5. Appendix

5.1. OTOM Guide

This section provides some documentation regarding the OTOM (spin-off software). This tutorial manual is based on the Beta version of the software. In future, many more functions shall be made operational in the software. The optical part of OTOM can be used to measure the intensity and transfer of the laser energy to different objects, and thermal model to estimate the temperature of the thermoplastic material. All the parameters that are provided as an input for OTOM can be divided into Geometrical Parameters, Process Parameters, and Computational Parameters. This manual illustrates a simple example to highlight the features of OTOM.

5.1.1. Definition of Geometric Parameters

In this section, the Geometric Parameters of Laser Assisted Tape Winding process are defined along with an interpretation of the values that are entered in the respective fields. Figure 65 shows the window that displays all geometrical parameters in the OTOM software.

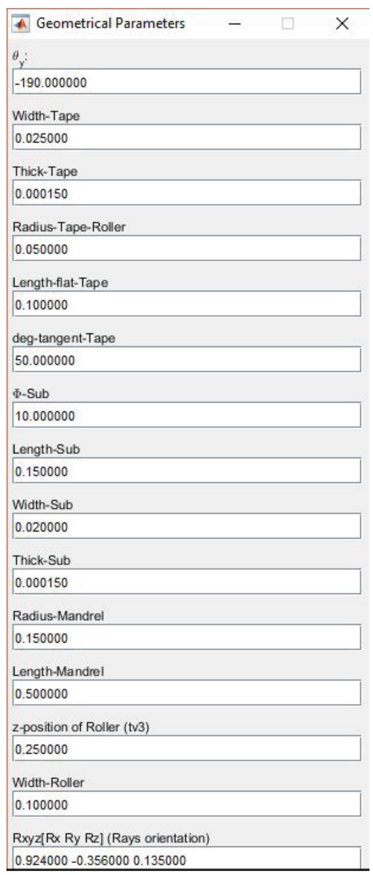


Figure 65: Geometrical Parameters Window.

Now the following figures give a brief description of each geometrical parameter that appears in the window shown in Figure 65. The parameter given in Figure 66 defines the angle of Tape/Roller with respect to Y axis. The unit for this field is deg.

Figure 66: Angle of Tape/Roller to Y axis.

The width of thermoplastic tape that is being used in Laser Assisted Tape Winding (LATW) can be defined in Figure 67. The width may be defined in meters(m).

Figure 67: Width of Tape.

The thickness of the thermoplastic tape that is being used in LATW can be defined in Figure 68. The unit for the width may be defined as meters(m).

Figure 68: Thickness of Tape.

The geometrical specifications of the roller can be inserted in following fields. First of all, Figure 69 defines the radius of the Tape/Roller. The unit for the radius is, again meters (m).

Figure 69: Radius of Tape/Roller.

The next geometrical parameter you see is the length of the flat part of the tape as shown in Figure 70. This parameter describes the part of tape length which do not have a contact with roller. This is defined in meters(m).

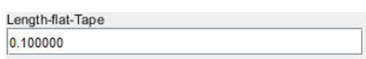


Figure 70: Length of flat part of Tape.

The next parameter, given in Figure 71 defines the tangent angle of tape to the roller. It is described in deg.

Figure 71: Angle of tangent of Tape to Roller.

The angle ϕ is the angle of substrate orientation.The unit for defining ϕ is deg.

Figure 72: Angle of substrate orientation.

The parameter shown in Figure 73 is used to define the length of the substrate on which the LATW process winds the thermoplastic tape. It is defined in meters (m).

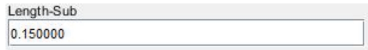


Figure 73: Length of the Substrate.

The width of substrate is defined in Figure 74 in meters(m).

Figure 74: Width of the substrate.

To complete the definition of the substrate, it is also necessary to describe the thickness. This can be done in the parameter field shown in Figure 75 in meters(m).

Figure 75: Thickness of the substrate.

The next important component used in LATW is the mandrel. So it is necessary to define the geometric dimensions of the mandrel. First of all, we define the radius of the cylindrical mandrel in the parameter field shown in Figure 76. The measurement is specified in meters(m).

Figure 76: Radius of mandrel.

After defining radius, the length of the mandrel is defined which is also as meters(m) in the field given in Figure 77.

Figure 77: Length of mandrel.

After defining the dimensions of the components, it is also required to describe their relative orientation in space in a global coordinate. First of all, Figure 78 allows you to define the location of the roller on the mandrel in meters(m).

Figure 78: The location of roller on mandrel.

In the next field in Figure 79, the width of the roller is determined in meters(m).

The field shown in Figure 80 is used to describe the direction of laser rays in terms of x,y,z components.

To describe the dimension of the laser head, half length and half width of laser head along with number of x and y nodes (meters, meters, digit, digit) can be defined which is shown in Figure 81.

Figure 79: Width of roller.

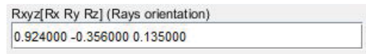


Figure 80: Direction of Laser rays (x,y,z components).

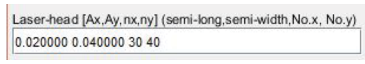


Figure 81: Dimension of Laser Head in terms of half of length and half of width and the number of x and y nodes.

The location of the laser head can be inserted in Figure 82 as meter.

Figure 82: Laser head location.

5.1.2. Definition of Process Parameters

In this section the parameters that govern the process of LATW/LATP will be defined in order to comprehend the meaning of their values. Thus the process parameters should be filled in the following table which is illustrated in Figure 83. This table appears in the window of Process Parameters in OTOM.

The Figure 84 shows material properties of both tape and substrate separately. The first value (from left to right) is $K_{x,y,z}$ which shows the thermal conductivity coefficient of tape or substrate and the corresponding unit is $Wm^{-1}k^{-1}$. The second value ρ is the density of tape or substrate which has the unit of kgm^{-3} and third value C_p shows the heat capacity with unit of $Jkg^{-1}K^{-1}$.

Next parameter is the velocity of tape feed which is defined in Figure 85 and the unit is $\frac{m}{s}$.

The total laser power describes the output power of laser which emits to all objects including tape, substrate, mandrel, and roller and the unit is watt(W). Figure 86 depicts the table which has to be filled for value of this parameter.

The Laser-ID parameter sets the intensity distribution of laser head as either Gaussian (2) or uniform (0). This values can be set in Figure 87.

The Figure 88 shows the absorption coefficient of tape or substrate (Not in use). This value has been replaced with a non-linear angle-dependent absorption curve of thermoplastic prepreg into the software.

The incoming temperature value of tape and substrate have to be filled in incoming-temperature for both tape and substrate and the unit is ^0C. Figure 89 illustrates how to describe this value.

The heat transfer coefficient for both tape and substrate can be defined in Figure 90 and the unit values for both of them are expressed in $wm^{-2}K^{-1}$.

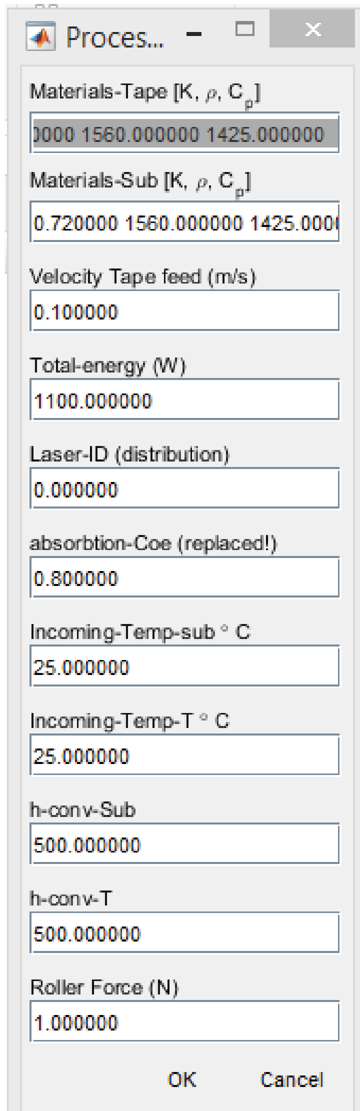
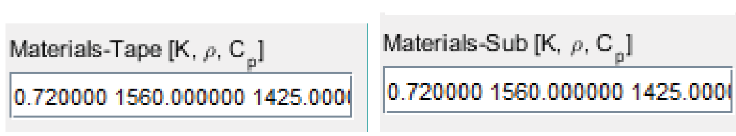


Figure 83: Table of Process Parameters.



(a) Tape (b) Substrate

Figure 84: Material properties of Tape and Substrate.

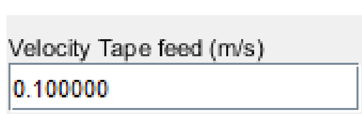


Figure 85: Feed velocity of Tape.

The force which is applied by roller on both tape and substrate is defined Figure 91 and the unit is Newton(N).

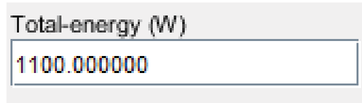


Figure 86: Total laser power.

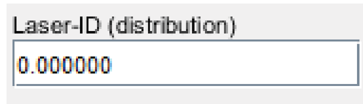


Figure 87: Laser ID (0 for uniform, 2 for Gaussian).

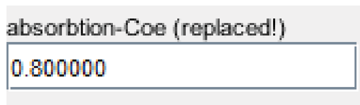
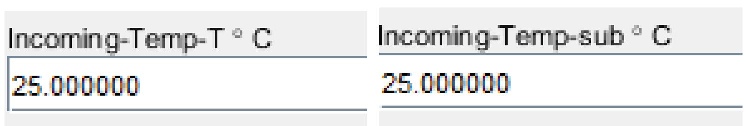
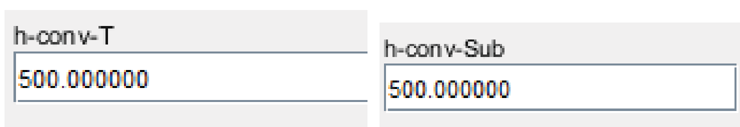


Figure 88: Absorption Coefficient (not functioning in current version).



(a) Tape (b) Substrate

Figure 89: Incoming temperature for both tape and substrate.



(a) Tape (b) Substrate

Figure 90: Heat transfer coefficient for both tape and substrate.

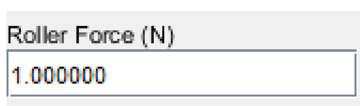


Figure 91: Roller force.

5.1.3. Computational Parameters

This section outlines the various adjustments that can be made in computational parameters. These parameters decide the time taken to perform a simulation of the process, as well as the accuracy. The various parameters in Figure 92 can be changed including the number of nodes of tape and substrate. The following figures show the individual text boxes for inputting various parameters. Their descriptions are also provided below.

First of all, it is required to set the number of nodes along the length of the substrate in the text box show in Figure 93.

Second, the number of nodes along half of the width of the substrate should be entered as shown in Figure 94.

Next, the number of nodes on the width of the thermoplastic tape being used for the process is entered in the blank shown in Figure 95.

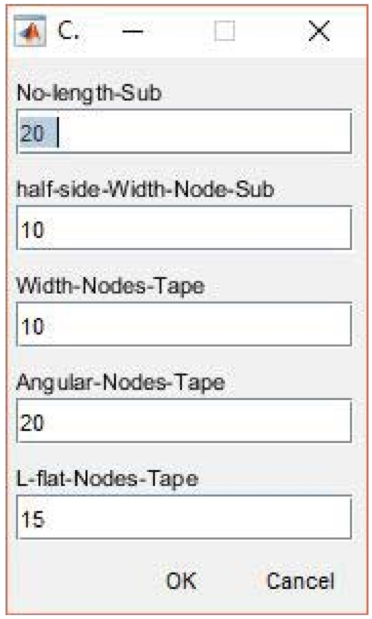


Figure 92: Window for setting Computational Parameters.

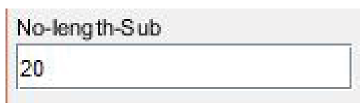


Figure 93: Number of nodes along the length of substrate.

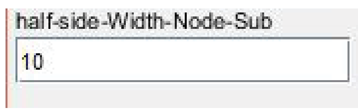


Figure 94: Number of nodes along the half width of substrate.

Figure 95: Number of nodes along the width of tape.

Then the number of angular nodes in modeling the tape is inserted as shown in Figure 96.

Figure 96: Number of angular nodes on tape.

The last computational parameter to be set is the number of nodes of the flat part of the tape. This is set in the text box shown in Figure 97.

Figure 97: Number of nodes of flat part of tape.

5.1.4. *Installation of OTOM*

For the installation of the OTOM package, there are two options. The first option is to install the whole package off-line which is about 500 MB. The other option is just 20 MB, and it uses the Internet to collect the data from the website. You can click on either one to install the respective types of packages. The following image in Figure 98 shows the respective images for the installation windows for both package installation wizards.

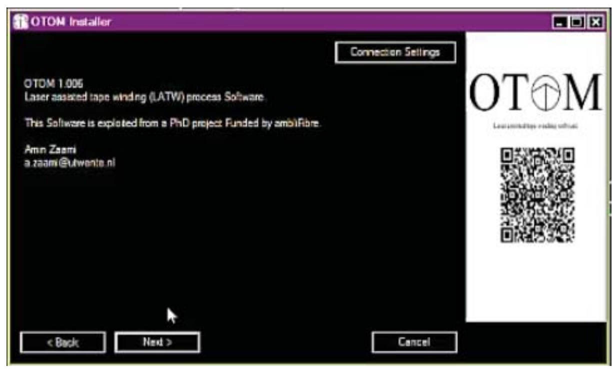


Figure 98: Installation window of OTOM.

Clicking Next, you are directed to a window in Figure 99 that asks you to choose the drive where you would like to install OTOM. It is recommended to add a shortcut of the installed software on the desktop.

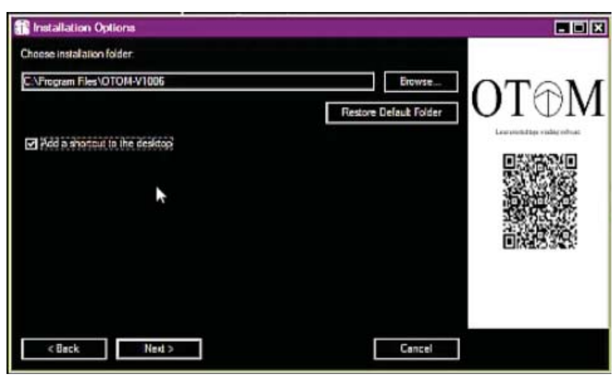


Figure 99: Location to install OTOM.

The Next button directs you to the License Agreement in Figure 100. Check the box stating that you agree to the terms of the license agreement and click Next.

This takes you to a confirmation window. Once you have confirmed the drive where you want to install OTOM, click Install, and the installation process begins. Now, all that is required is for the installation process to be completed and then OTOM is successfully installed on your computer.

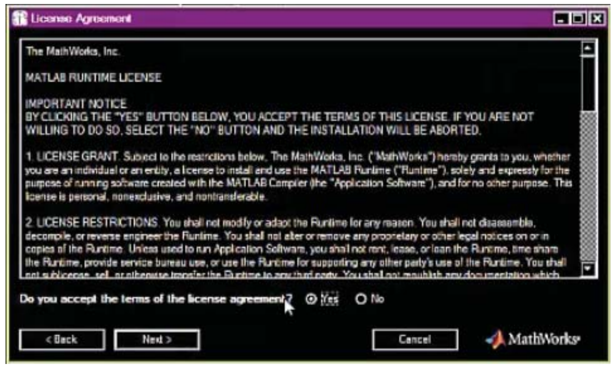


Figure 100: License agreement window of OTOM. (Use a proper licensed version to avoid problems).

The installation wizard will show you an installation successful window as in Figure 101 which indicates that OTOM can now be run on your system.

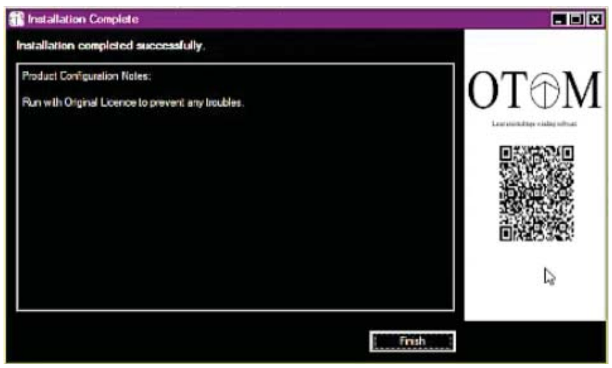


Figure 101: Window of installation successfully completed.

To open OTOM, you can double click on the created desktop shortcut. The graphical interface that opens is shown in Figure 102.

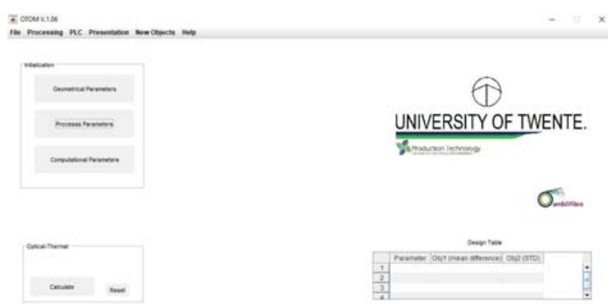


Figure 102: OTOM start page after successful installation.

5.1.5. 3D output

Simulating 2D and 3D model is discussed in this section. First go to tab ”Process” then choose ”Initialization” then click ”2D/3D Substrate” as in Figure 103.

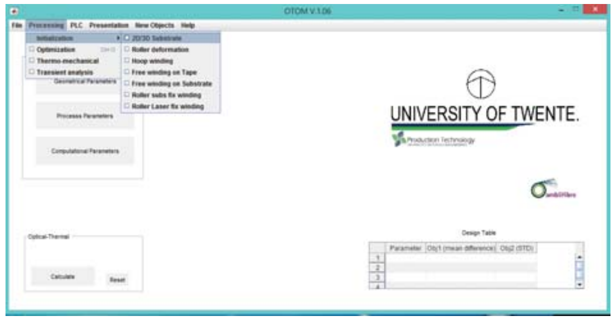


Figure 103: Initialization for modeling 2D/3D.

Then as Figure 104 a popped-up window shows the geometry of 2D/3D substrate to choose 2D, 3D or 2D/3D simulation.

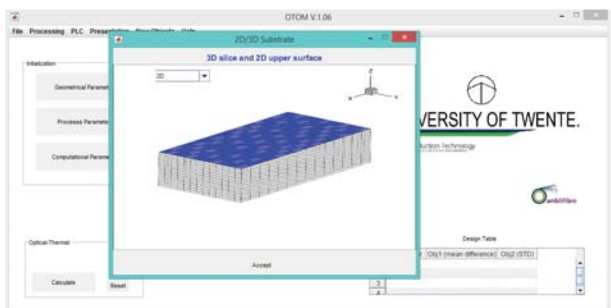


Figure 104: Selecting the simulation modeling 2D/3D.

In this case ”2D and 3D” simulation is chosen then the number of nodes in z-direction (Thickness direction) is inserted. At the left bottom for instance 6 has been set for number of nodes which means that the software considers substrate geometry with 6 nodes. Since during the LATW process the substrate may become thicker thus the thickness has to be considered as an important factor otherwise the wrong results may be obtained. The following Figure 105 depicts how to put the number of nodes.

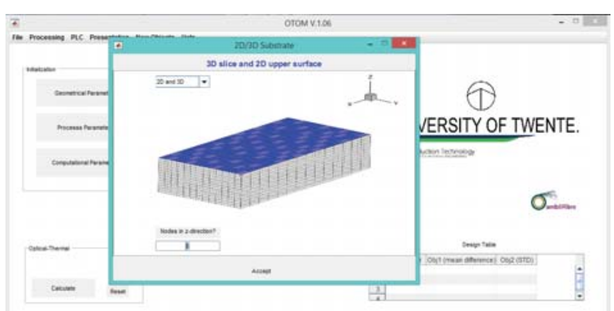


Figure 105: Modifying number of nodes in thickness direction.

After that by clicking in prescribed Geometrical, Process and Computational parameters and clicking OK at the end of each table the software will be ready for calculation. Figure 107 and Figure 108 show how to set these parameters.

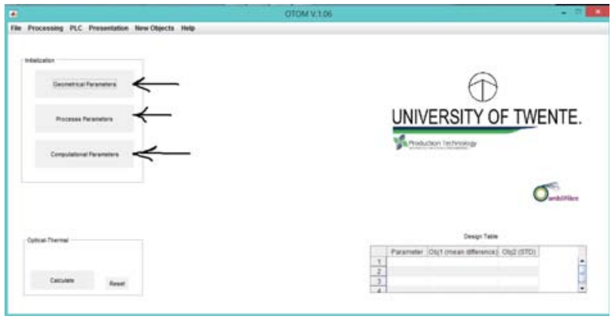


Figure 106: Selecting each prescribed parameters.

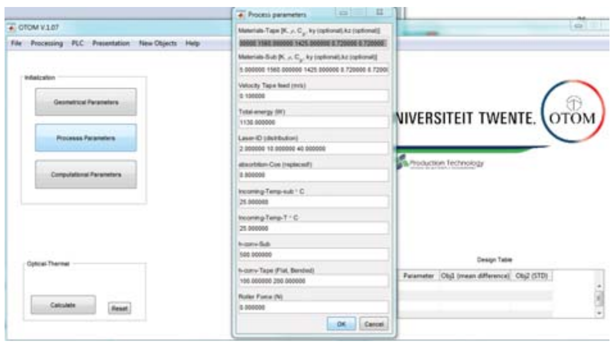


Figure 107: Setting each parameter for calculation.

Then by clicking on calculate on the left bottom of OTOM window the loading page will be appear and waiting for some seconds until the simulation will be doneFigure 108.

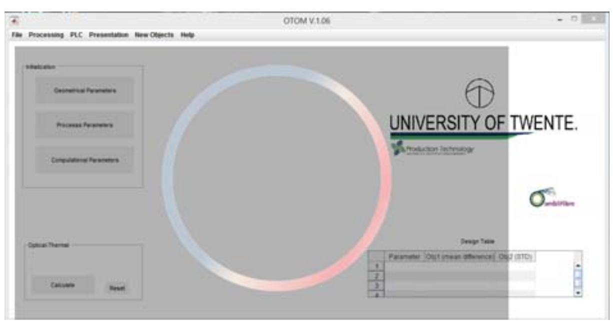


Figure 108: Loading page for progress of simulation.

Then by clicking the popped up window which shows the operation completeFigure 109. Then output figures will be appeared.

For instance in Figure 110 it can be seen that the horizontal axis defines the length of substrate and along the width nip point for upper and lower graph in 3D part, respectively and due the legend it can be said two results regarding upper and bottom layer of substrate have been extracted.

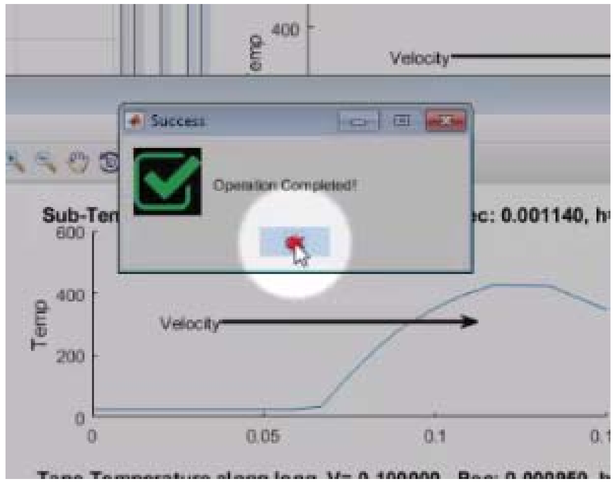


Figure 109: Operation complete window.

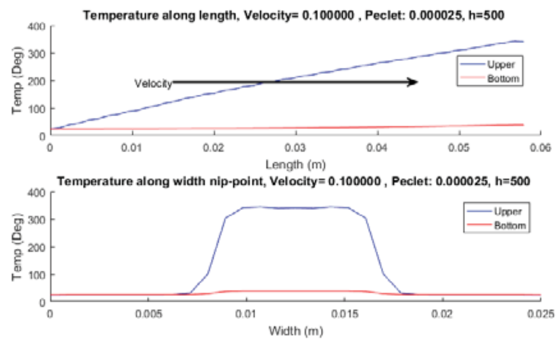


Figure 110: Temperature along length (winding direction) and width (nip-point) of substrate.

In Figure 111 contour plot temperature of the top surface and bottom surface in 3D part and in Figure 112 3D view of substrate are visualized and the rest of the output are for 2D part. For example Figure 114 shows the power distribution and Figure 115 shows the whole geometry in 3D.

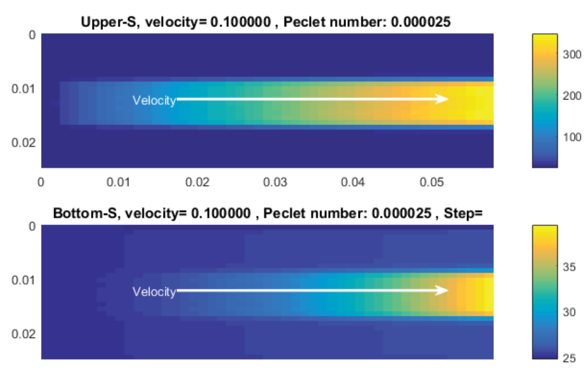


Figure 111: Substrate contour plot of temperature distribution of the top surface and bottom surface.

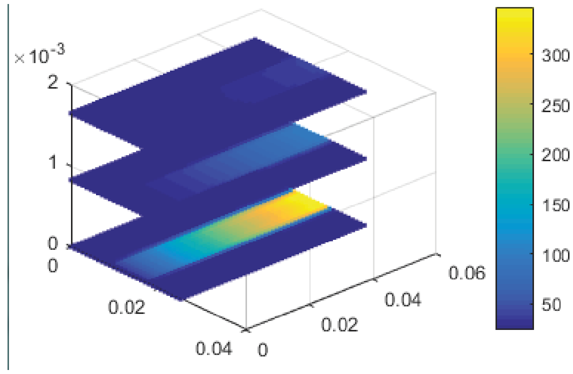


Figure 112: 3D visualization of substrate based on number of nodes in thickness direction.

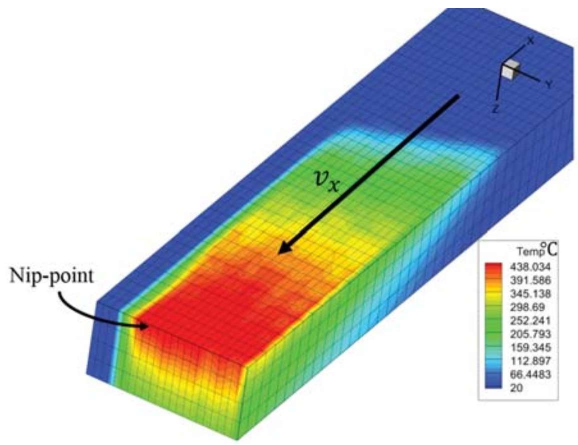


Figure 113: 3D visualization of substrate as a body.

5.1.6. Using the software

After the software is successfully installed, the next step is to be able to use it. This section highlights the basic features and the tasks that can be accomplished with OTOM. The window also comes with a drop down menu with the name ”Help” to get more helpful details as in Figure 116.

This section illustrates a simple example to highlight the features of OTOM. The first step is to click on the Geometrical Parameters. This opens an input window with several geometric specifications to model the simulation as shown in Figure 117.

It is suggested to check the Tutorial feature under ”Help”, which opens a PDF with a more comprehensive description of the geometric parameters. Using the schematic images in the tutorial file (also shown below) you can understand the role of each parameter as they are shown in Figure 118, Figure 119, and Figure 120.

For instance θ_y is the angle of winding direction. If you input -180 degrees, the orientation becomes exactly along the negative x-direction. Similarly, you can input other geometrical parameters according to your preference or data. Another important parameter is the degree of tangent of tape, which is the angle at which the tape leaves the roller. The angle is measured between the line connecting the roller center with nip point and the line connecting the center of the

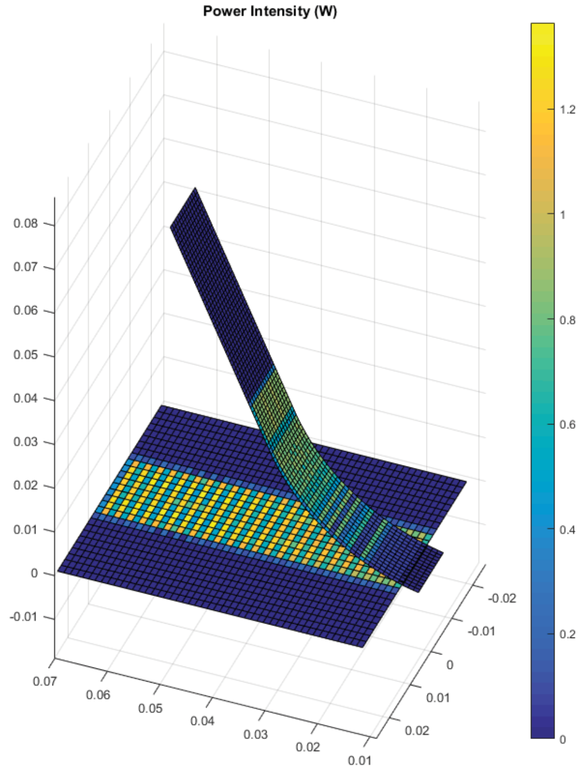


Figure 114: Intensity distribution on Tape and Substrate.

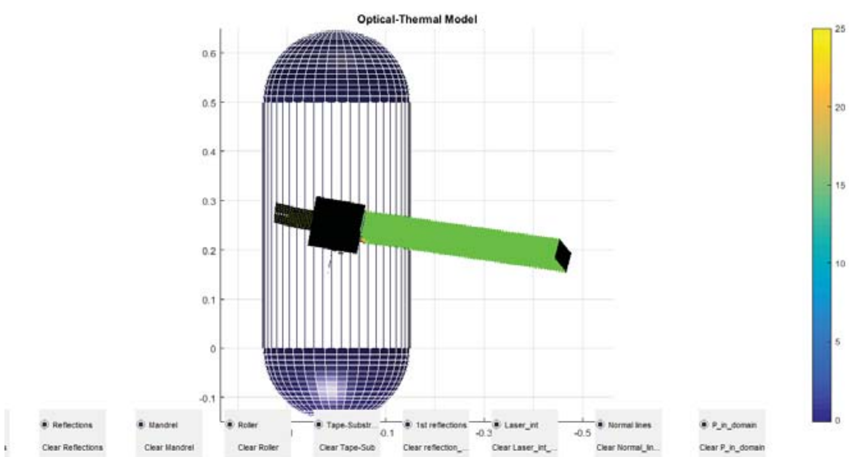


Figure 115: Whole optical-thermal output in 3D representation.

roller and the point at which the tape detaches from the roller. The default for this parameter is taken as 50 degrees. The ϕ_{sub} measures the orientation angle of the substrate with the horizontal. It is suggested that if the substrate is thick, one should opt for the 3D model. This has been explained in another section.

Note: It is important to note here that the units in the geometrical parameters are dependent on user definition (metric, inch, .etc) but it is suggested for simplicity to be defined mm (millimeters).

Figure 116: OTOM Help drop down menu.

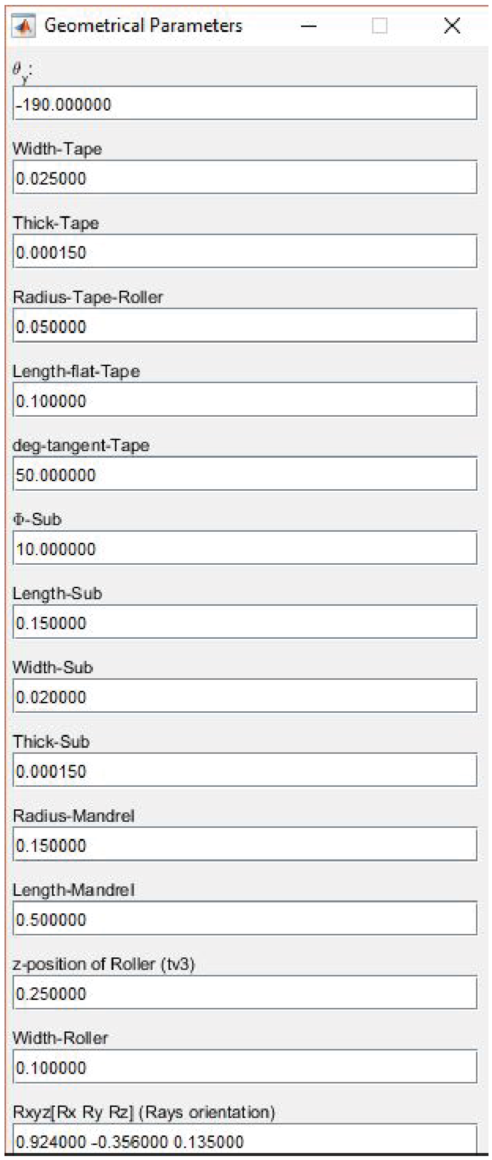


Figure 117: Geometrical parameters window.

After setting the Geometrical Parameters, click OK. The next step after specifying geometrical parameters is to define the Process Parameters.

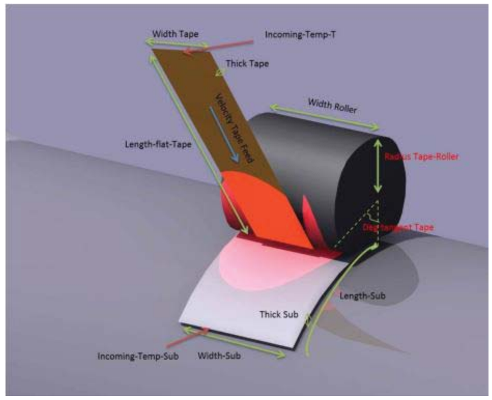


Figure 118: Process explanation in tutorial with input parameters.

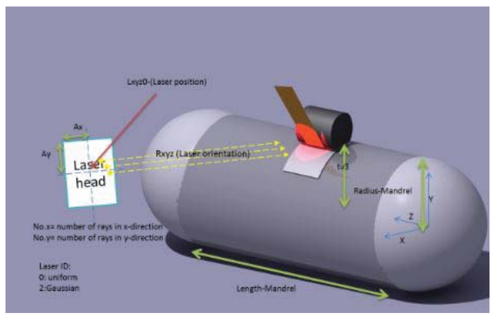


Figure 119: Complete process outline with all components including mandrel, laser head, tape, roller, and substrate.

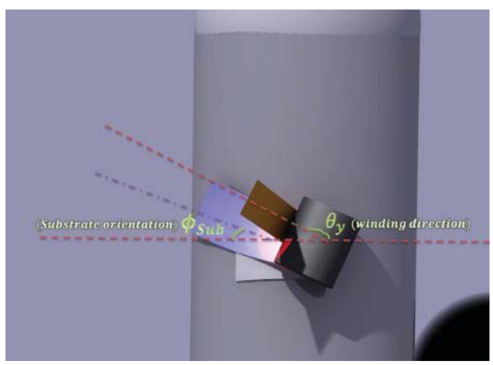


Figure 120: Orientation definition of tape and substrate.

The first parameter to be defined is the material property of the tape. This means to define the thermal conductivity (K), density (ρ) and C_p (The specific heat). The same three parameters are asked in the next text box to define the substrate properties. We can also define the velocity of the roller on the mandrel (for eg: 100 mm/s). The total energy is defined as the net energy emitted by the laser head. The laser ID right now can only be toggled between Uniform and Gaussian (input 0 and 2 respectively to set Laser ID). The incoming temperature of both tape and substrate are assumed to be room temperature (25 degree Celsius). The incoming temperature is the temperature of tape and substrate before being incident with the laser rays. The convection coefficient (h) from substrate to mandrel and the convection coefficient (h) from tape to substrate can be defined. We can also insert the normal roller force which is set as 0 here. Now, we move on to the Computational parameters as shown in Figure 122.

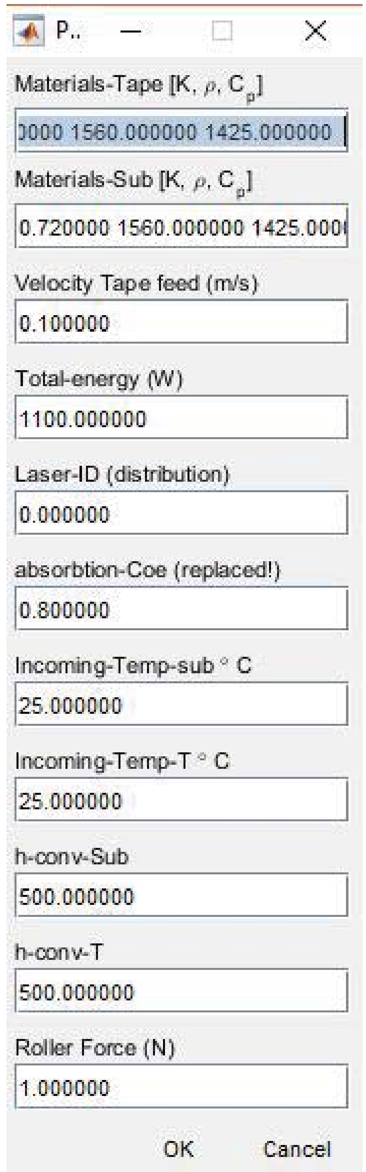


Figure 121: Process parameters window.

The first one is the No. Length of Substrate, which are the number of elements along the length of the substrate. The half side width node sub specifies the number of elements along half the width of the substrate. The width-Nodes-Tape parameter defines the number of elements along the width of the tape. The number of angular nodes are the nodes along the area where tape is touching the roller. The last parameter is the number of nodes on the flat part of the tape (the part of the tape not touching the roller). Now, all the parameters are specified, so the simulation can be conducted by clicking on calculate on the main GUI of the OTOM software. Once the computation terminates, OTOM yields several figures as results, the interpretation of which shall be explained in coming sections.

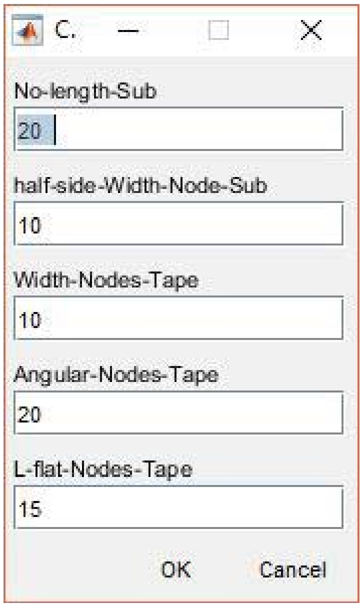


Figure 122: Computational parameters window.

5.1.7. Saving and Loading

This section explains how to save and load data in OTOM. Usually, it is needed to load previous data or save the new data as it could be required for future computations. For instance, if you to save Geometrical Parameters, go to the File menu, go to save, and select Geometrical Parameters. This will open a save window to choose the location where you want to save your Geometrical Parameters as a Text (.txt) file as shown in Figure 123.

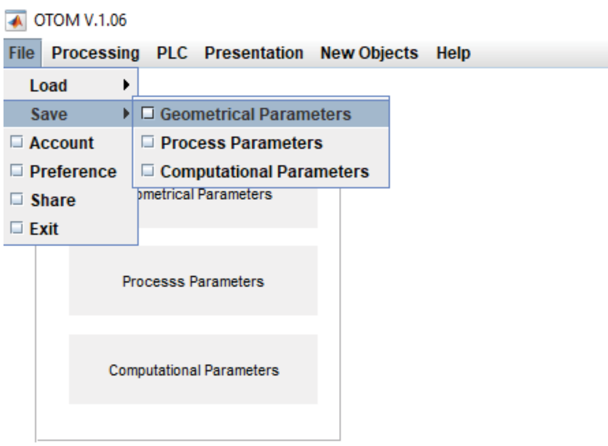


Figure 123: Save parameters as .txt file.

Suppose you would like to change the values of the saved text file. You can make changes in the file, save the changes in the parameter values and then load the changed parameters by going to Load as shown in Figure 124, and choose Geometrical Parameters and choose your previously saved file.

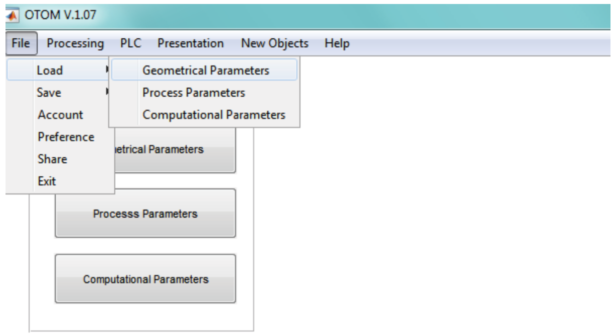


Figure 124: Load parameters from previously saved file.

5.1.8. Roller deformation

In this section the implementation of the roller deformation is discussed. Clicking process parameter a table is appeared, and then at the bottom of this table as shown in Figure 125, the value of roller normal force can be modified. In this example the value 100 is set. By clicking OK the process parameter can be modified.

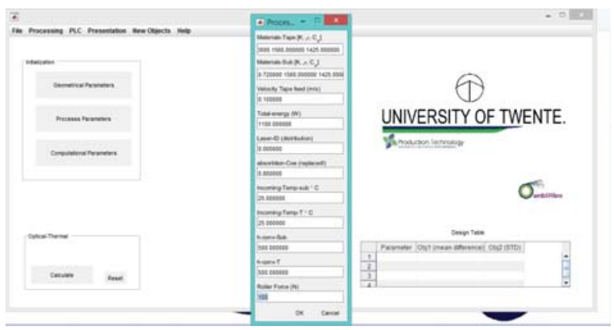


Figure 125: Changing the value of roller force.

By clicking calculate a warning dialog is appeared Figure 126 which says that data regarding force-displacement should be inserted. If the calculation continue without force-displacement data, a zero force will be assumed.

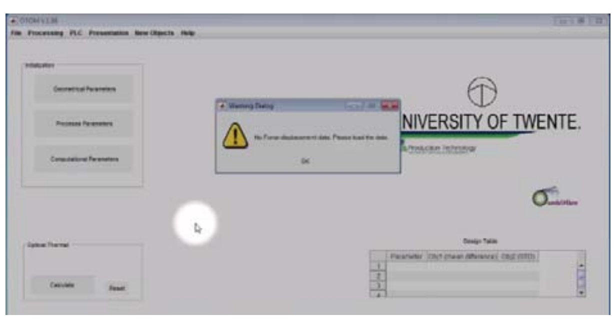


Figure 126: Warning dialog indicating no force-displacement data.

To make a force-displacement data, do right clicking in the desktop to create new text document as Figure 127 and change the text file name to ”force-disp” as shown in Figure 128. Then by clicking on it the relation between force and displacement can be defined due the following values as in Figure 129.

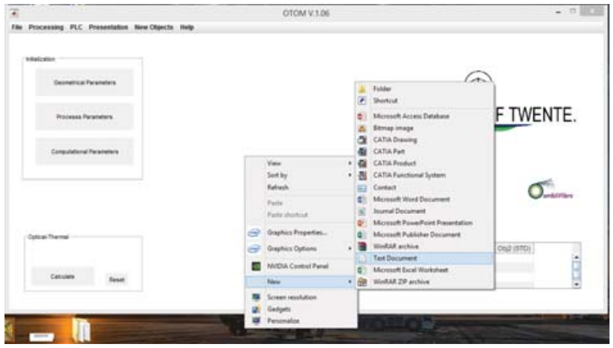


Figure 127: Creating new text document.

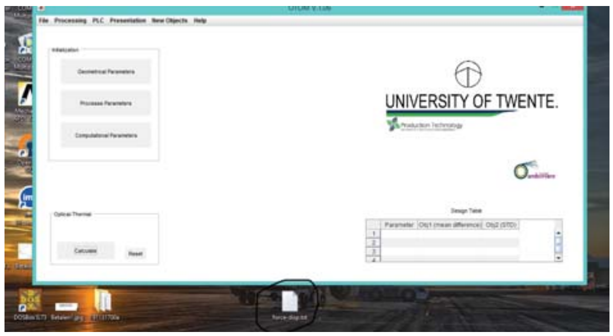


Figure 128: Renaming new text document

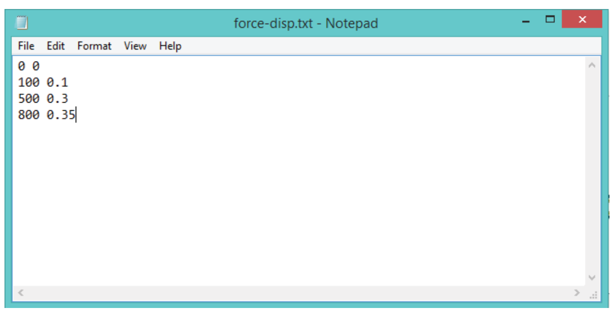


Figure 129: Defining new relation between force and displacement.

Next, go to processing tab and choose roller deformation as in Figure 130.Then by choosing force-displacement text file due to following Figure 131 the roller deformation will be approximated based on these data. After opening that file the following window will be opened Figure 132 and only four data points have been considered so the maximum polynomial degree is at least 3 so by click OK the window is opened.

Then OTOM make a curve fitting based on the selected data and the fitted curve is plotted as shown in Figure 133. By putting force 100 N, 0.1 m as deformation can be obtained then press on calculate.

Note: the software only calculate the maximum displacement to 75% of radius. In case of excessive force, the software shows an error, but the calculation will be performed based on 75% of radius as deformation.

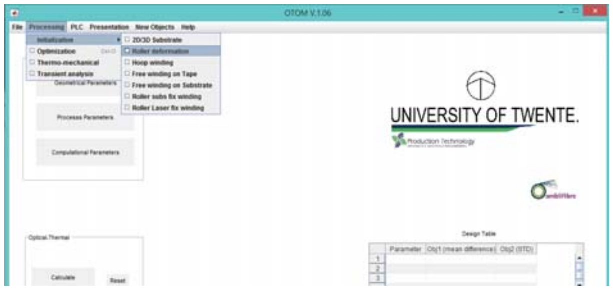


Figure 130: Choosing roller deformation option in OTOM.

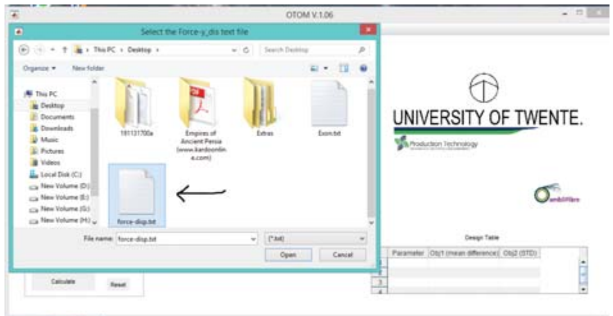


Figure 131: Choosing roller deformation file.

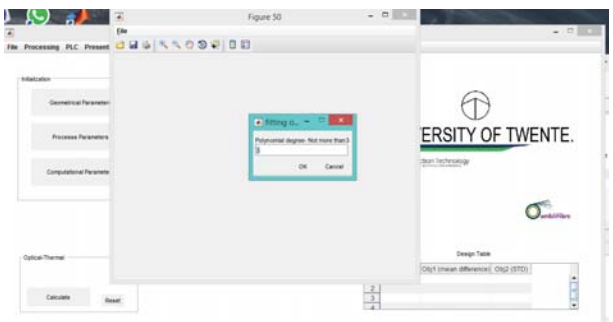


Figure 132: Selecting number of point for curve fitting.

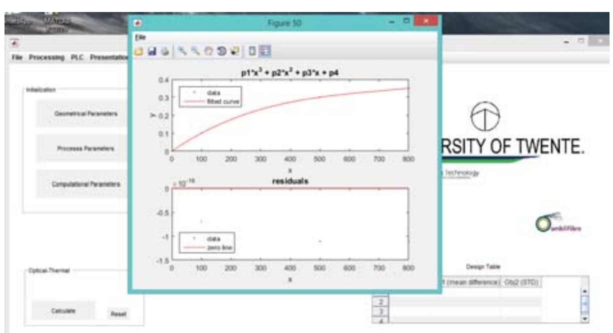


Figure 133: Fitted curve.

5.1.9. Interpreting Results in OTOM

This section outlines results that have been computed by OTOM. After filling in the three categories of parameters (Geometrical, Process and Computational) discussed in the previous sections, the simulation can be executed by pressing

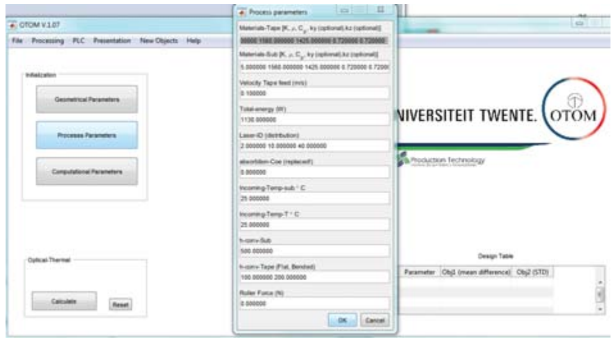


Figure 134: Changing force for deformed roller.

”calculate” button. After finishing computations, several windows showing the results will be opened which is seen in Figure 135.

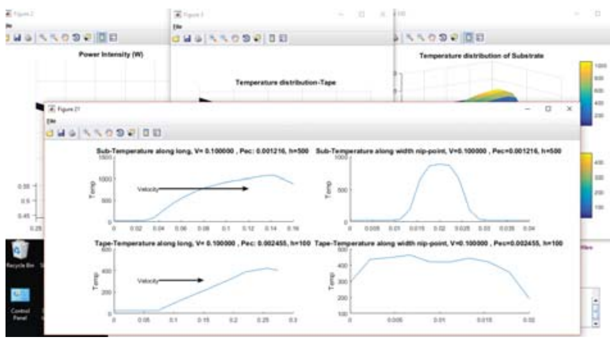


Figure 135: Various figures after finishing computations.

We can see the temperature distribution for the tape and the substrate in Figure 136. The temperatures are visibly higher near the nip point and reduce farther away.

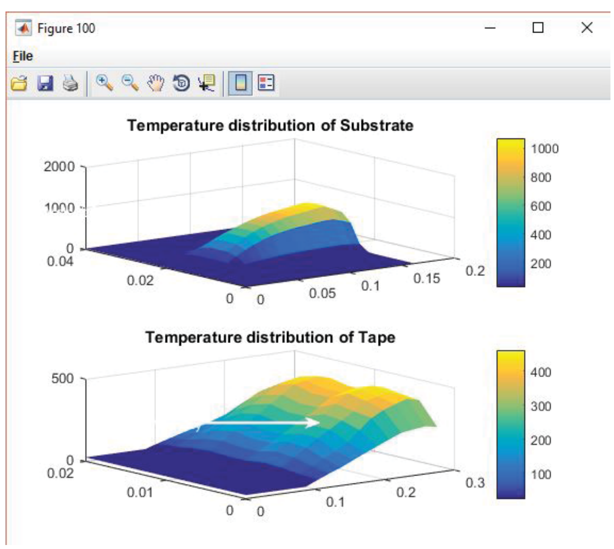


Figure 136: Temperature distribution of tape and substrate.

In Figure 137, four temperature profiles are shown. Two graphs show the distribution of temperature along the length for substrate and tape respectively and other two graphs show the temperature along the width of tape and substrate at nip point, respectively.

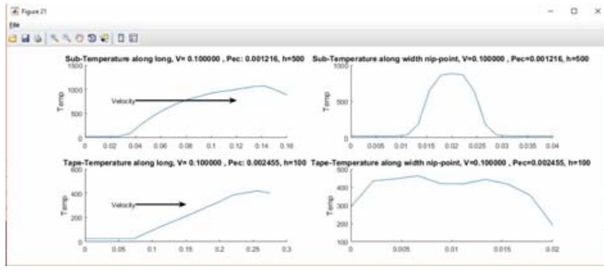


Figure 137: Temperature profile along length and width for tape and substrate.

In Figure 138, the curved tape and substrate models are colored to show temperature contour on the surfaces.

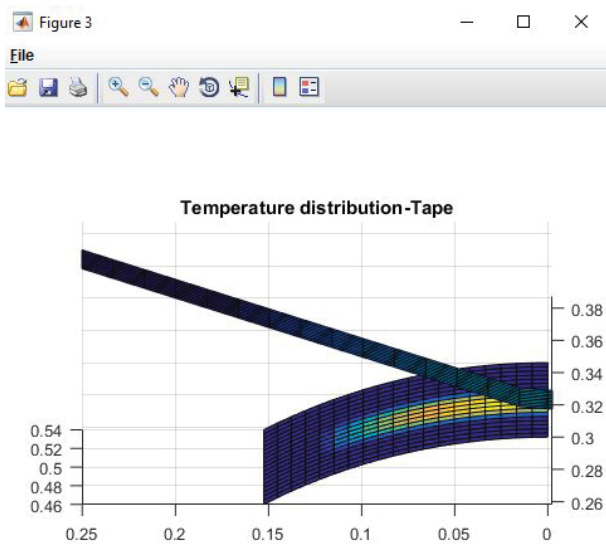


Figure 138: Tape and substrate temperature distribution on curved surfaces.

Figure 139 shows the power intensity distribution on a meshed model for both tape and substrate together. The unit for intensity distribution here is watt (W).

Finally, Figure 140 shows an overall configuration of the current simulation. The figure includes 3D models of all components that are involved in Laser Assisted Tape Winding including mandrel, laser head, laser rays, tape roller, tape, and substrate. The green lines originating from the laser head denote the laser rays, and the red lines at the intersection of mandrel with the green rays represent the reflections of the rays. OTOM allows you to suppress one or more components in the optical thermal model. At the bottom of the model, there are toggle buttons to turn on/off all the components of the model. This way, any one or more components can be isolated to study the effects on them at the end of the tape winding process simulation.

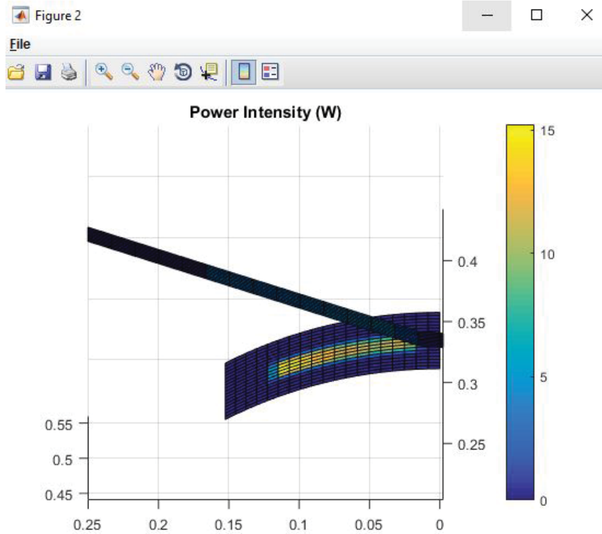


Figure 139: Intensity distribution on tape and substrate on curved surfaces.

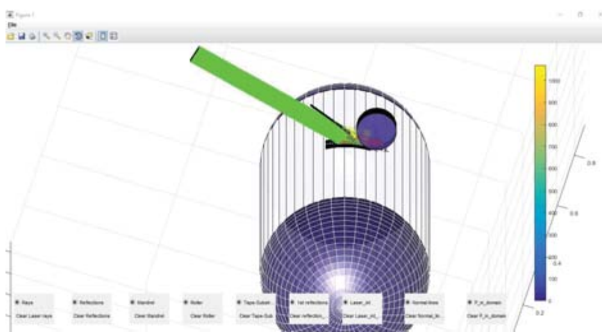


Figure 140: Complete configuration of objects in simulation.

5.1.10. Target Finder

In this section the exact location and direction of laser head towards the target will be found. First we have to input the geometrical parameters then input the process parameters which represent deformation. Second, as Figure 141 choose ”Lase roller fix winding” then you will be directed to the following view as Figure 142. As it can be seen, by using this figure the exact location of laser can be determined and by zooming on that you may see the exact location as in Figure 143. Next the distance can be set, here 0.3 m is inserted. Then click ”Accept” and ”Put the laser” as Figure 144.

So, the radius of green circle (sphere in OTOM V1.07) will be changed as shown in Figure 145. The exact location will then be computed with given nx,ny and nz as a direction of the laser rays. This approach is for the case when the nip point is the target but sometimes somewhere on tape/substrate should be assumed as the target.

To do so, choose ”Free winding on tape” as in Figure 147 and then click on it to set a target on the whole case as seen in Figure 148. Move that point on the tape till the desired location as shown in Figure 149. Then click on ”Put Laser” to see the laser direction (red arrow) on that shifted point and target will be linked as in Figure 150.

Note: you can also change the laser head by modifying the value 0.2 and then zoom in then change the laser point/head

Figure 151. But by zooming on the link between nip point and laser are not in the same line Figure 152. Thus by choosing ”Head align target” you can put them on a same line and green circle Figure 153 would be exactly aligned through target.

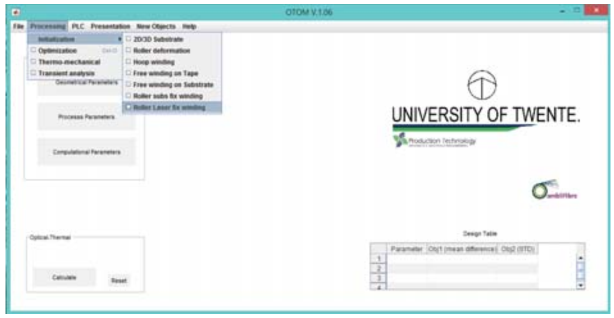


Figure 141: Lase roller fix winding.

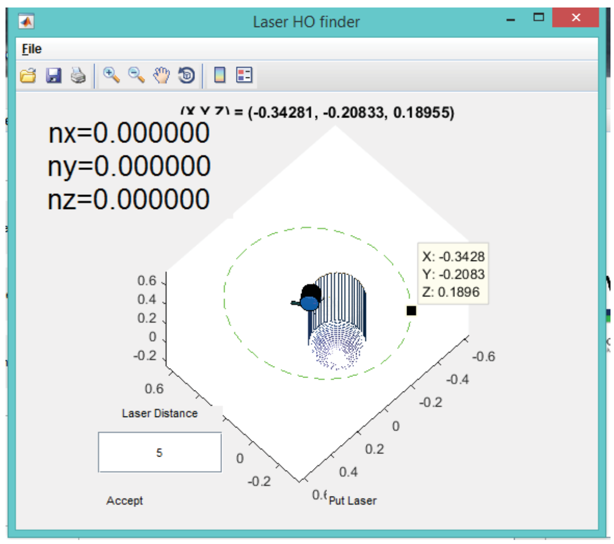


Figure 142: Laser HO finder.

It is also possible to set a target on the substrate by choosing ”Free winding on substrate” as shown in Figure 154. As it seen in Figure 155, any location on substrate can be chosen and then by putting the laser head, the orientation of laser head in the space can be found. All procedure is like the previous section. Using the ”Head align the target” and then by choosing the ”Put laser”, both the target and laser will be in same orientation as seen in Figure 154.

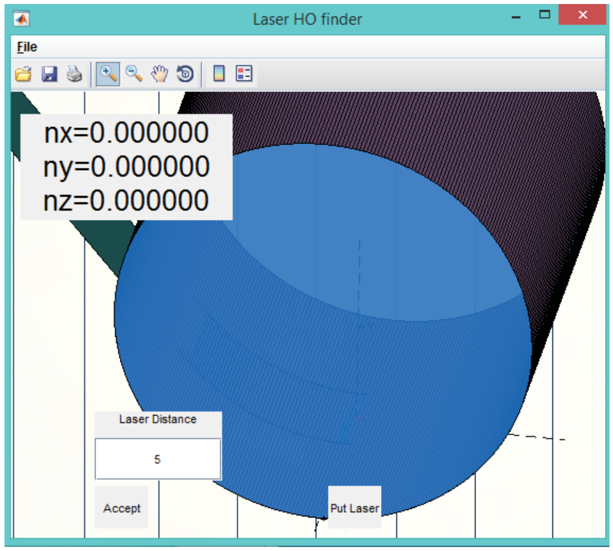


Figure 143: Closer view of visualization of target location.

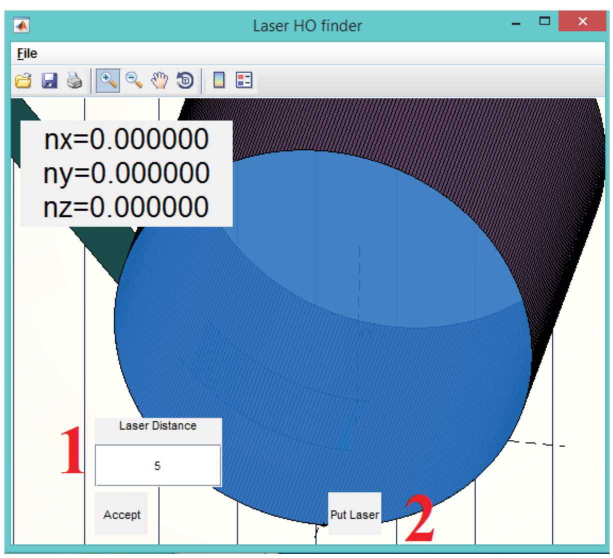


Figure 144: Changing the value of radius.

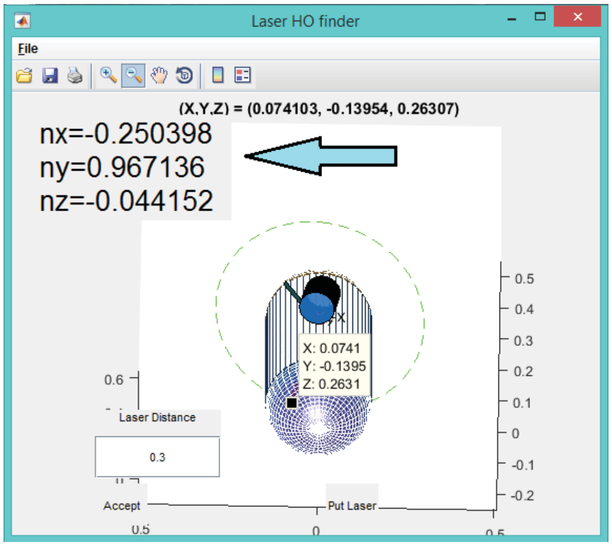


Figure 145: Calculating exact location and laser rays orientation.

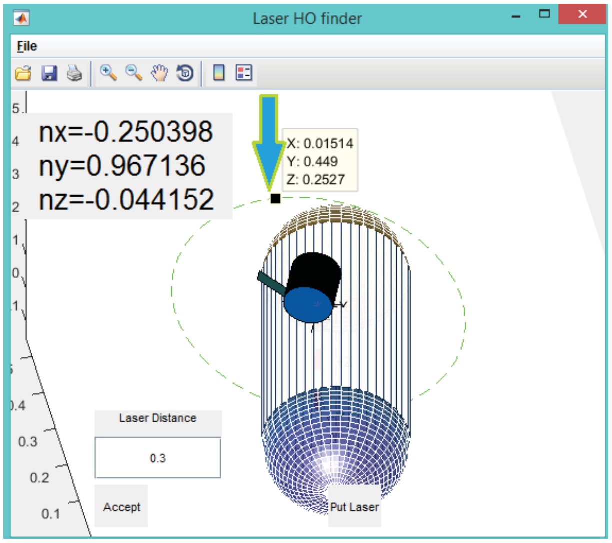


Figure 146: Changing the laser location.

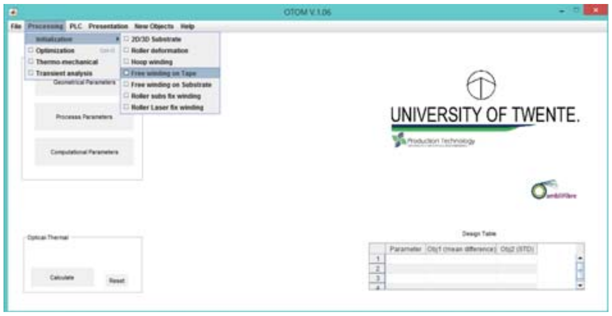


Figure 147: Choosing free winding option on tape in OTOM.

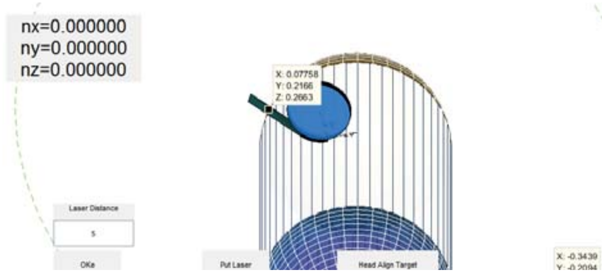


Figure 148: Setting a target on the tape.

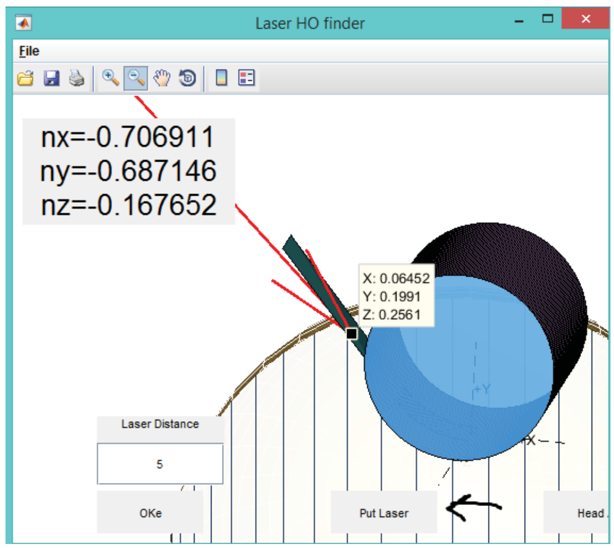


Figure 149: Linking target and shift point.

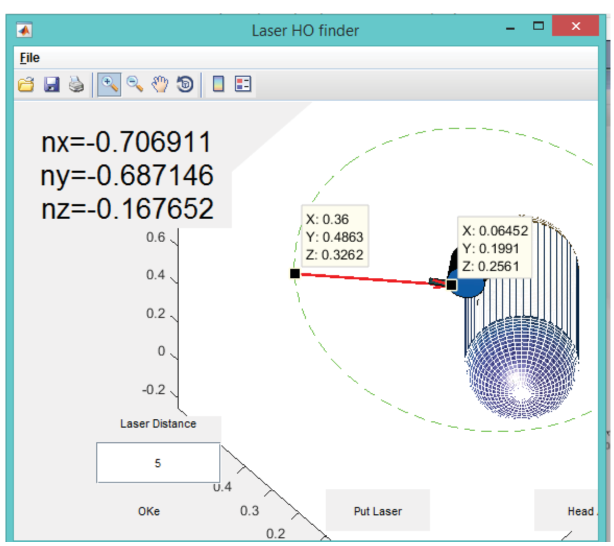


Figure 150: Moving that point on the tape.

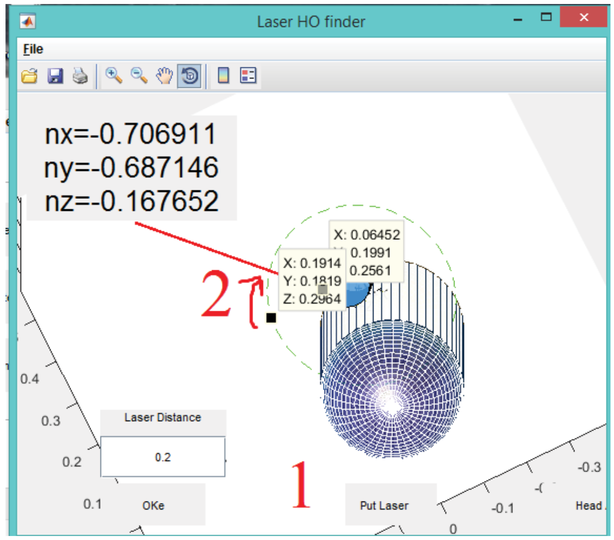


Figure 151: Changing the laser point/head.

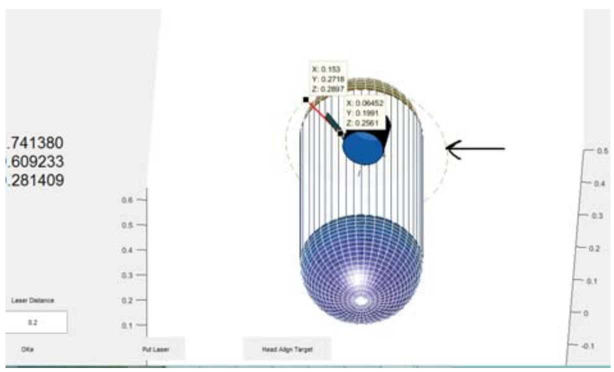


Figure 152: Misalignment between nip point and laser.

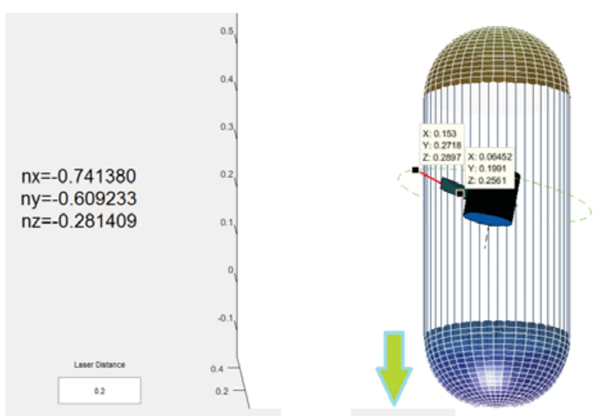


Figure 153: Head align target for better adjustment.

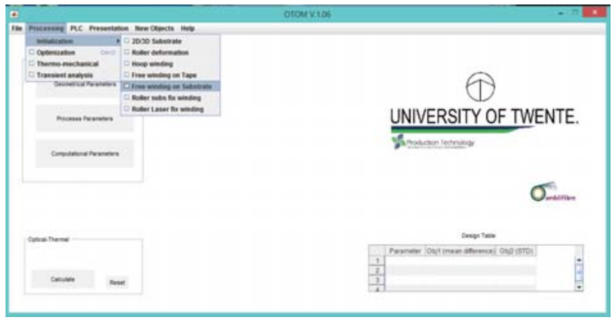


Figure 154: Free winding on substrate.

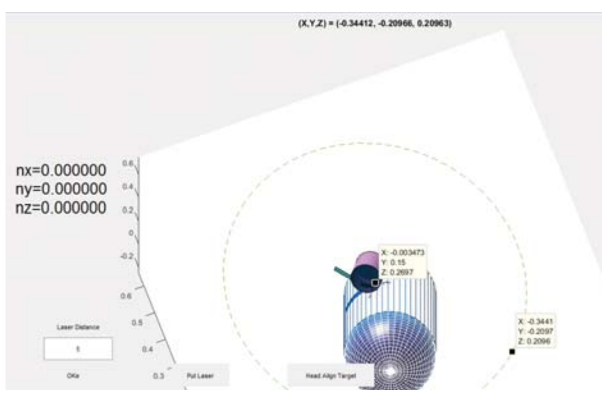


Figure 155: Head align target.