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Physics-based Creep Simulations of Thick Section Welds in High Temperature and Pressure Applications

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Quarterly Management Document – FY17, 2nd Quarter, Physics-based Creep Simulations of Thick Section Welds in High Temperature and Pressure Applications

Document # INL/EXT-17-41752

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	10/01/16	09/30/2017
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BUDGET AND COST REPORT

Prior Year Funds ($K)				**56**								
Total Current Year Commitment ($K)				**361**								
Projected Current Year Costs ($K)				**317**								
	O	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**
Planned Costs	**15**	**15**	**15**	**23**	**25**	**33**	**28**	**28**	**30**	**35**	**35**	**35**
Actual Costs	**14.4**	**7.9**	**14.8**	**13.0**	**14.6**	**47.2**						
Variance	**0.6**	**7.1**	**0.2**	**10.0**	**10.4**	**-14.2**						

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		

H	Calibration of Secondary creep	9/30/2017		
I	Stress Drop Tests	2/01/2017	9/30/2017	
J	Characterization of creep failure mechanisms	4/01/2017	6/01/2017	

TECHNICAL HIGHLIGHTS

Milestone G, "Creep Model Development – Stage 2"

Initial calibration of Alloy 617

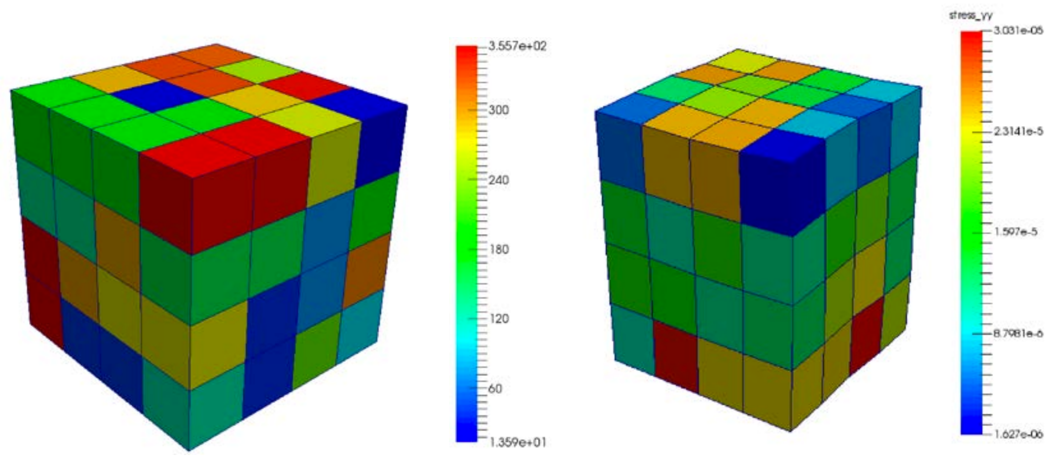

Figure 1. (a) Euler angle component in the representative polycrystalline microstructure (b) Stress along the loading direction

A cube of size 500x500x500 μm^3 with 64 grains is used to calibrate the dislocation density glide model. A pressure of 16 MPa is applied on the top surface and the symmetric boundary conditions are applied on the remaining surfaces. The temperature is given at 1000 C. Random orientations are assigned to every grain as shown in Fig. 1(a). The effect of grain orientation and strain compatibility leads to heterogeneous distribution of stress as shown in in Fig. 1(b). The constitutive parameters in the glide model is calibrated and listed in Table 1. The p and q are shape parameter for glide enthalpy curve. The creep response during 5000 hours are simulated and compared with experimental data in Fig. 2. They show good agreement and indicate that the glide mechanism dominates the initial creep response. The climb model provides important by-pass mechanism and will be calibrated in the future work.

Table 1. Experimentally calibrated parameters for the glide model (Elastic constants C11, C12, C44 and shear modulus G are taken from [1] and others are calibrated from experiment.)

C11 (GPa)	C12 (GPa)	C44 (GPa)	G (GPa)	p	q	Activation entropy (J)	Thermal resistance	Barrier factor	Self harden factor	Latent harden factor	Multiplication factor
170.64	108.39	77.82	77.82	0.78	1.15	5.148×10^{-19}	0.5	0.0045	0.052	0.052	0.01

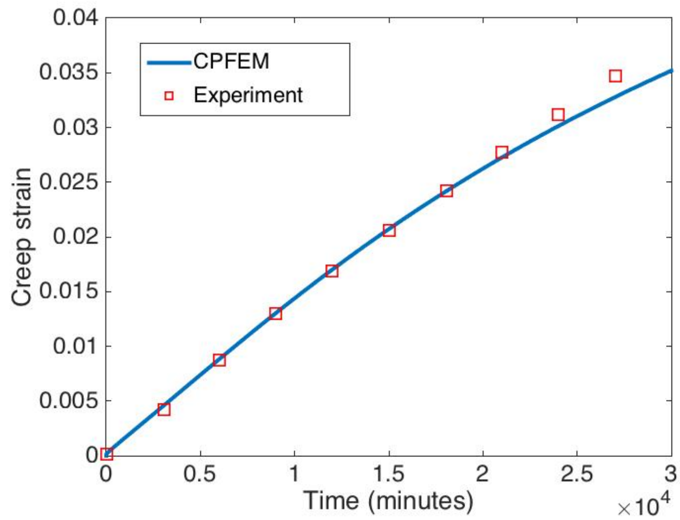

Figure 2. Creep strain of Alloy 617 at 16 MPa and 1000 C during 5000 hours.

Reference

[1] Xiang Zhang and Caglar Oskay, Polycrystal plasticity modeling of nickel-based superalloy IN 617 subjected to cyclic loading at high temperature, *Modelling and Simulation in Materials Science and Engineering*, 24(5), 2016

Milestone H, "Calibration of Secondary creep"
The secondary creep rate data obtained from existing creep data on Alloy 617 will be used to assess the accuracy of the model and then calibrate the model. Work is not scheduled to start on this task until 7/2017 after significant progress has been made on Milestone G.

Milestone I, "Stress Drop Tests"
Table 2 shows the aging matrix for the stress drop tests. These aging treatments will yield material with differently-sized γ' particles so the threshold stress due to the γ' distribution can be determined as a function of size. Aging of sample, SD-1, was completed and the plate was submitted for sample fabrication for the stress drop tests at temperatures of 700, 750 and 800ºC. Additionally, material in the as-received condition (solutionized and aged at 800ºC for 4 hours) was submitted for sample fabrication and stress drop tests also will be performed on this material at 700, 750 and 800ºC. The material aged at 750ºC and 8000 hours is due to be completed by the end of July (3^{rd} quarter of this year) at which time it will also be made into samples for stress drop testing to complete the dataset of three different γ' size distributions, all tested at three different temperatures to yield the relationship between the threshold stress and γ' size as a function of test temperature. This relationship will be needed for the modeling and simulation task.

Finally, a summer intern (a graduating senior in materials science) will be hired to carry out the stress drop tests and analyze the data, under the direction of the PI for this project, during the intern's 10 week summer appointment.

Table 2. Base Metal Aging Information for Stress Drop Tests

Sample ID	Aging Temperature	Target Aging Time, hours	Insertion Date	Expected Removal date
SD-1	750	4000	9/1/2016	2/15/2017
SD-2	750	8000	9/1/2016	7/31/2017

Milestone J, "Characterization of creep failure mechanisms"
As of the end of the second quarter, seven creep tests have been completed, see Table 3. They are being prepared for optical metallography and characterization of these samples using optical metallography and SEM, including orientation imaging microscopy (OIM), has begun and is planned to require a minimum of two months.

Other highlights

Short Term Creep Tests

Shorter term creep testing of welded Alloy 740H for development of model parameters is continuing and seven tests have been completed with one currently running, 740-Q1-10 at 750°C and 230 MPa. Once the FY17 funding arrived, additional creep samples were submitted for fabrication from welds made in the 4th quarter of FY16. Eighteen cross weld creep samples have been ordered as well as four all-weld metal samples to finish off the test matrix in Table 3. (Some creep tests with conditions that duplicate some of the tests in Table 3 will be run to assess variability of the creep behavior, due possibly to weld defects which can range in size and number from sample to sample.)

Table 3. Short term creep testing parameters for modeling development

Specimen ID	Test temperature, °C	Test type	Initial Stress, MPa	Orientation	Expected rupture life, hrs	Start date	Finish date	Rupture life, Hrs
740-Q1-01	700	Rupt	413	CW*	200	8/24/2016	9/21/2016	639
740-Q1-08	700	Rupt	413	CW	500	11/28/2016	12/27/2016	670.8
740-Q1-06	700	Rupt	395	CW	1000	01/09/2017	02/16/2017	879.3
	700	Rupt	344	CW	1000			
740-Q1-03	750	Rupt	350	CW	200	9/29/2016	10/07/2016	184
740-Q1-05	750	Rupt	305	CW	500	10/18/2016	11/06/2016	450
740-Q1-10	750	Rupt	230	CW	1000	03/10/2017		
740-Q1-04	800	Rupt	240	CW	200	10/10/2016	10/15/2016	123.6
740-Q1-02	800	Rupt	200	CW	500	11/08/2016	11/22/2016	326.8
	800	Rupt	138	CW	1000			
	700	Rupt	400	AWM**	500			
	750	Rupt	248	AWM	500			
	800	Rupt	144	AWM	500			

* CW = Cross weld
** AWM = All Weld Metal

Long Term Creep Tests

Two long term creep tests were started for verification of the final creep simulation. The test at 800°C and 83 MPa was expected to run on the order of 9700 hours. However, this sample failed during the second quarter of FY17 after only 4592 hrs. The fracture surface is being evaluated to determine if a welding defect was located in the gage section of this sample. The other long term test at 750°C and 141 MPa has surpassed 5200 hours with no indications of imminent failure (the expected rupture time is also on the order of 9700 hours).

γ' Aging Study

Aging of welds at 700, 750 and 800°C continues. Table 4 summarizes the current progress on aging. TEM samples will be made from base metal, weld metal and metal in the heat affected zone at each aging time and temperature Table 4. The γ' size, morphology and volume fraction will be characterized to understand coarsening behavior during extended times at elevated temperatures. Changes in size, shape and volume fraction can have a significant impact on creep behavior which will need to be addressed in the developing creep simulations with the coarsening relationships documented under this task. Characterization efforts were started. TEM samples from the HAZ were extracted by focused ion beam (FIB) methods.

Table 4. Aging Conditions for γ' Coarsening Study

Aging Temperature, ºC	Aging Time, hrs	Insert Date	Removal Target date	Date/time out	Actual aging hours
700	50	9/6/2016 8:56	9/8/2016 10:56	9/8/2016 10:55	50.0
	100	9/12/2016 9:34	9/14/2016 11:34	9/14/2016 11:30	99.9
	200	9/22/2016 9:35	9/26/2016 13:35	9/26/2016 13:38	200.0
	400	9/29/2016 9:15	10/7/2016 17:15	10/7/2016 15:00	397.7
	1000	10/13/2016 8:20	11/7/2016 8:20	11/4/2016 8:45	926.1
	3000	11/14/2016 10:39	2/8/2017 20:31	2/8/2017 20:00	2999.5
	6000	2/21/2017 9:35	6/26/2017 10:06		
	10000				
750	50	9/6/2016 8:56	9/8/2016 10:56	9/8/2016 10:56	50.0
	100	9/12/2016 9:34	9/14/2016 11:34	9/14/2016 11:30	99.9
	200	9/22/2016 9:35	9/26/2016 13:35	9/26/2016 13:38	200.0
	400	9/29/2016 9:15	10/7/2016 17:15	10/7/2016 15:00	397.7
	1000	10/13/2016 8:20	11/7/2016 8:20	11/4/2016 8:45	926.2
	3000	11/14/2016 10:39	2/8/2017 20:30	2/8/2017 20:00	2999.5
	6000	2/21/2017 9:35	6/26/2017 10:06		
	10000				
800	50	9/6/2016 8:56	9/8/2016 10:56	9/8/2016 10:56	50.0
	100	9/12/2016 9:34	9/14/2016 11:34	9/14/2016 11:30	99.9
	200	9/22/2016 9:35	9/26/2016 13:35	9/26/2016 13:38	200.0
	400	9/29/2016 9:15	10/7/2016 17:15	10/7/2016 15:00	397.7
	1000	10/13/2016 8:20	11/7/2016 8:20	11/4/2016 8:45	926.2
	3000	11/14/2016 10:39	2/8/2017 20:30	2/8/2017 20:00	2999.5
	6000	2/21/2017 9:35	6/26/2017 10:06		
	10000				

ISSUES

Report Prepared By	Date
Thomas M. Lillo	04/13/2017