the uniform tension case, the bond was found to fail mainly in the less desirable adhesive mode (clean pull-out of the elastomer from the retainer). The results of the localized tension tests showed adhesive peel-out of the entire seal similar to the uniform case, as well as S0383-70 material failure.

Neither tensile case indicated a strong correlation between the size of intentional disbond in the seal assembly and the failure load measured, or the failure modes observed. Failure loads on the order of 4000 lbf were measured for uniform tension case specimens. In the localized tension case, the Type B3 specimens showed lower failure loads because 1.0 inch disbonds were pulled with 1.0 inch lengths of RTV adhesive which represented a worst-case scenario and led to immediate peel initiation. However, the lack of a relationship in the other localized case tests between failure load measured and flaw level suggested that material and bond variability are more influential than the length of the disbond. Failure initiation loads on the order of 200 lbf were observed for specimens that failed in a relatively desirable material failure mode in the localized tension scenario. Analysis of the localized tension case results also suggested that once peel is initiated by high localized adhesion, there is a significant possibility of the entire seal being extracted.

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14. ABSTRACT The National Aeronautics and Space Administration (NASA) is currently developing a new universal docking mechanism for future space exploration missions called the Low Impact Docking System (LIDS). A candidate LIDS main interface seal design is a composite assembly of silicone elastomer seals vacuum molded into grooves in an electroless nickel plated aluminum retainer. The strength of the silicone-to-metal bond is a critical consideration for the new system, especially due to the presence of small areas of disbond created during the molding process. In the work presented herein, seal-to-retainer bonds of subscale seal specimens with different sizes of intentional disbond were destructively tensile tested. Nominal specimens without intentional disbonds were also tested. Tension was applied either uniformly on the entire seal circumference or locally in one short circumferential length. Bond failure due to uniform tension produced a wide scatter of observable failure modes and measured load-displacement behaviors. Although the preferable failure mode for the seal-to-retainer bond is cohesive failure of the elastomer material, the dominant observed failure mode under the uniform loading condition was found to be the less desirable adhesive failure of the bond in question. The uniform tension case results did not show a correlation between disbond size and bond strength. Localized tension was found to produce failure either as immediate tearing of the elastomer material outside the bond region or as complete peel-out of the seal in one piece. The obtained results represent a valuable benchmark for comparison in the future between adhesion loads under various separation conditions and composite seal bond strength.					
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