RADIOACTIVE MATERIAL PACKAGE CLOSURES WITH THE USE OF SHAPE MEMORY ALLOYS

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SUMMARY

When heated from room temperature to 165°C, some shape memory metal alloys such as titanium-nickel alloys have the ability to return to a previously defined shape or size with dimensional changes up to 7 per cent. In contrast, the thermal expansion of most metals over this temperature range is about 0.1 to 0.2 per cent. The dimension change of shape memory alloys, which occurs during a martensite to austenite phase transition, can generate stresses as high as 700 MPa (100 kpsi). These properties can be used to create a closure for radioactive materials packages that provides for easy robotic or manual operations and results in reproducible, tamper-proof seals.

This paper describes some proposed closure methods with shape memory alloys for radioactive material packages. Properties of the shape memory alloys are first summarized, then some possible alternative sealing methods discussed, and, finally, results from an initial proof-of-concept experiment described.

INTRODUCTION

Handling of radioactive material packages exposes personnel to strictly controlled doses of radioactivity. Under the United States Nuclear Regulatory Commission's policy of making these doses "as low as reasonably achievable," robotic operations are often proposed as a method to reduce or avoid exposure of personnel during closure operations on such packages. If simple yet secure seals can be achieved without threaded bolts, then such complex robotic operations as engaging threads, tightening and application of correct torque can be eliminated.

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Such a simplified procedure would result in both time and cost savings as well as reduced radiation doses for personnel. Shape memory alloys can provide an alternative to bolted or screwed closures that are simple to install, strong, and tamper-proof. For example, by slipping rings of shape memory metal over metal posts and then applying heat from an electric hot-air pistol, seals can be achieved in a few minutes without complicated actions. Once activated, the seals remain stable over the wide range of temperatures specified for such closures, and will not return to the expanded state even if exposed to vibrations that can loosen bolts.

SHAPE MEMORY ALLOYS

Various shape memory alloys such as copper-aluminum-nickel, copper-zinc-aluminum, iron-manganese-silicon and nickel-titanium have been discovered over the years. Good summaries describing these alloys and their uses are provided by Borden, 1991, and Hodgson, 1990. Titanium-nickel alloys have been commercially used for several years because of their high strength and compatibility with other materials. Initially the titanium-nickel shape memory alloys were cryogenically processed and held in dewars of liquid nitrogen for use in various applications such as connecting hydraulic and coolant lines in industrial plants or aircraft. Upon reaching room temperature, these alloys shrink by several per cent providing a secure clamping action on tubing joints. In contrast thermal expansion of most metals is limited to a few tenths of one per cent over similar temperature ranges.

The shrinkage of shape memory alloys that can be used to seal radioactive materials packages occurs during a martensite to austenite phase transition. In the martensitic phase, two crystalline structures are possible: a twinned martensite that forms directly from the austenitic phase of the metal as it is cooled, and a deformed martensite that can be formed from the twinned martensite phase when it is strained to a new shape in a controlled manner. The strained martensite retains its deformed shape until the original shape and dimensions of the material in the austenitic phase are recovered at the austenitic phase change temperature. Once regained, the original shape remains stable as long as the material is not cooled to temperatures that convert the crystalline structure back to martensite and then again strained to the deformed state. Depending on the alloy, strains up to 7 per cent are possible while the material is in the martensitic phase.

To make the shape process usable without cryogenics at the application site, special alloys such as Tinel from Raychem have been developed. The Tinel alloy contains niobium in addition to titanium and nickel and remains stable in the strained martensite phase at room temperature. When heated to 165°C, the material completely recovers its original shape. Fastening rings made from this material are commercially available. After conversion to austenite, these rings retain their shape to very high temperatures, and to temperatures as low as -65°C. The temperature range for the stable austenitic shape exceeds the temperature range requirements set by regulations such as International Atomic Energy Agency Safety Series 6, 1990.

Strength of the nickel-titanium shape memory alloys is high, with yield strengths near 500 MPa, and tensile strengths of about 750 MPa. This allows for relatively small rings or devices that can produce significant clamping forces.

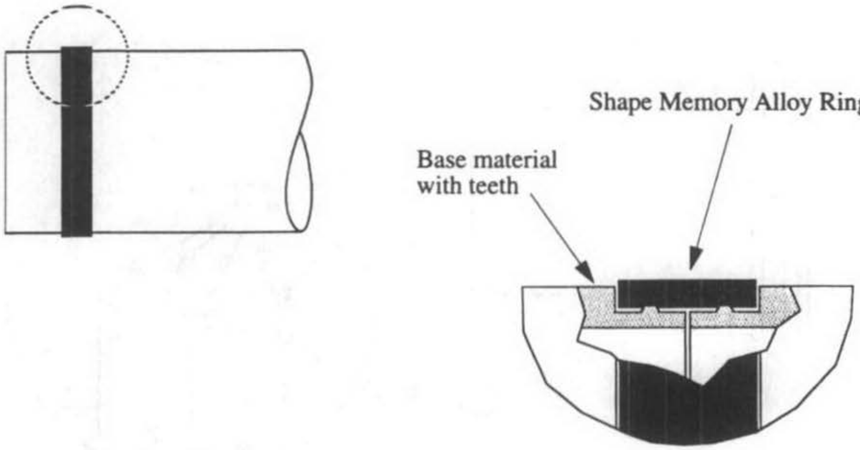

Figure 1. Cylinder sealed with shape memory alloy ring resting on teeth in base material.

POSSIBLE CLOSURE CONFIGURATIONS

Several schemes that use the properties of shape memory alloys to effect closures on radioactive material packages are possible. For example, a toothed ring such as shown in Figure 1 could be used to mate a cap to the end of a package cylinder. This configuration could be useful for small sample containers, or for caps or outlets on larger packages.

For larger packages, wires of the shape memory material could be used to compress a split ring that presses on deformable material as shown in Figure 2. Wires could be several welded rings, or a spiral wrap with ends welded to the fixed ring.

The use of sealing rings to compress half posts on each side of a flange is shown in Figure 3. Variations on this arrangement are also possible. For example a single sealing post could be used as a tamperproof seal to secure a bayonet type or screwed mechanism where tapered teeth or threads provide the actual sealing force.

In another arrangement, shape memory rings could be used to secure the retaining rings holding the lids on standard steel drums. Many other configurations are possible, including the use of shape memory rings simply as detents or locks for screwed caps on canisters.

Once placed in the austenitic phase, shape memory alloys retain their shape, forcing their destruction in order to permit a package to be opened. The concept of placing the rings in a cryogenic bath in order restore them to the expanded shape was considered, but since a controlled strain must also be applied, this method was not considered to be feasible for easy field applications. Grinding or cutting of the rings has proven to be the most effective way to remove them. If such shape memory locks are individually coded or identified, "counterfeiting" would be difficult since the shape memory alloy materials are not widely available. Thus, the effort

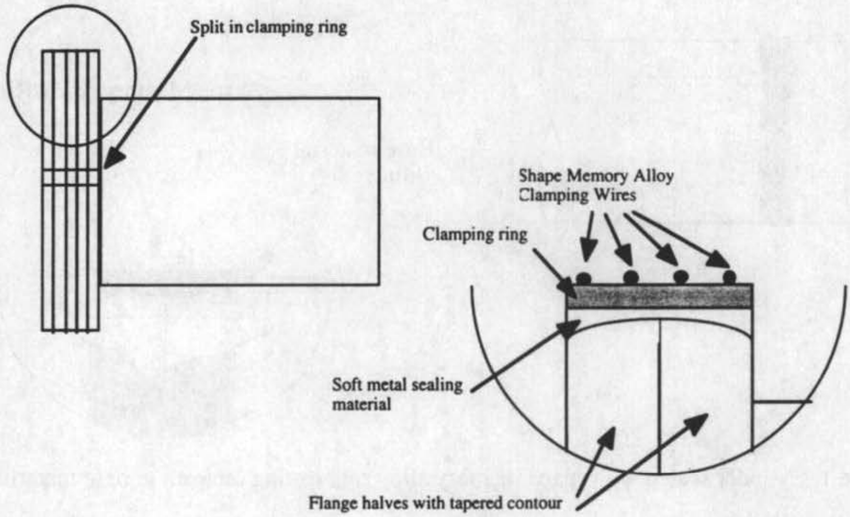

Figure 2. Flange sealed with clamping wires on split ring with soft sealing material.

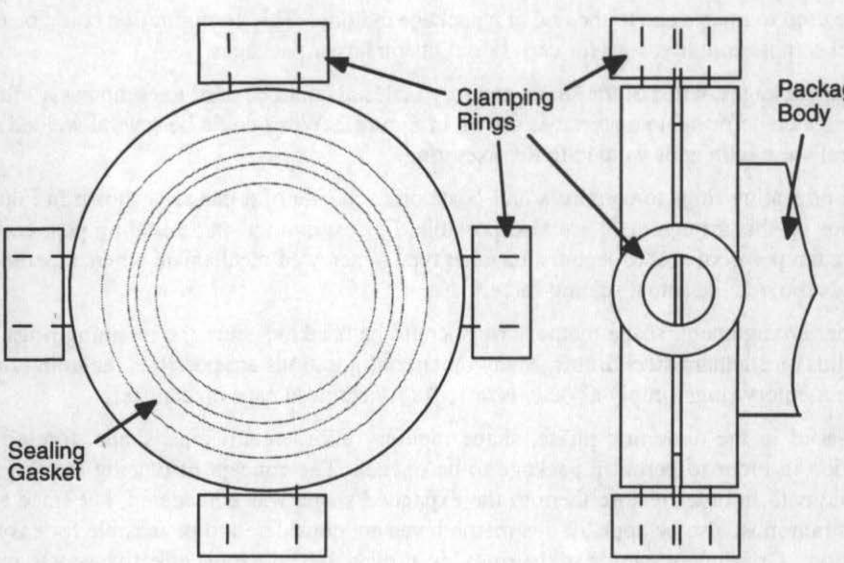

Figure 3. Flanges clamped together with sealing rings on posts.

necessary to gain entry into shape memory sealed packages could be easily detected, making the locks tamper-resistant.

Heating methods for the shape memory materials also allow for some variation. For example, low voltage, high current electrical resistance heating of the alloy is possible. Hot-air pistols, developed for heat-shrink plastic electrical insulation, also develop the temperatures required to achieve the necessary austenitic phase change. Typically, high temperature sources such as furnaces or inductive heating are not required.

Because of the relatively low temperatures that are applied during the sealing process, a wide range of sealing methods can be considered. For example, the 165°C phase change temperature for sealing is well within the temperature limits for most elastomeric seal materials. Since the heat can be applied for a short time and primarily to the area containing the shape memory material, temperature excursions in other parts of the package would be considerably below 165°C.

PROOF-OF-CONCEPT EXPERIMENT

To demonstrate the shape memory alloy sealing concept, a small test package was constructed from standard parts available from a vacuum vessel parts vendor. A nominal 2-3/4 inch (70 mm) vacuum flange and flange cover with a copper sealing ring were modified to accept shape memory alloy closure rings as shown in Figure 3. Six circular posts over which the shape memory alloy closure could be placed were created by machining the standard vacuum flange and cover together on a lathe. Each half-post was located on the flange or the cover so that when an expanded sealing ring was slipped over the posts and shrunk. The rings drew the cover and flange tightly together. The sealing rings provided the force to pull the knife-edge sealing surface of the mating flange surfaces securely together. A photograph of the completed test assembly is shown in Figure 4. Although copper seals were chosen for the proof-of-concept experiment, elastomeric or other seal materials could also be used.

Tests with different numbers of shape memory alloy sealing rings on the test assembly were conducted indicating that two to four rings are sufficient to compress the copper gasket and achieve a seal that meets regulatory leak rate standards.

Initial tests were conducted in a furnace to assure similar heating of all shape memory rings, and helium leak tests were applied to confirm that a tight closure had been achieved. Subsequent furnace tests, with an internal helium pressure in the assembly, to temperatures as high as 315°C demonstrated that the seals remained leak-tight even when they were cycled to elevated temperatures that could occur, for example, during an accidental fire.

To simulate field applications of the method, closures to the test assembly were made with the use of hand-held propane torches and hot-air pistols. Adequate temperature control with torch flames proved difficult, but uniform heating with hot-air pistols proved successful in creating leak-tight seals. A photograph of the test arrangement with hot-air pistols is shown in Figure 5. Helium leak checks following closure confirmed that the a leak tight seals had been achieved.

CONCLUSIONS

The proof-of-concept tests demonstrate the feasibility of the shape memory alloy closure approach. Since closure rings are available from vendors in sizes up to 100 mm diameter, the

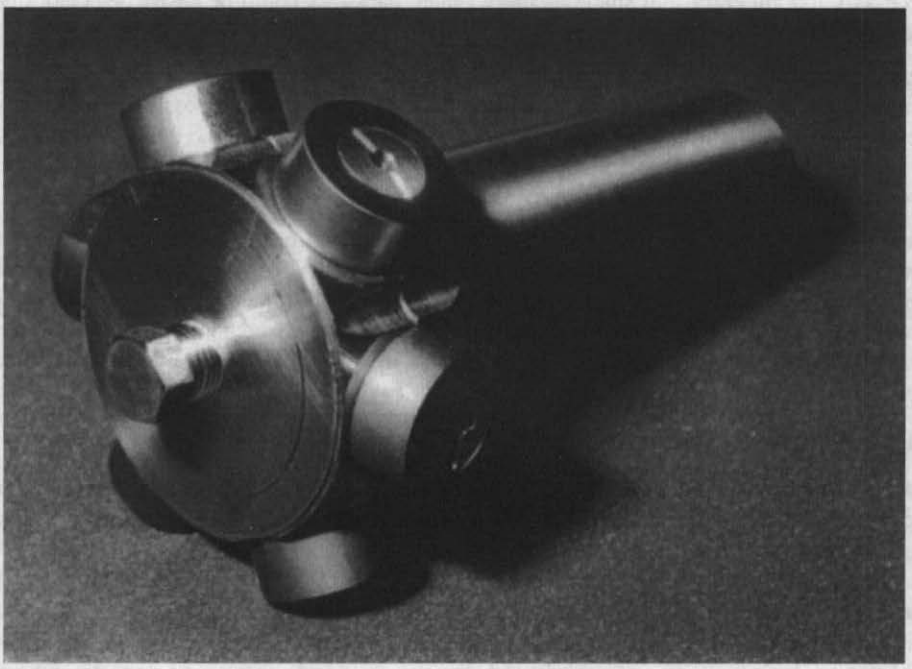

Figure 4. Seal test assembly with shape memory alloy sealing rings.

approach could be applied to a wide range of radioactive material packages. Furnace tests indicate that the seals can retain their integrity through temperature excursions simulating fires.

Although further testing for a particular package seal configuration is necessary to confirm applicability, all parts necessary to engineer closures based on the shape memory approach are currently commercially available. Areas needing further investigation include the detailed stress analysis of the sealing system to determine the gaps, tolerances, and surfaces necessary to assure consistent seals under all regulatory tests and conditions. For example, the nickel-titanium shape memory alloy has a smaller thermal expansion coefficient than stainless steel, so that during a temperature transient induced by a fire, sealing rings could exert increased forces on seal surfaces. Once returned to normal temperatures, these forces would relax, and any permanent deformation of the sealing surface could reduce leak tightness. If this proves to be a problem, spacers or other means for limiting seal excursions during fires could prove necessary. A potential advantage of the shape memory closure approach is that the engineering necessary to assure a tight seal is considered during the package design and testing phase, so that when used in the field, closure integrity does not rely on the expertise or training of personnel that must perform detailed tasks such as torquing of bolts in a particular sequence.

Creep of the seals over time is an issue that must also be resolved through further testing. Since Ti-Ni memory metal alloys have been used in other applications that require creep resistance including high pressure hydraulic fittings, this is not likely to prove a problem.

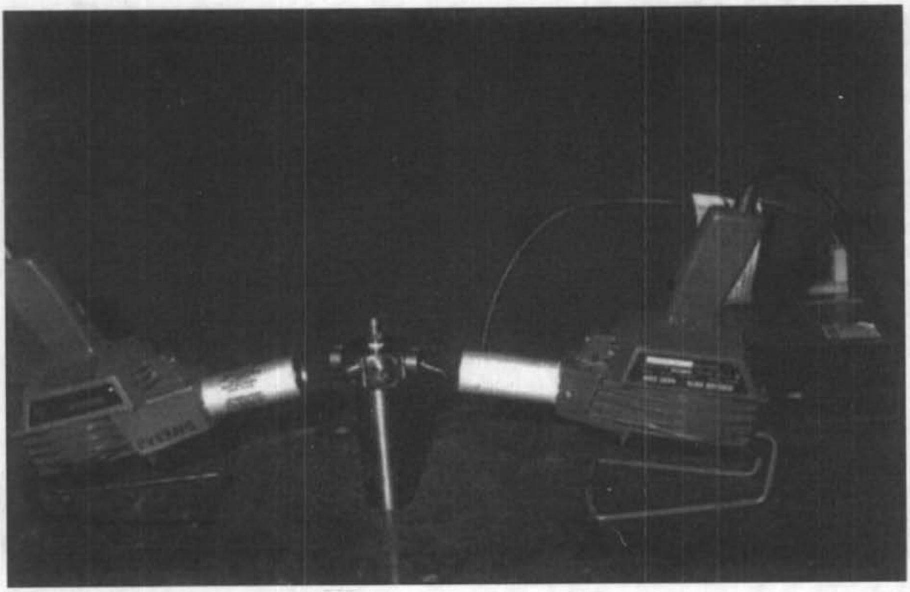

Figure 5. Hot-air pistol arrangement for sealing test cylinder.

Another area of investigation is the use of O-ring type elastomeric seals. Whether the shape change of the shape memory alloy produces a large enough deformation of the O-ring to produce a leak-tight seal requires investigation. Shape memory seals may be limited to seals that require smaller excursions of the sealing surfaces, such as the copper gasket approach described for the test assembly.

To determine if the shape memory metal closure approach is patentable, a technical disclosure document was filed with the Sandia Intellectual Property Department. Based on the disclosure document, a committee determined that the concept is patentable, and that a United States patent may be pursued. Regardless of the patent status of the concept, the process is available for potential use with new package designs.

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SESSION 4.2

Container Design