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An Evaluation of the Potential for Creep of 3013 Inner Can Lids (U)

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ABSTRACT

This report provides the technical basis to conclude that creep induced deformation of Type 304L austenitic stainless steel can lids on inner 3013 containers will be insignificant unless the temperature of storage exceeds 400 C. This conclusion is based on experimental literature data for Types 304 and 316 stainless steel and on a phenomenological evaluation of potential creep processes.

INTRODUCTION

The end of the Cold War and the associated nuclear readiness programs created an excess of plutonium and other nuclear materials. The handling, storage and disposition of this excess includes the stabilization, packaging and storage of plutonium-bearing metals and oxides containing at least 30%, by weight, plutonium plus uranium. The U S Department of Energy has developed a Standard, DOE-STD-3013 [1], for “assuring that plutonium-bearing materials will be stable forms of safe, long-term storage at DOE facilities in sound packages requiring minimal surveillance under anticipated handling, shipping and storage conditions until their final disposition.” Much of the plutonium covered by this Standard will be stored at the Savannah River Site’s, K-Area Material Storage (KAMS) facility. The plutonium-bearing materials will be stabilized to criteria outlined in the Standard and then packaged in welded austenitic stainless steel containers. These containers are termed 3013 Containers and the package includes both an inner Type 304L container and an outer Type 316L container (Figure 1). The stabilized, plutonium-bearing materials are seal welded into the inner can and this can, with its contents, is placed in the outer 3013 container that is also seal welded to form the 3013 packages which are stored in the KAMS facility. Selected packages are systematically evaluated to assure that the package system is performing as anticipated.

Potential, long term container degradation processes have been assessed and, because of the stringent stabilization and packaging requirements, only corrosion and internal pressurization are considered viable [2]. The viability of these two processes requires that a surveillance program be conducted to assess the condition of the stored inventory of 3013 packages [1]. This program includes the non-destructive determination of internal pressure build-up in the inner container and indications of leakage and/or container degradation. Part of this program is routine digital radiography of selected 3013 packages. This radiographic examination allows the determination of the position of the lid on the inner 3013 container and, from the lid position, the internal pressure in the inner container can be established. The internal pressure determination involves the determination of the deflection of the inner container lid from its baseline position and empirical determinations of lid deflection versus internal pressure (Figure 2) [3].

During the development of the data in Figure 2, observations of lid positions in test containers pressurized to predetermined levels, showed that the deflection increased with time, approaching a steady state position (Figure 3). This observation raised the question of the potential for creep in the stored containers and the analysis presented in this paper was made to assess that potential.

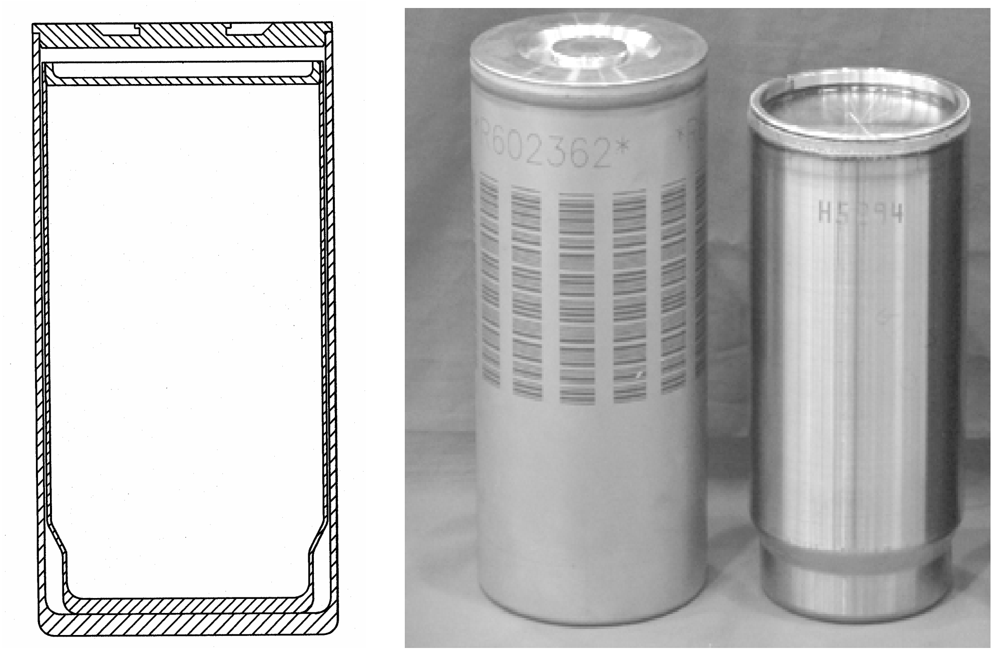


Figure 1. Schematic of a 3013 package and Photograph of Inner and Outer Container System

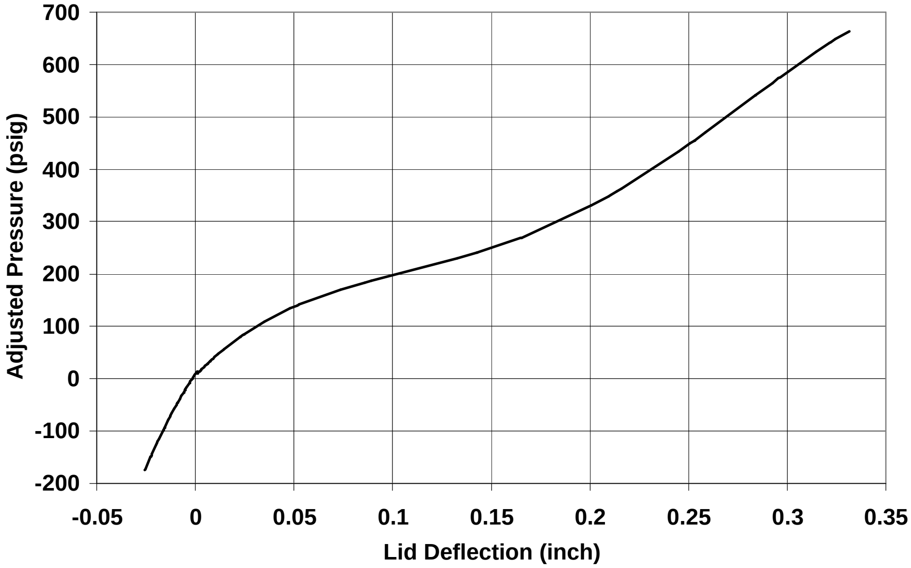
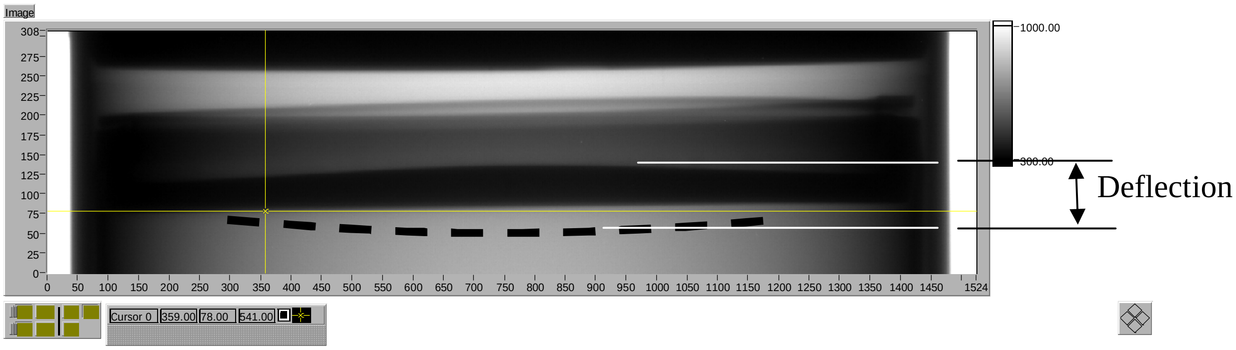


Figure 2. Effect of Internal Pressure on Lid Position in 3013 Inner Container [3]



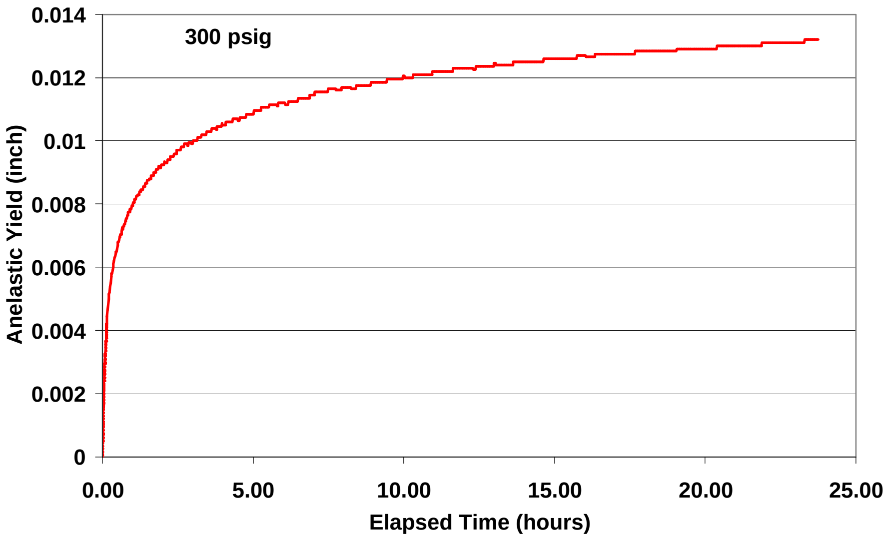


Figure 3. Digital Radiograph of inner container lid position with 300 psig internal pressure [3], and plot of change in lid position over time at that pressure [4].

ANALYSIS

Creep is time dependent plastic deformation and generally involves the motion of dislocations. When a metal is loaded to a stress level below the yield stress, it undergoes immediate elastic deformation but does not deform plastically because the dislocations in the metal are pinned by a variety of obstacles. The obstacles include jogs, kinks, dislocation pileups, grain boundaries, precipitates, twin boundaries, alloy and impurity atoms and other microstructural defects in the metal lattice. During a very short time frame immediately following the load application the metal may make plastic adjustments by dislocation motion in regions of stress concentrations and high interstitial concentrations. These regions include grain boundaries, the metal adjacent to inclusions, precipitates and second phase particles and lattice regions near microscopic cracks and notches. The strain rate associated with these adjustments decreases with time until plastic deformation ceases or reaches a constant rate. The strain associated with this dislocation adjustment period is termed primary creep and the constant strain rate that develops after the initial period is generally considered the creep rate of the alloy. The creep rate is dependent on temperature and stress, and will be essentially zero unless the temperature is high enough for vacancy motion to take place. If the metal is under a constant load, the strain associated with the creep process (creep strain) will reduce the cross sectional area supporting the load thereby increasing the stress acting on the metal. Eventually the increased stress acting on the metal will accelerate the creep process. A typical creep curve, Figure 4, shows three stages of creep: Stage I (primary creep), Stage II (steady state creep) and Stage III (tertiary creep).

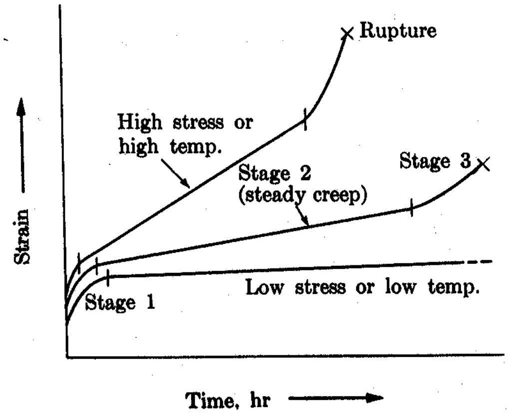


Figure 4. Creep Curves Illustrating the Three Stages of Creep and the Effect of Stress and Temperature on the Creep Process [5]

As the temperature increases the mechanical strength of an alloy may become limited by creep rather than yield behavior. The temperature of this transition is roughly one third the absolute melting temperature of the metal; however, this rule of thumb only provides a rough estimate for alloys such as Type 304L stainless steel. Iron melts at 1538 C (1811 K), thus the rule of thumb predicts that Type 304 L stainless steel could have a measurable steady state creep rate at temperatures slightly above 330 C. The nickel, chromium and other alloy additions to the iron will raise the transition temperature and creep of Type 304 stainless steel is not observed experimentally at such low temperatures. The 1985 Desk Edition of the ASM International Metals Handbook [6] places the transition temperature at 540 C. This placement is consistent with the Aerospace Structural Metals Handbook [7] which does not publish any creep data for Type 304 stainless steel at temperatures below 482 C. These data demonstrate that the steady state creep rate of the inner can lid (and all other stainless steel portions of the 3013 container system) will be essentially zero if the operating temperature is maintained below 400 C.

The interface between the inner can and its contents will not exceed 189C (372F) for a maximum internal heat generation rate of 19 watts, when packaged in a 9975 package and exposed to an ambient temperature of 37.8C (100F) [1]. In KAMS, the maximum calculated ambient temperature for non-accident conditions is 72.2C (162F) [8]. If this increase in ambient temperature is conservatively applied as a direct addition to the internal temperature profile, the inner can temperature does not exceed 223C (434F).

Fracture maps for metals and alloys were developed as a technique to summarize a tremendous body of elevated temperature data and provide for rapid estimates of alloy behavior at various stress/temperature conditions. A fracture map for Type 304 stainless steel is presented in Figure 5, and shows that creep does not occur at normalized tensile stresses below 10^{-3} (approximately 30,000 psi, the minimum room temperature yield strength for Type 304 stainless steel) and homologous temperatures below 0.4 (451C, or 844F).

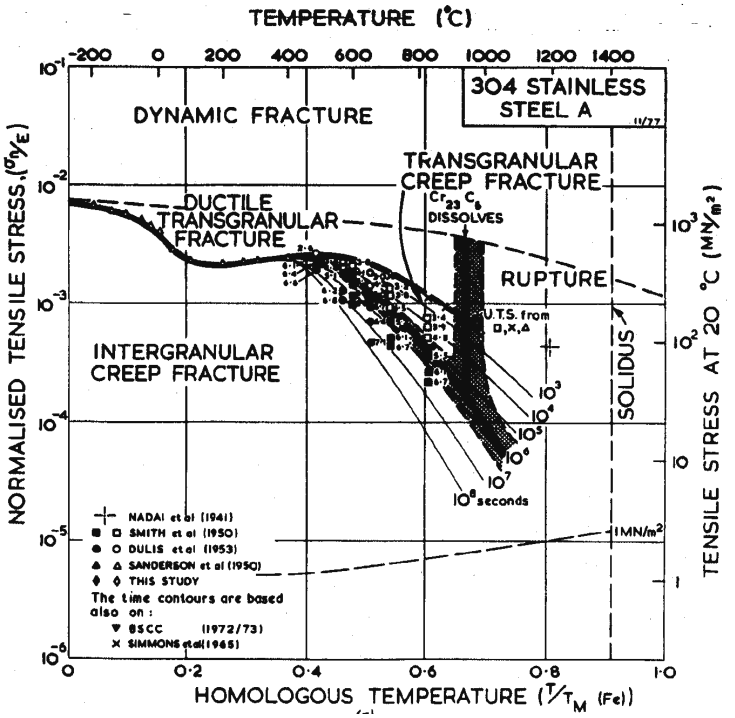
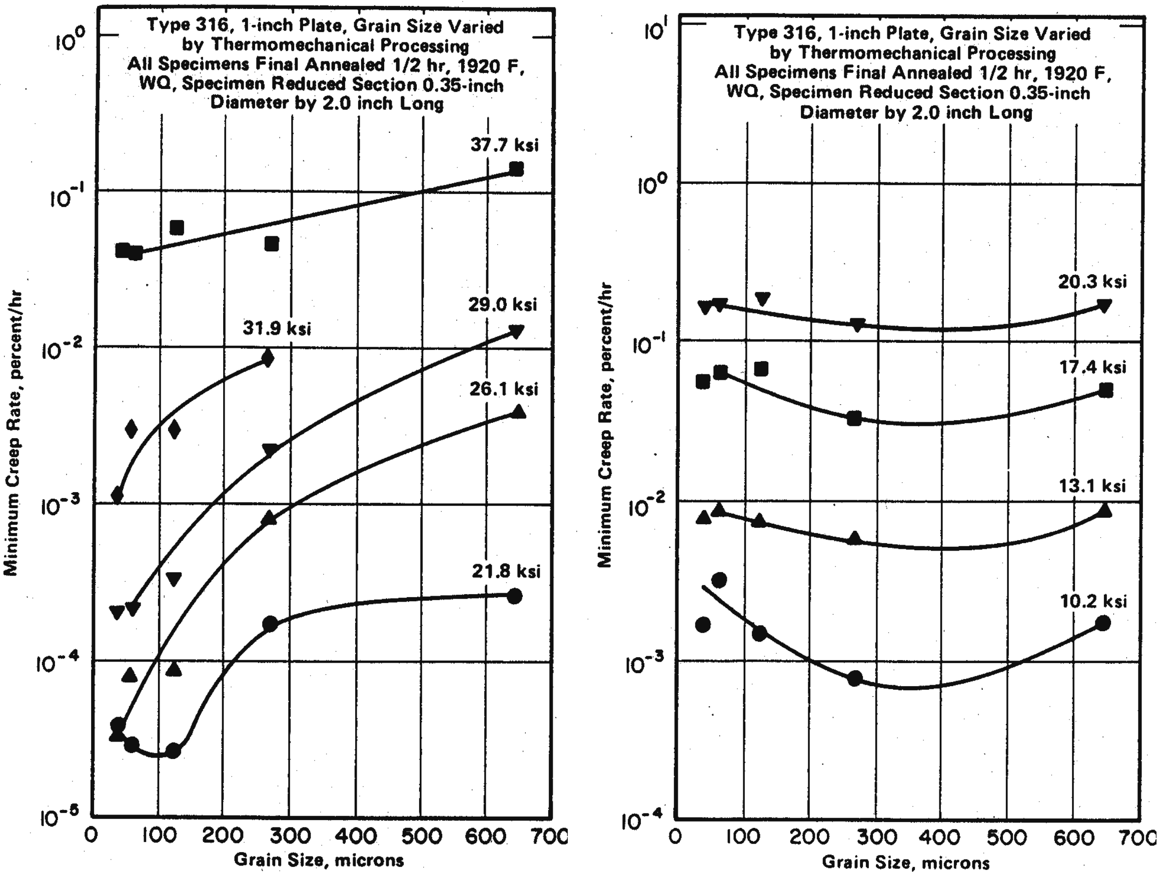


Figure 5. Fracture Map for Type 304 Stainless Steel [9]

The data summarized on this fracture map are from a variety of sources, and include bar stock similar to that used for the 3013 inner can lids, which has a typical grain size of about 60µm. For this case, the position of the lines on the fracture map demonstrates that steady state creep of the inner can lid is very unlikely.

During lid deformation under internal pressure, the adjacent can wall also deforms and contributes to the overall lid deflection behavior. The can wall is heavily cold worked, and has an extremely fine grain structure. The heat affected zone in the can wall contains larger grains up to ~60µm immediately adjacent to the weld, with grain size rapidly decreasing away from the weld. For such microstructures, alternate creep mechanisms directly involving diffusion rather than dislocation motion can become dominant. Rates for these mechanisms (e.g. Coble creep, Nabarro-Herring creep) are dependent on the grain size, and increase with smaller grain size. Additionally, grain boundary sliding can also contribute to the strain that develops. The relative importance of these various creep processes will cause steady state creep rates to increase with decreasing grain size. Figure 6 shows this becomes significant in Type 316 stainless steel only at higher temperatures (~1290F) and lower stresses. (Type 304 stainless steel is expected to behave similarly.)

To the extent that deformation of the can wall contributes to lid displacement, and such deformation extends beyond the closure weld and heat affected zone, creep in this region of the can wall will be important. However, grain boundary sliding is significant only at homologous temperatures exceeding 0.4 (451C) [10]. Creep studies on Type 316 stainless steel at 475 C conclude that “there is little evidence of grain boundary sliding or intercrystalline cavity formation” [11] and in the absence of grain boundary sliding, the effects of grain size on creep are small [10]. Additionally, vacancy motion is required for both Nabarro-Herring and Coble creep. Nabarro-Herring creep occurs by diffusion or vacancy motion through the lattice and Coble creep occurs by grain boundary diffusion. Therefore, these grain size dependent creep processes will not be significant in the can wall due to the relatively low service temperatures, and time dependent lid deflection by Nabarro-Herring and Coble creep or by grain boundary sliding is not anticipated.



(a) 1110 ºF (600 ºC) (b) 1290 ºF (700 ºC)

Figure 6. Effect of grain size on creep rate of Type 316 plate at various stresses. [7]

This evaluation thus supports the earlier conclusion that steady state creep will not occur in Type 304 stainless steel, 3013 inner cans if the operating temperature is maintained below 400 C. Tertiary creep cannot occur in the absence of steady state creep; thus, available data show only Stage I creep is possible for Type 304 stainless steel under anticipated 3013 storage conditions.

The dislocation rearrangements that cause Stage I creep can be due to the motion of interstitials, vacancies or both. At temperatures below 400 C, vacancy motion is insignificant and primary creep is due to the motion of iron, chromium and nickel interstitials. Most of these interstitials are created by jog dragging during plastic deformation and will not be replenished during anticipated storage conditions. Therefore, at anticipated storage conditions, primary creep will cease when the interstitial supply is exhausted. This process is then termed exhaustive creep and may lead to a very limited amount of post loading strain, if the load is rapidly applied. The time dependence of this strain is identical to the anelastic behavior of iron carbon alloys and, because of the similarity, has been termed anelastic creep.

Exhaustive (anelastic) creep could cause minimal, post pressurization deflection of an inner can lid, if the can were pressurized in a relatively short period of time (hours). Such deflections, if they are even significant, should be completed within several days following the short time pressurization. This conclusion is supported by the time dependence of anelastic yielding shown in Figure 2. In-service can pressurization will be very slow and any exhaustive creep of the can lid will occur as the pressure increases. Therefore, if post pressurization can lid deflection is observed in the development of a pressure – deflection correlation, the lid position after completion of the exhaustive creep should be used to characterize the effect of pressure on lid position.

CONCLUSION

The analysis demonstrates that steady state creep will not occur in the can lids on 3013 inner containers stored under anticipated storage conditions in the KAMS facility. This conclusion provides the technical basis to use the short time, pressure versus deflection curve (Figure 2) to determine the internal pressure in 3013 inner containers, providing that the short term data were obtained after completion of the exhaustive or anelastic creep process.

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