5.7 TASK 7
Weld Residual Stresses in Low Symmetry HCP-Beryllium Materials
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Task 7 Technical Requirements

Suitable welding and joining techniques are an essential prerequisite for the design and construction of complex components and assemblies. The efficacy of any given welding technique and joint performance is a complex derivative of the primary materials in play and the precise methodology in use to construct the joint. Residual stresses arising as a direct outcome of heat input during joining, the subsequent expansion and rapid cooling induced contraction of metal in the fusion zone are a severe problem affecting service life. This is particularly important in precise, highly toleranced systems where distortion resulting from residual stresses can often overshadow dimensional tolerances.

The incidence of residual stresses is particularly acute in low symmetry, low ductility material Beryllium. Beryllium is a prime material in the aerospace and nuclear industry. It has a high elastic modulus, low density and a high strength-to-weight ratio, which can provide lightweight, stiff structures for aerospace applications. It also exhibits low thermal neutron absorption and excellent reflection desirable in nuclear applications.

The inherent problem in fusion based joining is the low ductility and the high modulus of the material coupled with the high thermal conductivity, which allows steep thermal gradients to form within the fusion zone. This combination of steep thermal gradients and the high modulus result in large residual stresses with a propensity to cracking in the vicinity of the joint. The problem is further compounded as Be exhibits a diminishing ductility as it cools thereby exacerbating the cracking. Few metals have any appreciable solubility in Be and as such alloying does not readily rectify the behavior. Solution approaches require that the evolution of such stresses be efficiently monitored and modeled with a view to mitigating their impact. A successful outcome could help develop a spectrum of end uses for Be components in the tactical nuclear and aerospace applications. UCSD and UT (subcontractor) will collaborate with LANL to develop appropriate experimental and computational methodologies to explore and mitigate the debilitation issue residual stresses in Beryllium welds.

The primary goals for UCSD and UT students assigned to this task are:

(1) Identify the critical parameters exacerbating the evolution of residual stresses in conventional welding of Be;
(2) Monitor the severity of critical parameters on component life via model experimental tests accompanied by parametric variations;
(3) Measure the magnitude of residual stresses via conventional and novel experimental techniques available at LANL and UCSD;
(4) Explore a thermal-mechanical model construct for computational simulations to track and calibrate the residual stresses; and ultimately to

(5) Explore and validate suitable process paths to mitigate such residual stresses and consequently mitigate failure.

A comprehensive plan is put forth to engage the research students in a multi-dimensional exploration of the Be welding problem. In the second year of this program the UCSD research tasks will explore a spectrum of experimental efforts coupled with theoretical-computational modeling to devise meaningful solutions. Students will develop the essential FEM modeling tools to analyze underlying residual stresses and their overall impact on component performance and mechanical response. The students will perform all essential mechanical testing necessary to validate FEM results. Expertise acquired in this task will have the technical background to directly impact LANL programs such as the advanced material modeling and data interrogation associated with our predictive modeling efforts that supports almost all large-scale nuclear weapons engineering programs and the pit manufacturing program.

We note here that access to beryllium and associated joining processes activities may well be limited. Therefore, an essential pre-requisite in this case is the identification of suitable surrogate material, of like low symmetry crystal structure (HCP) with limited slip systems and plasticity. The current surrogate material of choice is Co-10wt%Mo with similar CTE and mechanical response to Beryllium. We envisage that welding/brazing trials on Co-10wt%Mo alloys will provide critical residual stress insight and failure proclivity of sufficient merit applicable to beryllium alloys.

Task 7 Deliverables

	Task 7 - Deliverables	Due Date (days after contract award)
7.1	Determine and evaluate the appropriate mechanical testing regimes for base metal and welded segments. Report of preliminary mechanical testing and joint properties submitted with 2nd quarter report	90
7.2	Develop preliminary Finite Element Mesh for the various fusion welded and brazed sample geometries. Report of FEM computational protocol & results will be submitted in 3rd quarter report	180
7.3	Measurement of parametric sensitive residual stresses via contour mapping and neutron diffraction methods. Provide report of experimental data of residual stress distributions	270
7.4	Develop a thermal-mechanical model using input from 7.1, 7.2 and 7.3 to compute, calibrate and validate the residual stress evolution in simple weld geometries Report on computed results of Residual Stresses in simple butt-joint, lap-joint configurations.	360