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INVESTIGATIONS ON THE LONG-TERM BEHAVIOR OF METAL SEALS FOR DUAL PURPOSE CASKS

Tobias Grelle **Ulrich Probst**

Dietmar Wolff **Matthias Jaunich** **Holger Völzke**

Bundesanstalt für Materialforschung und -prüfung (BAM)
12200 Berlin, Germany

ABSTRACT

In Germany, spent nuclear fuel and high active waste from reprocessing is stored in transport and storage containers with double lid systems that are equipped with metal seals completing the primary sealing barrier. The tasks of the Bundesanstalt für Materialforschung und -prüfung (BAM) within the interim storage licensing procedures ruled by the German Atomic Energy Act include the long-term safety evaluation of the container design regarding the permanently safe enclosure of the inventory. In order to generate a knowledge base for the safety evaluation, research regarding the long-term behavior of the critical components is performed. So far, the containers are licensed for an interim storage period of 40 years. However, due to significant delays in establishing a final repository, the required time span for interim storage is expected to increase significantly. Thus, a widespread investigation program is run to gain systematic data on the long-term behavior of the seals and to develop prediction models.

Long-term seal investigations consider the development of their restoring seal force, their useable resilience and their achievable leakage rate caused by aging at temperatures ranging from room temperature up to 150 °C. This year, the total time span of the tests reaches 10 years. Furthermore, seal segments are aged at the selected temperatures for up to 300 days. From these segments additional information on the sealing behavior, changes of the seal contact and the material behavior is gained.

This contribution deals with the current results of the long-term seal investigations at BAM. Furthermore, insights of the more in-depth component and material investigations of the metal seals with focus on the seal contact development are discussed and the ongoing work aiming for an analytical description of the thermo-mechanical aging effects on metal seals are presented.

INTRODUCTION

In Germany, spent nuclear fuel and high active waste from reprocessing is stored in transport and storage containers with double lid systems that are equipped with metal seals completing the primary sealing barrier. These seals are made of three components that allow for good sealing and long-term properties under thermal, mechanical and radiation loads. The innermost part of the seal is a helical spring made of Nimonic 90 which is surrounded by a jacket of stainless steel and an outer jacket made of a softer material which in the aforementioned application is aluminum or silver. In the closure process, the seals are placed in a groove and compressed by placing a lid on the cask and fastening it with bolts. Due to the compression of the spring, a reaction force is generated that applies pressure, homogenized by the inner jacket, on the outer jacket which is plastically deformed and is thus able to adapt to the sealing surface of the cask and the lid. In this way potential leakage paths can be closed and a high sealing performance, quantified by measuring the helium leakage rate, is obtained.

So far, the containers are licensed for an interim storage period of 40 years. However, due to significant delays in establishing a final repository, the required time span for interim storage is expected to increase significantly. At BAM the containers and its components are evaluated regarding the safe storage of the inventory. To ensure state of the art knowledge of science and technology continuous investigations are performed by BAM. Furthermore, in case longer interim storage becomes necessary the investigated aging times have to be increased as well.

It has been shown by multiple studies, that the reaction force of the seal decreases with time and temperature [1,2,3]. The main reason for this is the creep deformation of the outer jacket that is caused by mechanic load and high temperatures. Over time the thickness of the outer jacket decreases, which combined with the constant overall compression ratio defined by the groove depth leads to an expansion and relaxation of the spring.

A decreased restoring seal force in turn leads to a reduced useable resilience, as the amount of possible decompression of the seal while maintaining a defined leakage rate decreases. This value is especially of importance, when the accident safety of the lid system is to be evaluated. In case of a partial release of the lid from the cask body, the resulting gap has to be closed by the expanding metal seal to ensure the required leak tightness.

In order to evaluate the decrease of the seal force over time and temperature as well as its impact on the seal behavior and sealing performance widespread investigation programs of the seals are run at BAM.

LONG-TERM INVESTIGATIONS UNDER REALISTIC CONDITIONS

For a detailed investigation of the development of the seal force, useable resilience and leakage rate a long-term investigation program under realistic conditions is run at BAM. Al- and Ag-seals are assembled in specialized testing flanges and aged at temperatures ranging from room temperature to 150 °C [4,5]. The cross-sectional diameter of the seals is identical to those used in the containers and only the inner diameter is reduced for better handling. The temperatures of 75 °C and 100 °C are realistically expected in the lid area of the containers, whereas 150 °C is higher than the thermal load that is present in the actual application and allows for an accelerated aging. At regular time intervals, the flanges are taken out of the heating chambers and placed in an universal testing machine. Here, the restoring seal force is measured as well as the leakage rate and the useable resilience.

The seals that were aged at 150 °C and room temperature have reached an aging time of 10 years this year. The results for the restoring seal force of Al-seals that could be measured so far are shown in Fig. 1.

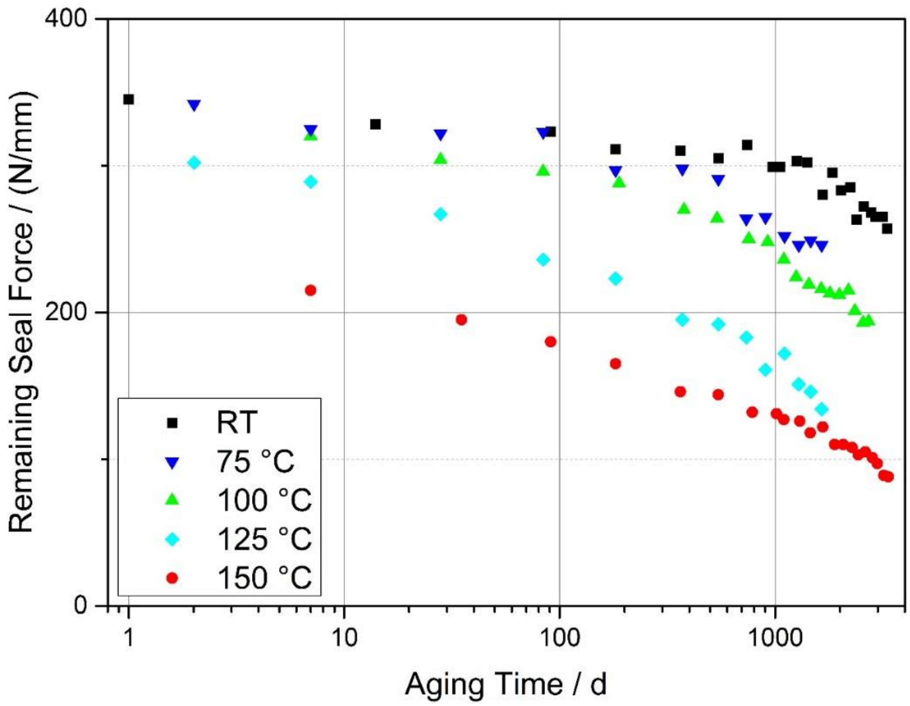

Fig. 1: Remaining seal force of Al-seals after aging at different temperatures for up to 10 years

The resulting curves confirm the initial assumption, that the restoring force that is generated by the spring decreases over time. This process is stronger for higher temperatures. A similar behavior as in Fig. 1 was found for the seal force of Ag-seals as well as for the general change of the useable resilience.

A detailed investigation of the described behavior has been started by developing testing equipment that allows for a continuous measurement of the seal force. A testing flange is equipped with a load cell, contact-less displacement sensors and a temperature sensor. After assembly of the seal, the flange system can be placed inside a heating chamber and the restoring seal force as well as the compression ratio of the seal is measured continuously. The actual temperature of the seal is verified with the temperature sensor. With this approach, the initial phase of the aging process can be monitored in more detail and at the respective temperature. Earlier investigations only allowed for isolated measurements after certain aging times, as the flanges have to be taken out of the heating chambers and cooled down to ambient temperature.

COMPONENT AND MATERIAL INVESTIGATIONS

In the long-run an analytical description of the thermo-mechanical aging effects of the seal and its components is needed to assess the sealing behavior for timespans exceeding the aging times reached in the long-term investigations. Thus, a comprehensive investigation program regarding the seal as a component as well as material tests is run at BAM.

For a better understanding of the time and temperature dependent changes of the seal, segments have been cut from Al-seals, compressed in small aging flanges as can be seen in Fig. 2 and aged at temperatures ranging from room temperature to 150 °C for aging times of 3 to 300 days.

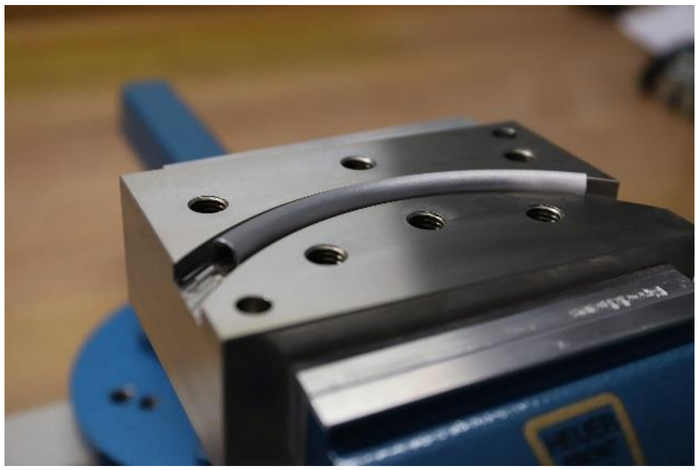

Fig. 2: Assembly of Al-seal segment in aging flange

With this procedure specimen at different stages of aging can be obtained and investigated concerning geometry and material changes [6]. One aspect of the geometry changes of a seal upon aging is the change of the seal contact area width. It is affected by the creep of the outer jacket, the surface roughness as well as the geometry of the spring and the stress distribution.

The width of the contact area of the Al-seals is measured with an optical microscope and a digital camera. Exemplary results of the measurements on segments that were aged at 125 °C are shown in Fig. 3.

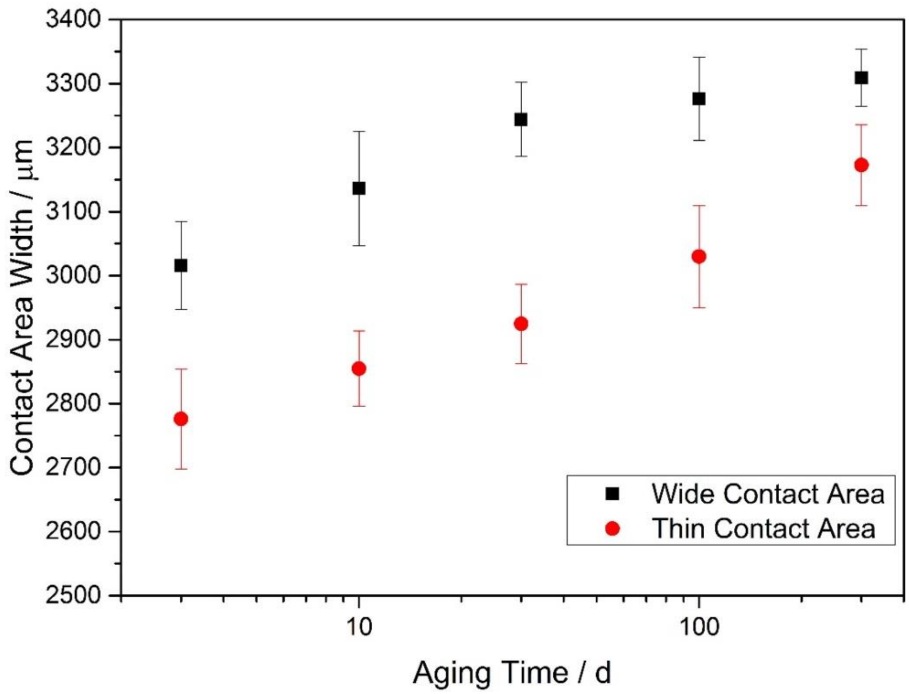

Fig. 3: Contact area width of Al-seal segments aged at 125 °C

For each aging time three segments were investigated with six measuring points, three on each side. For longer aging times at 125 °C the width of the contact area increased, which, like the decrease of the seal force, could be attributed to the creep of the seals outer jacket. It was found, that for each segment there exists one side of the seal with a wide contact area and one with a thinner contact area. This could be caused by the manufacturing process, in which one side of the sheet material for the outer jacket is subjected to a higher degree of plastic deformation than the other which could lead to different layer thicknesses on both sides of the seal.

CONCLUSION AND OUTLOOK

In general, the main influence on the behavior of the metal seals that was observed is the creep of the outer jacket. It has a negative effect on the seal performance by leading to a decreased seal force and useable resilience. Especially under dynamic loading such as transportation of the containers or in accidents this change of the seal parameters could be of importance and has to be investigated further. However, the creep deformation also leads to a wider contact area and, potentially, to a better seal contact, which has a positive influence on the seal performance.

The combination of multiple aging effects influences the long-term behavior of the seal and further investigations of the component and the materials are necessary. Therefore, ongoing work at BAM to gain more information for a thermo-mechanical description of the seal e.g. continuous force development, spring relaxation and material investigations are performed or scheduled.

ACKNOWLEDGMENTS

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