INL/EXT-18-51887-Revision-0

Quarterly Management Document - FY18, 4th Quarter, Physics-based Creep Simulations of Thick Section Welds in High Temperature and Pressure Applications

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Document # INL/EXT-18-51887

WBS Element	Project Title	Contract Number	Contract Start	Contract End
C.B.10.02.02.40	Physics-based Creep Simulations of Thick Section Welds in High Temperature and Pressure Applications	FEAA90	10/01/17	09/30/2019

Performer Name and Address	Principal Investigator(s)
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BUDGET AND COST REPORT

Prior Year Funds ($K)	**230**
Total Current Year Commitment ($K)	**0**
Projected Current Year Costs ($K)	**230**

	O	N	D	J	F	M	A	M	J	J	A	S
Monthly Planned Costs	16	15	16	21	19	21	31	18	20	15	15	23
Actual Monthly Costs	26	17	9	17	12	32	23	17	13	9.9	5.9	2.1
Monthly Variance	-10	-2	7	4	7	-11	8	1	7	5.1	9.1	20.9
Total costs – planned	16	31	47	68	87	108	139	157	177	192	207	230
Total costs - actual	26	43	52	69	81	113	136	153	166	176	182	184

MILESTONE REPORT

Milestone Designation	Milestone Description	Due Date	Revised Due Date	Completion Date
A	Evaluate current MOOSE capabilities	09/30/2015		09/30/2015
B	Complete Alloy 617 weld characterization	10/30/2015		11/18/2015
C	Receipt of Alloy 740H plates	10/30/2015		11/05/2015
D	Complete welds in Alloy 740H	11/16/2015	7/31/2016	7/31/2016

E	Characterize Alloy 740H welds	02/01/2016	09/30/2016	9/02/2016
F	Creep model development – Stage 1	09/30/2016		9/30/2016
G	Creep Model Development – Stage 2	8/29/2017	11/30/2018	
H	Calibration of Secondary creep	9/30/2017	11/30/2018	
I	Stress Drop Tests	2/01/2017	5/31/2018	6/28/2018
J	Characterization of creep failure mechanisms	4/01/2017	04/30/2018	5/04/2018
K	Secondary creep calibration for welds	5/30/2018	12/15/2018	
L	Creep model development – Completion of Stage 3	8/30/2018	12/30/2018	
M	Creep simulation of a welded joint in Alloy 740H	9/30/2018	1/30/2019	
N	Validation of creep simulation model via an Alloy 740H weld consisting of refined microstructure	9/15/2018	2/28/2019	

TECHNICAL HIGHLIGHTS

Milestone G, "Creep Model Development – Stage 2"

The main task remaining in this milestone is the incorporation of the microstructure into the model. A focused effort was renewed to understand and implement Dream.3D, with an emphasis on reproducing the work performed by a previous summer intern, Doug Smith (summer of 2017). Dream.3D is not a user-friendly software package and considerable effort is needed to correctly simulate microstructures that accurately reflect experimental microstructures, using data obtained from EBSD. Equiaxed microstructures reflecting EBSD data have been generated with success. Next the procedure for simulating elongated grain structure in the weld will be addressed. Then the two microstructures will be joined by either the Potts model or, alternatively, we use a voxel-based representation of the grain structures without creating a conformal surface mesh for each grain boundary, the use simple hexahedron elements to mesh the whole region and thus naturally merge the base and weld parts together without any compatibility issues associated with finite element method.

Milestone H, "Calibration of Secondary creep"

This task is also dependent on the utilization of Dream.3D. However, this calibration is performed on equiaxed, Alloy 617 material – with and without γ' present. This can now be started. A completion date of 11/30/2019 is anticipated.

Milestone I, "Stress Drop Tests"

This task is now completed and the results analyzed.

Milestone J, "Characterization of creep failure mechanisms"

This task is completed.

Milestone K, "Secondary creep calibration for welds"

The simulated secondary creep rates in cross weld creep specimens of Alloy 617 will be calibrated using existing creep data for welds in that alloy obtained in a previous project. It was found that two additional creep tests were needed to perform the calibration. Therefore, two welded samples of Alloy 617 left over from a previous project were creep tested during the 4th quarter. The creep tests provide two additional stress levels at 750°C to allow accurate calibration of the secondary creep rate in the presence of a low volume fraction of γ'. However, calibration of the model is dependent on the successful generation of the duplex weld microstructure using Dream.3D outlined above in Milestone G. Therefore, this task will not start until Milestone G is complete. Projected completion date for this task is now 12/15/2018.

Milestone L, "Creep model development – Completion of Stage 3"

This is the last stage in the development of the creep simulation. The evolution of γ' particles during the creep test will be incorporated into the simulation to allow proper handling of the dislocation interactions with the γ' particles as they grow during long-term, creep tests. The constitutive equations describing γ' growth as a function of temperature in Alloy 740H was completed during this quarter. The radius of the γ' particles has been plotted in Fig. 1 along with data from Alloy 617 which is similar in alloying elements except has lower concentrations of γ'-forming elements and, thus, fewer γ' particles. The coarsening behavior of γ' in Alloy 740H is similar to that in Alloy 617, see, for instance, 750°C plots in Fig. 1a. Fig. 1b shows the coarsening behavior is described adequately by the radius cubed for each aging temperature in both alloys. The temperature dependence of the growth parameter, k, in the equation shown in Fig. 1b, is plotted on a log scale in Fig. 2 as a function of reciprocal temperature. Not only is a linear relationship found but the best fit line equally describes the temperature dependence of k on reciprocal temperature for both the alloys, at least for the data collected at INL. Generally, the grow rate constant is taken as:

$$k = A' \, \boldsymbol{exp}(-Q_{Eff}/RT) \qquad \text{Eqn. 1}$$

where Q_{Eff} is the activation energy associated with the diffusing species as well as the activation energy for vacancy formation, i.e., (Q_{therm}+Q_{Diff}). Thus the relationship in Fig. 2 is a result of:

$$\boldsymbol{ln}\, k = -Q_{Eff}/RT + \boldsymbol{ln}\, A' \qquad \text{Eqn. 2}$$

with the slope of the line in Fig. 2 being equal to Q_{Eff}. In this case, Q_{Eff} is found to be about 320 kJ/mol which is somewhat higher than either the activation energy for aluminum diffusion in nickel, ~250 kJ/mol [1] or molybdenum diffusion in nickel, ~250-280 kJ/mol [2]. Further search of literature is being performed to determine whether values of Q_{Therm} are available to verify the measured value of Q_{Eff}.

The constitutive equation describing the growth of γ', using Eqn. 2, and the value found for Q_{Eff} from Fig. 2, will be incorporated into the model during the 1st quarter of FY19. A completion date of 12/30/2018 is anticipated.

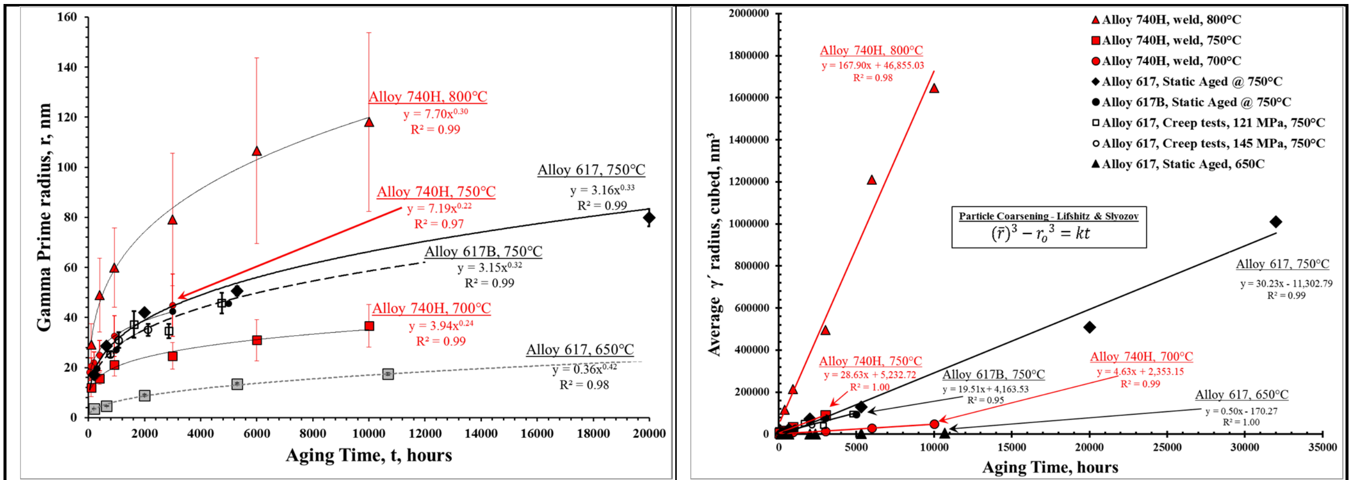

Figure 1. (a) Plot of the γ' radius as a function of aging time and (b) the cube of the γ' radius as a function of aging time. Data includes both Alloy 740H and Alloy 617.

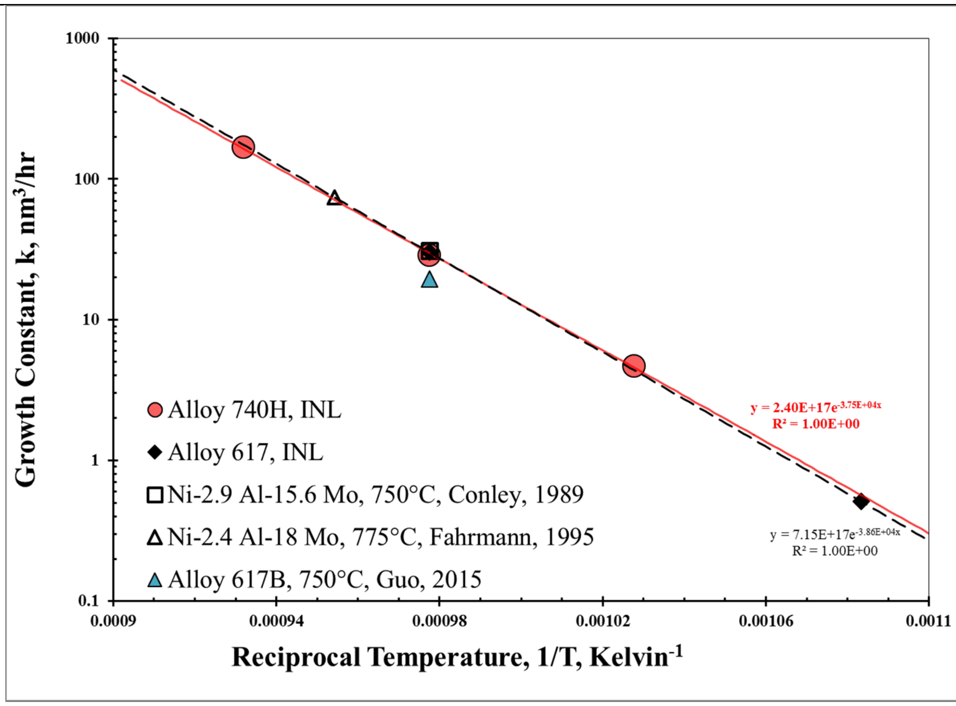

Figure 2. Plot of the growth rate constant as a function of reciprocal temperature for Alloy 740H, Alloy 617, Alloy 617B and two Ni-Al-Mo alloys.

References

[1] H. Allison and H. Samelson, J. Appl. Phys., 30, 1959, pp. 1419-1424.

[2] V.Divya, S.Balam, U.Ramamurty and A.Paul, Scripta Mater., 62, 2010, pp. 621-624.

Milestone M, "Creep simulation of a welded joint in Alloy 740H"

This task will not start until after the model has been calibrated and verified with the existing creep data on welds in Alloy 617 and various material parameters for 740H welds, including generation of synthetic microstructure for welds in Alloy 740H, have been determined.

Completion of this task has been targeted for 1/30/2019.

Milestone N, "Validation of creep simulation model via an Alloy 740H weld consisting of refined microstructure"

Quotes for fabrication of creep samples from the hybrid laser arc weld made and characterized during the 3rd quarter are being obtained and creep specimens should be received by mid-November with creep testing completed by mid-December. Comparison with model simulations using the hybrid laser arc weld metal microstructure then will be performed.

The completion date of this task is targeted for 2/28/2019

ISSUES

Currently no issues are evident other than completion dates have been moved back. Carryover for work in FY19 is $46k.

Report Prepared By	Date
Thomas M. Lillo and Wen Jiang	10/25/2018