Finite Element Analysis of Vibrating Canisters Filled with Calcined Nuclear Waste

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A finite element analysis is performed to investigate the dynamic responses of canisters during the vibrational compaction of calcined radioactive waste. This study shows that the maximum internal stress consistently occurs in the canister wall, but its actual location varies and depends on the loading and boundary conditions. The mechanical properties of the granulated calcined nuclear waste have appreciable impact on the internal stress of the canister container at higher fill percentage. Finally, a set of loading parameters has been suggested for safe operation of the canister system.

Calcine is a more desirable material to store than liquid radioactive waste because it reduces volume, is much less corrosive, less chemically reactive, less mobile under most conditions, easier to monitor and more protective of human health and the environment. This paper describes the technical issue involved in the development of a feasible solution for further volume reduction of calcined nuclear waste for transportation and long term storage. This will be accomplished by developing a process wherein the canister is transformed into a vibrational machine, for further volume reduction by about 35%. The random compaction experiments show that this volume reduction is achievable. The main goal of this paper is to demonstrate through computer modeling that it is feasible to use volume reduction vibrational machine without developing stress/strain forces that will weaken the canister integrity.

In the study, a canister was simplified as a cylindrical container of uniform wall thickness. No damping factors were incorporated in the model. This significantly reduced the computational time without losing accuracy. However, this simplification was restricted to the vertical modes of oscillation only, and inapplicable to the horizontal shaking modes. In simulating the vertically modes, a vibrating harmonic displacement was applied along the axial direction at the bottom of the canister. The nonlinear dynamic analysis was performed by using the commercially available code ABAQUS/Explicit [1] through the explicit direct integration option. A full cycle of the sinusoidal load was simulated to capture the fundamental features of the problem. Stainless steel properties have been used for the canister container. The waste material is primarily composed of calcium fluoride. However, the effective elastic modulus and the density of particles are much different from those of continuous solid [2,3]. Here the modulus of CaF_2 particles was assumed proportional to the mass density. Since the density of solid CaF_2 is 3.18 g/cm^3 and the modulus is 75.8 GPa, and the measured density of the waste material is 1.3 g/cm^3, we estimated the effective modulus of the granular material to be 31.0 GPa.

The natural frequency response was the first thing examined for possible structural resonance. It turns out that for an empty canister, the first natural frequency is approximately 65 Hz. When the canister is completely filled with the waste material, the frequency is around 146 Hz. This range of the natural frequency is much higher than the applied loading frequency. Therefore our conclusion is that a horizontal shaking mode will not excite system resonance either. Further, a reexamination of the first natural frequency of the vertical mode for the empty canister shows a result of 382 Hz, which is very close to the result obtained from

the axisymmetric model. The small discrepancy could arise from the different mesh refinements used in the two models.

The lateral shaking mode shows that the maximum Von Mises stress increases with the load frequency, with only a slight variation. The increase rate or the slope of the curve is about 20 MPa/Hz. This is much smaller than the vertical mode, which shows a rate of 50 MPa/Hz. Therefore, at the same load frequency, the vertical modes induce higher internal stress than the horizontal modes. The maximum stress also increases with fill percentage of the waste material. In comparison with the vertical mode, the waste material plays a more important role here: in an empty canister, the maximum stress is slightly above 50 MPa, whereas at the 100% fill, the stress increases significantly to 300 MPa. It has also been noticed from the curve that the increase in the stress mainly occurs when the fill percentage is greater than 50%.

The yield stress for stainless steel varies, but typically below 300 MPa. It has been noticed that some of the computed maximum stresses, especially for the vertical modes, are much higher than this threshold and therefore the canister is unsafely designed. Apparently the internal stress will decrease when the amplitude of vibration is attenuated. For example, when a standard canister filled with 80% of the calcined waste operates under a load frequency 10 Hz and amplitude 0.005 m, the maximum stress in both vertical and horizontal vibration modes will be below the yield stress.

The following conclusions have been obtained from this study:

i. The maximum stress concentration always occurs inside the canister wall.

ii. The vertical vibration mode typically induces higher internal stress than the lateral mode.

iii. The first natural frequencies of the canister are generally much greater than the applied loading frequencies and therefore the structure resonance that may cause damage to the canister is unlikely to occur when the suggested parameters are used.

iv. The mechanical properties of the granulated calcined nuclear waste may have significant impacts on the internal stress of the canister container.

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Finally, the calculated data suggest that by appropriate selection of the loading parameters, we are able to maintain the maximum internal stress below a certain threshold so that the entire canister can operate safely without defects. This will have significant economical benefits of handling nuclear waste in the calcined forms, including waste manipulation, storage and transportation.

References

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