Next Generation Adhesive Seal

Glen A Warren, Jacob Benz, Nikhil Deshmukh, Wenbin Kuang, Matt MacDougall, Kevin L Simmons, Jennifer Tanner
Pacific Northwest National Laboratory

Paul Murphy, Kerr Wallace
CCL Design

The Next Generation Adhesive Seal project has developed a pressure-sensitive adhesive seal designed for high-security applications, such as potential treaty monitoring and verification applications as well as other applications that require high-confidence chain of custody. The new seal incorporates security, integrity, and authenticity features to allow it to be reliably deployed in many scenarios. A critical component is a robust adhesive that adheres to a wide range of materials and maintains a high level of adhesion over a broad range of operational conditions. It provides indication for proper application, tampering, and exposure to solvents. There are multiple means to confirm the seal identity, with and without supporting technology. This talk will present the high-level design requirements, the various features of the seal, an overview of the testing, and the current design of the seal.

1.0 Introduction

Several years ago, Pacific Northwest National Laboratory (PNNL) began working on an improved adhesive seal design for arms control supported by the Warhead Verification Program in the Department of Energy/National Nuclear Security Administration's (DOE/NNSA). This effort was driven in part by the fact that many of the tamper indicating features that were being investigated and developed for chain of custody applications readily lent themselves to incorporating into an adhesive-type seal. Additionally, lessons learned from arms control exercises at the time highlighted the utility of adhesive seals, some limitations with available seals, and a belief that adhesive seal strength and security could be readily enhanced.

The development process began with defining use cases and requirements for the envisioned high-security adhesive seal. These requirements included environmental, operational, functional, and security requirements as well as a list of substrate materials (Tier One materials) that the seal must adhere to. Four conceptual designs that were likely to meet those requirements were developed and reviewed. One of the important outcomes of that review process was a recommendation to engage commercial partners to facilitate in the development of the seal. In 2017, CCL Design was selected as the commercial partner for developing the seal. Since that point, CCL Design and PNNL have been collaborating to develop the Next Generation Adhesive Seal (NGAS).

In 2022, we described information on the use case, seal design, and application restrictions . At the time of that paper, we were waiting for the production and evaluation of the next prototype. In the intervening year, we have tested the new prototype, identified issues in the fabrication, and are awaiting another round of prototype fabrication to evaluate the solutions to the issues. This document describes those issues and our proposed solutions, as well as presents a full description of the new design. Information about the use case and application restrictions can be found in the 2022 conference paper.

2.0 2023 Design Overview

The NGAS is a multi-layered seal, with adhesive, face stock, various inks, and a hardened layer over parts of the seal. The 30-mm wide seal is comprised of two sections: a 100 mm long seal body and a 25 mm long seal tab. Before installation, these two portions are separated at the perforation, demarked by the vertical dashed line in **Error! Reference source not found.**. The seal tab enables a quick confirmation of seal identity and of the level of activation of the thermochromic inks. After application, the seal tab is stored for comparison against the applied seal during inspections.

The seal is designed to provide indication for tampering as well as unique identification. The seal body features four windows with deadened adhesive (i.e., no face stock). The windows are critical for physical removal indication as the windows tend to remain applied to the substrate when attempting to remove the seal body. The face stock is a paper, which easily tears when attempting to remove the seal. A solvent indication treatment is embedded into the face stock. The grid pattern provides unique identification and tamper indication.

The components of the seal, from bottom to top as shown in **Error! Reference source not found.**, are:

- Adhesive: Avery N38
- Substrate: Tullis Russell TruSecurity Paper
- Pressure Indication: CTI Pressure Indicating Ink
- Window Ink: Flint Group High Density White UV
- Serial Number: laser etched

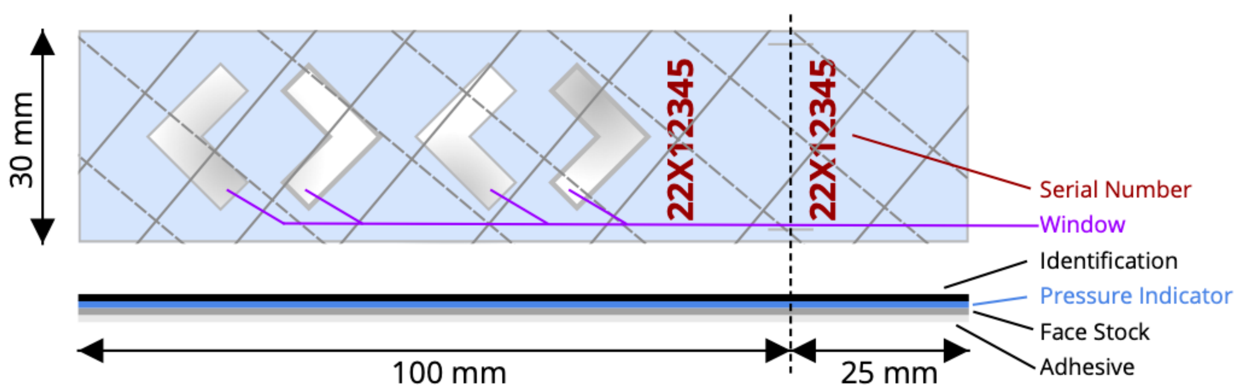

Figure 1. Current Prototype of the Next Generation Adhesive Seal

3.0 2022 Prototype Evaluation

The evaluation of the prototype produced in August 2022 raised two concerns. First, the pressure indicating ink on the prototypes was difficult to activate compared to earlier versions of seal. It was quickly identified that approximately half the pressure indicating ink was used for the 2022 prototypes compared to earlier prototypes, so that this concern can be readily addressed. The second concern was that the seals were difficult to remove from the slip sheet frequently resulting in tearing the windows. This new window shape had been tested earlier, so these results were unexpected.

One of the changes in the 2022 prototype was the shape of the windows. Earlier prototypes used offset bar-shaped windows, but for 2022 design used chevron-shaped windows. Samples seals with the chevron-shaped windows were fabricated in December 2021 and evaluated for use. No concerns were raised in those evaluations. It was discovered that the white ink used to deaden the adhesive in the December 2021 samples was approximately 35 μm thick, whereas this ink was only about 5 μm thick for the August 2022 prototypes. We concluded that the white ink used to deaden the adhesive provided structural support to the seal, which explained the different observations between the December 2021 samples and the August 2022 prototypes.

For the 2021 prototypes, the application layer of the Tedlar™ was found to be slightly beneficial for removing the seal from the slip sheet. For the December 2021 partial prototypes, little to no benefit was observed for the Tedlar™. The thicker layer of ink to deaden the adhesive in the windows for the December 2021 samples provided structural integrity so that the Tedlar™ was no longer beneficial. The 2023 design does not include the Tedlar™.

4.0 2023 Design Details

4.1 Adhesive

The pressure-sensitive adhesive in the NGAS is Avery N38. It was selected due to its high adhesion to a variety of surfaces and over a range of temperatures. In general, the cohesion of the TruSecurity paper is weaker than the adhesion of the N38 to either the paper or the mounting surface, so that the NGAS is frangible (i.e., more likely to tear rather than separate from the mounting surface). This behavior is true at low temperatures, where the adhesion of the N38 is reduced, but the cohesion of the TruSecurity paper even more so, so that the seal remains frangible at low temperatures.

4.2 Pressure Activation

The “Pressure Indicator” shown in **Error! Reference source not found.** is CTI Pressure Indicating Ink. The adhesive in the NGAS is a pressure-sensitive adhesive, which requires a minimum amount of applied pressure for the adhesive to develop the proper adhesion. When the appropriate amount of pressure is applied, the blue ink will turn a faint blue enabling an observer to confirm that the seal was appropriately applied. The light-blue pressure-activated indication will anneal with time; the blue color will fade over several days. Since the pressure indication is only important during the seal installation, the annealing does not impact performance.

4.3 Windows

The windows are a section of the seal where there is only adhesive and ink on top of the adhesive. The windows do not have the face stock. Two inks are printed on the windows. A white ink is printed to eliminate adhesion of the adhesive. A random gray scale pattern is then printed on the white ink. These patterns serve as unique identifiers as well as making it more challenging to replicate the seal.

4.4 Unique Identifiers

The NGAS has four different unique identifiers that provide different levels of confidence for the unique identification: the serial number, the grid pattern, and the randomly distributed threads embedded in the face stock, and the randomly generated gray-scale window pattern.

The serial number is eight characters. The first two characters present the year the seal was fabricated, while the third character is a letter for the month of fabrication. Incorporating the fabrication date into the serial number is a means to manage shelf-life of the product. The last five characters are a unique number for each seal. The serial number is laser etched through all layers of the seal.

The grid pattern forms a unique identifier that is confirmed by matching the pattern on the seal body to the pattern on the seal tab. When comparing the pattern on the body and the tab, the lines should be continuous and smooth (i.e., should not suddenly change direction across the body-tab boundary). Guide lines are printed on the seal to facilitate alignment of the body and tab.

The grid patterns on the seals were selected to be unique at the perforation across 3,000 possible seals. Two patterns were identified as matching, and therefore not unique, if all lines matched within 0.5 mm in the position and 0.1 in the slope of the line. In addition, the patterns were restricted to be at least 1 mm away from the guidelines. The grid pattern provides a medium level of confidence as a unique identifier because it can confirm the pattern at only one location on the seal body.

The gray-scale patterns on the windows were selected to be unique across 1,000 possible seals. The gray-scale pattern and the grid patterns are randomly chosen, so that there are three million unique combinations. The pattern on the windows could support unique identification if photos of the seal are recorded.

The face stock contains small colored threads randomly distributed throughout the paper. These threads can be used to uniquely identify in a medium-confidence manner by recording a written description of some of these threads (e.g., “straight red thread immediately above serial number”) using the grid pattern as a means to indicate location on the seal. For a high-confidence verification, photos of the seal immediately after installation and during an inspection can be compared to ensure all these unique features match.

4.5 Tamper Indication

The NGAS is designed to provide indication against physical and chemical tampering. The construction of the seal supports physical tampering indication. The face stock is paper. The windows provide large areas of increased frangibility. The grid lines printed across the windows will indicate if the windows have been tampered with. The adhesive is remarkedly strong over a very broad range of temperatures. Earlier prototypes incorporate temperature indications to indicate a possible temperature attack. However, testing suggested that the adhesion of the adhesive remained very high at extreme temperatures, while frangibility of the face stock increased, so that these temperature indicators were not necessary.

The face stock used in the NGAS provides solvent indication. When exposed to some solvents, small black dots will appear. This indication works for a range of solvents including ethyl acetate, isopropyl alcohol, and carbon tetrachloride.

5.0 Future Work

By August of 2023, CCL Design will have fabricated a set of seals for the current prototype design. Three different amounts of white ink on the windows will be fabricated and evaluated. In addition, in the summer of 2023, PNNL will complete a three-year long study on aging of the seals to better understand the shelf-life of the seal.

6.0 References

Warren, Glen A, Jacob M Benz, Nikhil Deshmukh, Wenbin Kuang, Matt R. Macdougall, Kevin L Simmons, Jennifer E Tanner, Paul Murphy, and Kerr Wallace. "Next Generation Adhesive Seal." Paper presented at the Institute of Nuclear Materials Management Annual Meeting, Online, 2022.

7.0 Acknowledgements

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Pacific Northwest National Laboratory

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99354

1-888-375-PNNL (7665)

www.pnnl.gov