## AM COMPUTATIONAL TECH Software

Manual of the free version

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## MANUAL

# Software for process modeling of metals additive manufacturing

Thermomechanical simulation and simulation of microstructure

# Chapters

- Introduction
- Menus and toolbars
- Example I: Simulation of DLD printed sample
- Example II: Simulation of SLM printed sample

#### **INTRODUCTION**

AM Computational Tech (ACT) is software for process modeling of metal 3D printing. This manual explains how to simulate metals 3D printing process with the free version of ACT software. The free version of ACT has some computational algorithms for thermomechanical simulation of metals 3D printing with direct laser deposition (DLD) and selective laser melting (SLM) methods. Although the free version of ACT has limitations, this is useful for teaching and research activities.

Computational features of ACT software for DLD method are:

- Time-dependent thermomechanical simulation (thermal history, thermal deformation, and thermal stress)
- Extracting cooling/heating curves for any desired point of the printed sample
- 3D microstructural simulation (grain topology of solidified and heat-affected zones)
- Manual printing of simple 3D shapes
- Adjusting print parameters
- Simplifying laser heat input by a constant temperature
- Exporting results to excel
- Saving snapshots of the results

Computational features of ACT software for SLM method are:

- Time-dependent thermal simulation
- Creating a 3D shape to print
- Adjusting print parameters
- Extracting cooling/heating curves for any desired point of the printed sample
- 3D microstructural simulation (grain topology of solidified and heat-affected zones)
- 2D solidified microstructure
- Predicting melt-pool shape
- Predicting the final printed sample
- Considering Gaussian function for laser heat input
- Exporting results to excel
- Saving snapshots of the results

#### **MENUS and TOOLBARS**

ACT software has a menu, a toolbar for thermomechanical simulation and results-postprocessing, a toolbar for manual 3D microstructure simulation, and several screens.

	🚰 AM Computational Tech - Free Version (only for accademic teaching and research activities)	- D ×	
Menu —	File View Tools Add Process Solution Post-Processing Result Processing Help		
Toolbar	D.D. • Malanda Later Porter Opt. Excludion Opt. Port. Resp. v.t. • Resolut. v.t. • Rev. Index 10. December 2010. December 2010. X	Plane •	
For thermomechanical simulation and automatic 2D microstructural simulation	Relation (1)         13         Relation (2)         15         Relation (2)         15         Relation (2)         15         Relation (2)         15         Relation (2)         16         Weath         100         Height         100         Graphic Resultation         40         Add a layer >>         1         Paire Chronic           0000         000         15         Relation (2)         15         Zerme         1         Medit         100         Graphic Resultation         40         Add a layer >>         1         Paire Chronic           0000         000         100         100         Height         100         Graphic Resultation         40         Add a layer >>         1         Paire Chronic	SIM 2D Proife Mcroatructure	Screens
Screens	Reads 1 2 K Source	Grier Size	Model and results viewers (microstructure)
Model and results viewers (thermomechanical)	[011] [Sense] [311.5		
Toolbar →	BU Monstructure toolhare Coptions Call + RearIts + States Ready		

Although everything is available for simulation in the menu, toolbars are designed for easy using computational tools.

<u>F</u> ile	<u>V</u> iew	Tool	Add Process	Solution	Post-Processing	Result Processing	<u>H</u> elp
DLD	•		M <u>a</u> terials Propertie <u>H</u> eat Source <u>D</u> LD Options <u>S</u> LM Options	es Ctrl+A Ctrl+H Ctrl+D Ctrl+S	ot. Solution	Opt. Print	
een	Rotati		<u>C</u> FD	Ctrl+C	Rotation (Z):	15 Zoom:	1
oling (			3D <u>M</u> icrostructure	Ctrl+M			
<u>8</u> <u>–</u>			<u>P</u> ostprocessing	Ctrl+P			
reen			<u>A</u> dd Module				
LD Sc		_	Solution Options	Ctrl+0			
File	View	Tool	s Add Process	Solution	Post-Processing	Result Processing	Help
				Solut	ion/Results Saving (	Options	
DLD	-	Ma	terials Lase	Print			
<u>F</u> ile	<u>V</u> iew	Tool	Add Process	Solution	Post-Processing	Result Processing	<u>H</u> elp
		$\square$				DLD/SLM too	

ACT has two toolbars. In the toolbar for thermomechanical simulation, you can choose the print method (DLD or SLM). For each method, different results-postprocessing tools are available.



Simulation steps are straight forward with the toolbar.



The next step is applying materials properties after selecting the print method. In the free version of ACT, only constant value for the material properties could be applied.



Materials Laser Printer Opt. Solution Opt.	Print
Heat Source       Image: Comparison of the system of the sy	Heat Source Laser (SLM) Laser (DLD) Temperature of the motien metal (C) 2000

The third step is the definition of laser heat input.

The next step is the adjustment of some technical parameters for printing like chamber temperature, powder feeding rate in the DLD method, scan speed, hatch spacing, the print pattern in the SLM method, etc.

DLD Materials Laser	Printer Opt. Solution Op	rt. Prin	nt				
DLD Options Delions Manual Print Auto Print Torch	B	DLD Op Options	tions Manual Print	Auto Print	Torch	Ļ	
Chamber temperature (C) 27			🔿 Auto Pr	rint	Manual Print		
Bed temperature (C) 27			Mesh Size	e	X Shift (mm)	0	
Mass (mg/s)			Print Leng 15	gth (mm)	Y Shift (mm)	0	
Speed (mm/s) 2			Print Widt	th (mm)	Print Dire	ection	
☑ Fully attached to the substrate	<ul><li>Show the plastic region</li><li>Show the crack formation</li></ul>		Number o	of layers		Y-Dir	
	Cancel OK				[	Cancel	ОК

The fifth step is numerical solution options and some configurations for results-postprocessing.

DLD Materials Laser Printer O	pt. Solution Opt. Print	
Solution Options	Solution Options	Solution Options
SLM Solution Options DLD Solution Options Saving Results	SLM Solution Options DLD Solution Options Saving Results	SLM Solution Options DLD Solution Options Saving Results
Mcrostructural Mesh Resolution (um) Themomechanical Mesh Size (un) b/a: 1 50000000000000000000000000000000000	Microstructural Mesh Resolution (um)  Themomechanical Mesh Size (mm)  0.5	SLM     DLD     Temperature Viewer       X
Fast Solution (Low accuracy) Full Solution (high accuracy) Cancel OK	Cancel OK	Cancel OK
Solution Options	Solution Ontions	
SLM Solution Options DLD Solution Options Saving Results	SLM Solution Options DLD Solution Options Saving Results	
SLM     DLD     Temperature Viewer       X	SLM       DLD       Temperature Viewer <ul> <li>Maximum Value</li> <li>Set a fixed value</li> <li>3000</li> </ul> Interval of results saving         Simulation Time Step(s)         5	
Cancel OK	Cancel OK	

The sixth/last step is a click on the print button. A simulation with ACT needs several minutes to hours, depending on the size of the model and the accuracy of the simulation.

Some results-postprocessing options are available for each of the DLD or SLM mothed to extract results versus time at any point and results from the profile at any cross-section.



It is possible to extract results at any cross sections by selecting the 'X Plane' or 'Z Plane' and position of the cross-section from the origin.

Temp. Profile (K)	Thermal Stress (MPa)	Deformation (um) 🔻	X Plane 👻	

Manual simulation of 3D grain structure is simple with its toolbar. First, the size of the simulation domain needs to be specified (a) in  $\mu$ m. Then, melting point and kinetics parameters must set for heterogeneous and homogeneous nucleation by considering Arrhenius forms. Then, the software is using the Cellular Automata method for microstructural simulation.

If the heating/cooling curve is available for the point selected for microstructural simulation, heat affected zone microstructure could be estimated, too.





### **EXAMPLE I:** Simulation of DLD printed sample

In this example, a wall will be printed with the DLD method. The thickness of the wall is 3 mm, and the length is 15 mm. The scan speed is 1 mm/s, the metal powders feeding rate is 1 mg/s, and the laser temperature is 2000 C. Print five layers on each other.

Solution:

Step 1: Select DLD in the toolbar.



Step 2: Insert material properties.

Physical Properties	
Thermal Expansion	13e-7
Heat Capacity	500
Density	7800
Thermal Conductivity	7.1
Mechanical Properties	
Mechanical Properties	1.8=11
Mechanical Properties	1.8e11
Mechanical Properties Elastic Modulus Poisson Ratio	1.8e11 0.3
Mechanical Properties Elastic Modulus Poisson Ratio Yeild Strength	1.8e11 0.3

Step 3: Apply molten metal temperature received from the nozzle.

Temperature of the motlen metal (C)



Step 4: Apply metal powders feeding rate and scan speed.

Chamber temperature (C)	27
Bed temperature (C)	27
Mass (mg/s)	1
Speed (mm/s)	1
☑ Fully attac	hed to the substrate

Continued Step 4: Define the number of the print layers, the print length, and width.

Manual Print
X Shift (mm) 0
Y Shift (mm) 0
Print Direction
X-Dir
Y-Dir

Step 5: Set the mesh size of the thermomechanical numerical simulation. Although you can select any value lower than the wall size, 1 mm is selected.

SLM Solution Options	DLD Solution Options	Saving Results	
Microstructural M	1 um	$\sim$	
Thermomechani	1		

Continued Step 5: Select some points to extract results versus time.

SLM	DLD	Temperature Viewer	
	х	2	
	Y	8	
	Z	4	Clear
			Add Point
Point1 Point2 Point3 Point4	- X: 72, - X: 72, - X: 72, - X: 72, - X: 72,	f: 18, Z: 1 f: 18, Z: 2 f: 18, Z: 3 f: 18, Z: 3 f: 18, Z: 4	

Cancel OK	

Continued Step 5: Adjust some parameters for results-postprocessing. Saving results in folder '...\Results\DLD\Thermo' for every five time-steps.

SLM Solution Options	DLD Solution Options	Saving Resu	lts
SLM DLD	Temperature Viewer		
(	Maximun Value		
	1700		
Interv	al of results saving		
Sim	ulation Time Step(s)		
		Cancel	ОК

Step 6: Run simulation!



Activate results-postprocessing after solution.

<u>F</u> ile	<u>V</u> iew	<u>T</u> ools	Add Process	Solution	Post-Processing	Res	sult Processing	<u>H</u> elp
		$\square$					DLD/SLM tool	

Export the results of the selected points by click on DLD Points.

Temp. vs t	rs t	Temp. Profile (K)	The	rmal Stress (MPa)		Deformatio	n (um) -	X Plane	•	
DLD Points	120 H	eight: 120	Graphic Resolution	40	Add a layer >>	1	Paint Clear			SLY
Export to Excel	DLI	D Points								120 P

Then, results could be found in the cooling curve screen.



Select 'Z Plane' and 7 mm as an off-set to extract profiles of the last time step results (temperature, von Mises stress, and deformations). You can find the results in thermal, stress, and deformation screens.









Some snapshots could also be found in '...\Results\DLD\Thermo'.



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### **EXAMPLE II:** Simulation of SLM printed sample

In this example, a cube will be printed with the SLM method. The size of the cube is 150  $\mu$ m by 100  $\mu$ m by 100  $\mu$ m. The scan speed is 1250 mm/s. The laser thickness is 80  $\mu$ m, and the powder layer is 30  $\mu$ m. The hatch spacing is 50  $\mu$ m, and the laser power is 200 W.

#### Solution:

First, create a model by drawing a grid with 150  $\mu$ m width and 150  $\mu$ m height. Different values could be selected for the resolution, but 50  $\mu$ m is selected. The size of the graphic resolution will not affect the computational results. Click on 'Paint' when you input all the values of width, height, and graphic resolution to see the grid. If you click in each of the small squares of the grid, you will select it and create a cube 50  $\mu$ m by 50  $\mu$ m by 50  $\mu$ m in the 3D view (SLM Screen I).

Width:	150	Height:	150	Graphic Resolution	50	Add a layer >>	1	Paint Cle	ar	SLM
										2D Prolit
										fe Micros
										tructure
										Grian Size
									1	Γ
								1	1	



Continue selecting squares to create the first layer (150  $\mu$ m by 100  $\mu$ m by 50  $\mu$ m).

Click on 'Add a layer' to add a new layer on the previous one.

Width:	150	Height:	150	Graphic Resolution	50	Add a layer >>	1	Paint Clear
,								

In the 2D graphic, the green color would be changed to light gray. Click on the gray ones to create the second layer.

Width:	150	Height:	150	Graphic Resolution	50	Add a layer >>	2	Paint Clear
Г								
l								
L MC IN	150		150	C. L. D. L.C.	50	LAULT	2	
; width:	150	Height:	150	Graphic Resolution	50	Add a layer >>	2	Paint Clear
				1				



Finally, there is a cube with 150  $\mu m$  by 100  $\mu m$  by 100  $\mu m$  size for simulation.

Step 1, select DLD in the toolbar.

Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	
DLD - DLD SLM	Materials	Laser	Printer Opt.	Solution Opt.	Print	

Step 2: Insert material properties.

Physical Properties	
Thermal Expansion	13e-6
Heat Capacity	500
Density	7800
Thermal Conductivity	7.1

Step 3: Apply the laser parameters.



Step 4: Input the powder layer thickness, scan speed, and hatch spacing.



Continued Step 4: Select a print pattern (Only a print pattern is available in the free version of ACT).



Continued Step 4: Select a cross-section to see the estimated melt pool shape and depth.

Options Print Patterns 2D Microstru	ucture
Active simulation of	2D microstructure (SLM)
2D cross section position (h)	20
Activation Energy (J/mol.K)	245000
(Heterogeneous Nucleation in	melt-pool)

Step 5: Set the mesh size of the thermomechanical numerical simulation. Although you can select any value, 4  $\mu$ m is selected.

Suppose the cube is the whole sample, input 1 for b/a parameter. If the sample is part of the real sample, you need to input another value for b/a.

SEM SOLUTION	Options	DLD Solution Options	Saving Results
Microstru	ictural M	esh Resolution (um)	1 um 🗸 🗸
Thermo	mechani	ical Mesh Size (um)	4
b/a:			
1			$ \prec $
		$\langle$	
			Com Domain (a)
			to Real Size (b)
			Sample
			-
	1		a de la 🕈 de la del
Fast Solution	Low ac	curacy) F	Full Solution (high accuracy)
Fast Solution	(Low ac	curacy) F	Full Solution (high accuracy)
Fast Solution	(Low ac	curacy) F	Full Solution (high accuracy)
Fast Solution	(Low ac	curacy) F	Full Solution (high accuracy)
Fast Solution	(Low ac	curacy) F Temperature Viewer Maximun Value	Full Solution (high accuracy)
Fast Solution	(Low ac DLD (	curacy) F Temperature Viewer Maximun Value Set a fixed value	Full Solution (high accuracy)
Fast Solution	(Low ac DLD (	curacy) F Temperature Viewer Maximun Value Set a fixed value 3000	Full Solution (high accuracy)
Fast Solution	(Low ac DLD ( (	curacy) F Temperature Viewer Maximun Value Set a fixed value 3000	Full Solution (high accuracy)
Fast Solution	(Low ac DLD ( ( ()	curacy) F Temperature Viewer Maximun Value Set a fixed value 3000 al of results saving	Full Solution (high accuracy)
Fast Solution	(Low ac DLD ( ( () Sim	curacy) F Temperature Viewer Maximun Value Set a fixed value 3000 al of results saving nulation Time Step(s)	Full Solution (high accuracy)
Fast Solution	(Low ac DLD ( ( () Sim	curacy) F Temperature Viewer Maximun Value Set a fixed value 3000 al of results saving nulation Time Step(s) 5	Full Solution (high accuracy)
Fast Solution	(Low ac DLD ( ( (	curacy) F Temperature Viewer Maximun Value Set a fixed value 3000 al of results saving nulation Time Step(s) 5	Full Solution (high accuracy)
Fast Solution	(Low ac DLD ( ( (	curacy) F Temperature Viewer Maximun Value Set a fixed value 3000 al of results saving nulation Time Step(s) 5	Full Solution (high accuracy)

Step 6: Run simulation!

-	Step 6	
	Print	
L	-	J

Activate results-postprocessing after solution.

<u>F</u> ile	<u>V</u> iew	<u>T</u> ools	Add Process	Solution	Post-Processing	Result Processing	<u>H</u> elp
		$\square$				DLD/SLM tool	

Check the folder '...\Results\SLM\Thermo' for thermal results snapshots.



Check the folder '...\Results\SLM\ Micro' for 3D melt-pool shape and solidified shape.



Check the folder '...\Results\SLM\ Micro' for 2D melt-pool shape at the cross-section.

