Altair® FluxMotor® 2022.1

Materials

General user information

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Contents

1 MATERIALS OVERVIEW

1.1 Main areas of “Materials”

Materials is a dedicated application to create and manage materials.

All materials are distributed into seven families:

- Lamination
- Solid
- Magnet
- Electrical conductor
- Electrical insulator
- Gas
- Liquid

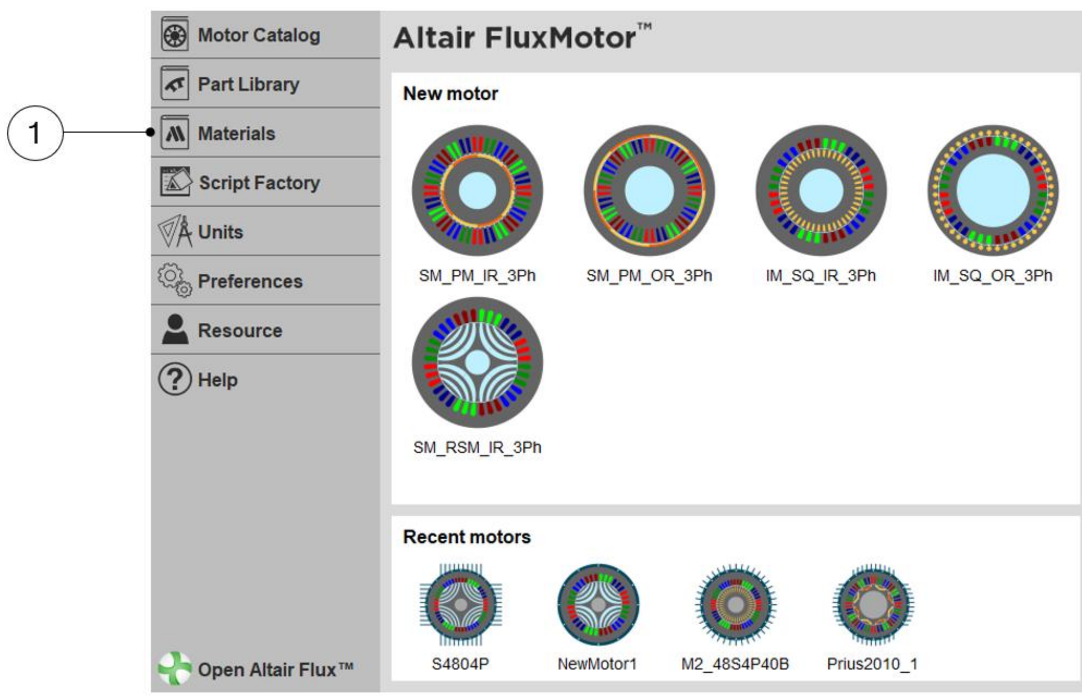
All the above seven families contain some materials individually. When clicking on each family, the corresponding materials are displayed under a reference material database.
The users can create their own materials. It will be stored under USER material database.

1.2 How to get into “Materials”?

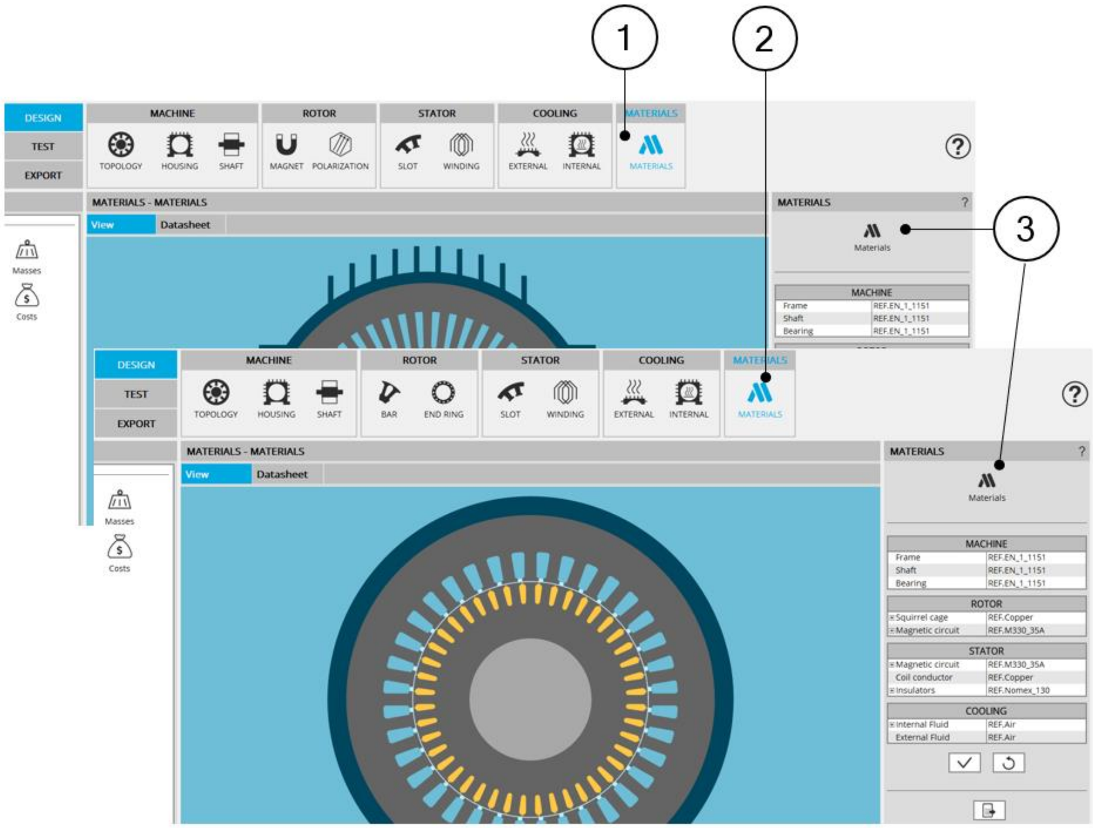
Two ways are possible:

1) From the supervisor, click on “Materials” button.

2) From the Motor Factory DESIGN area, it is possible to check the properties of materials through the STATOR/MATERIALS section, in ROTOR/MATERIALS section or in STATOR/WINDING section.



1	Click on Materials on the left part of the supervisor to open “Materials” application



How to get into “Materials” from Motor Factory?

1	From Motor Factory / DESIGN / MATERIALS section for synchronous machines – Inner and outer rotor
2	From Motor Factory / DESIGN / MATERIALS section for induction machines – Inner and outer rotor
3	In “Materials” environment of Motor Factory, the Material database can be opened by clicking on this button.

1.3 Advice for use

Altair® FluxMotor® is dedicated to the predesign of electrical motors. The target of Altair® FluxMotor® is to get a quick overview of technical and economic potential of motors.

In this way, the motive of the associated material database is to cover the field of needed materials to build a machine.
So, the aim of the material database is not to give perfectly accurate properties of all the specific materials given by the main material suppliers all over the world.

The objective of the material database is to propose the main types of needed materials for building a motor to have a general overview of performance of motor by using the different kind of materials.

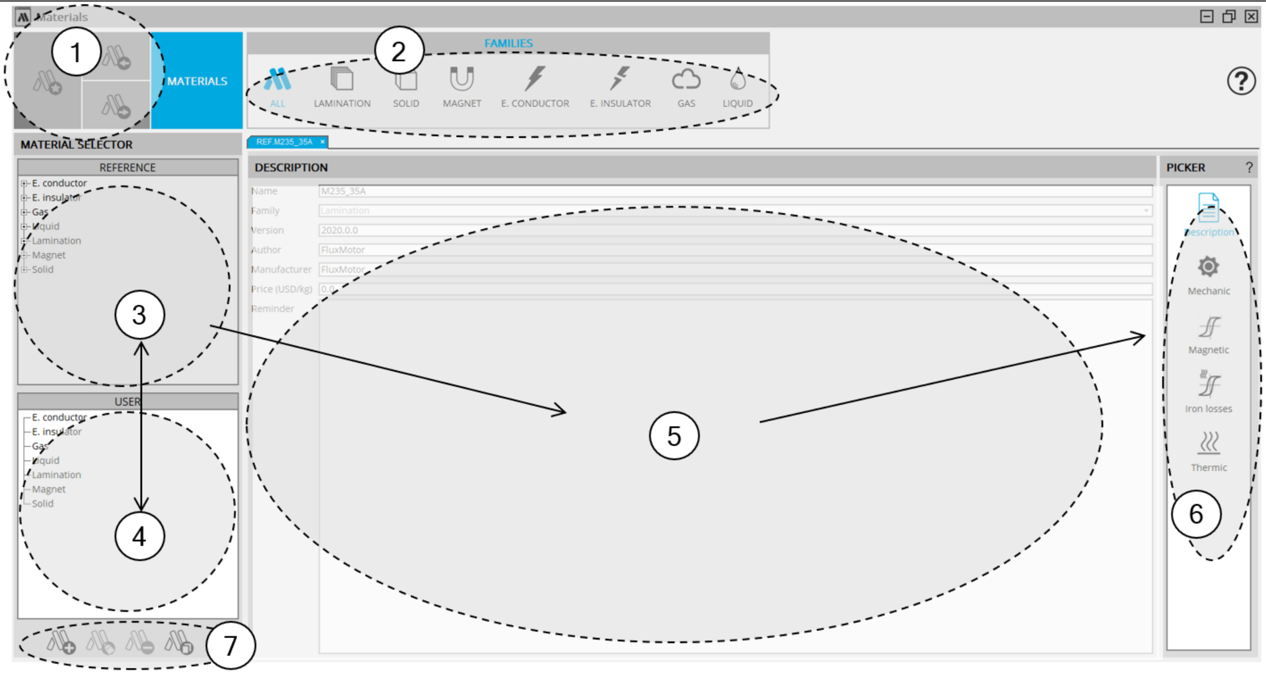
This principle must simply allow visualizing the variation of performance when substituting a material type for another one.

However, the users of FluxMotor® will be able to build their own material database by specifying all the properties needed. Specifying accurate properties of materials remains the responsibility of the user.

2 MANAGE MATERIALS

2.1 Overview

Here are the main areas of the "Materials" application.

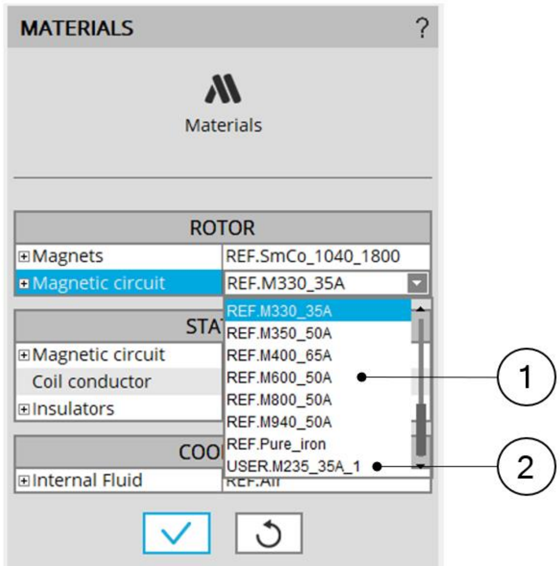


Zones of "Materials" application

Zone 1	Access to the system function: • Assignment of default materials • Export materials • Import materials See more details on these functions below.
Zone 2	Presentation of the seven material families available in "Materials" application. Selecting an icon will display the materials belonging to the selected family.
Zone 3	Reference material database. In each material family there are some materials which are proposed by FluxMotor® to cover the basic needs.
Zone 4	User material database. One user material database is available. All the materials created by the user are stored in the user database.
Zone 5	Area in which the physical properties of the selected material are displayed.
Zone 6	Shortcuts for displaying the corresponding section of the material properties.
Zone 7	Functions to manage the materials in the selected family: • New • Edit • Delete • Duplicate

Note 1: In Motor Factory a material from the reference material database has the following prefix: “REF.” Example: REF.M250.50A.

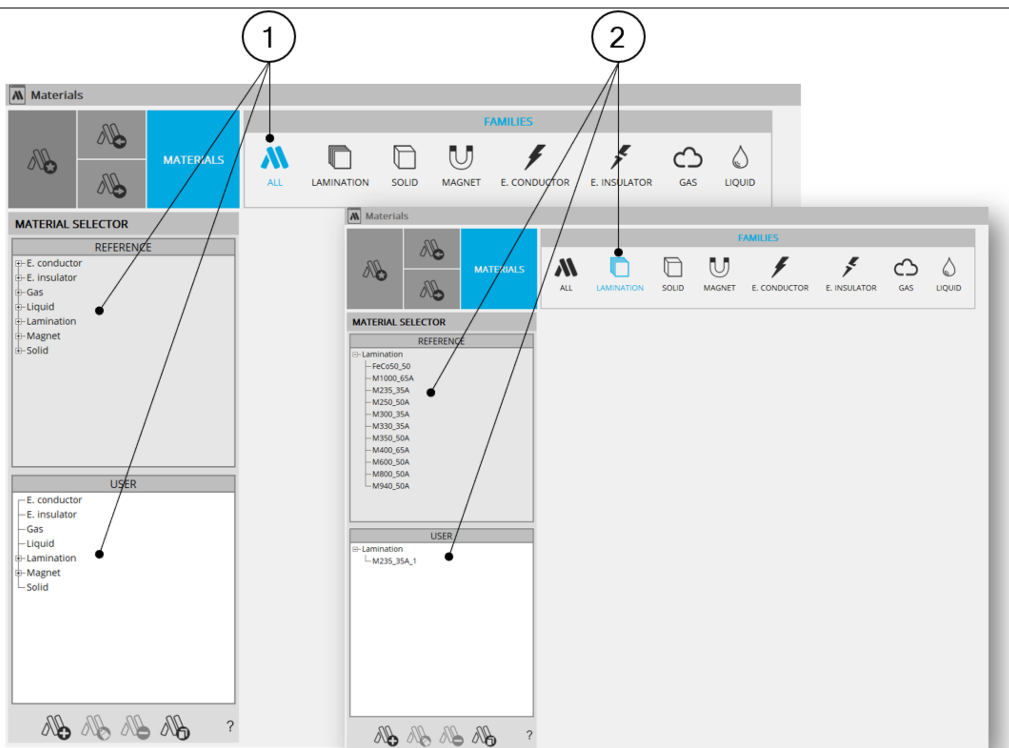
Similarly, a material from the user material database has the following prefix: “USER.” Example: USER.M250.50A.



Selection of a material from the Motor Factory

1	Material stored in the reference material database (Prefix REF.).
2	Material stored in the user material database (Prefix USER.).

Note 2: In Materials application, the icons on the top part of the screen allow to filter the visualization of the available materials in the two databases: reference material database and user material database.



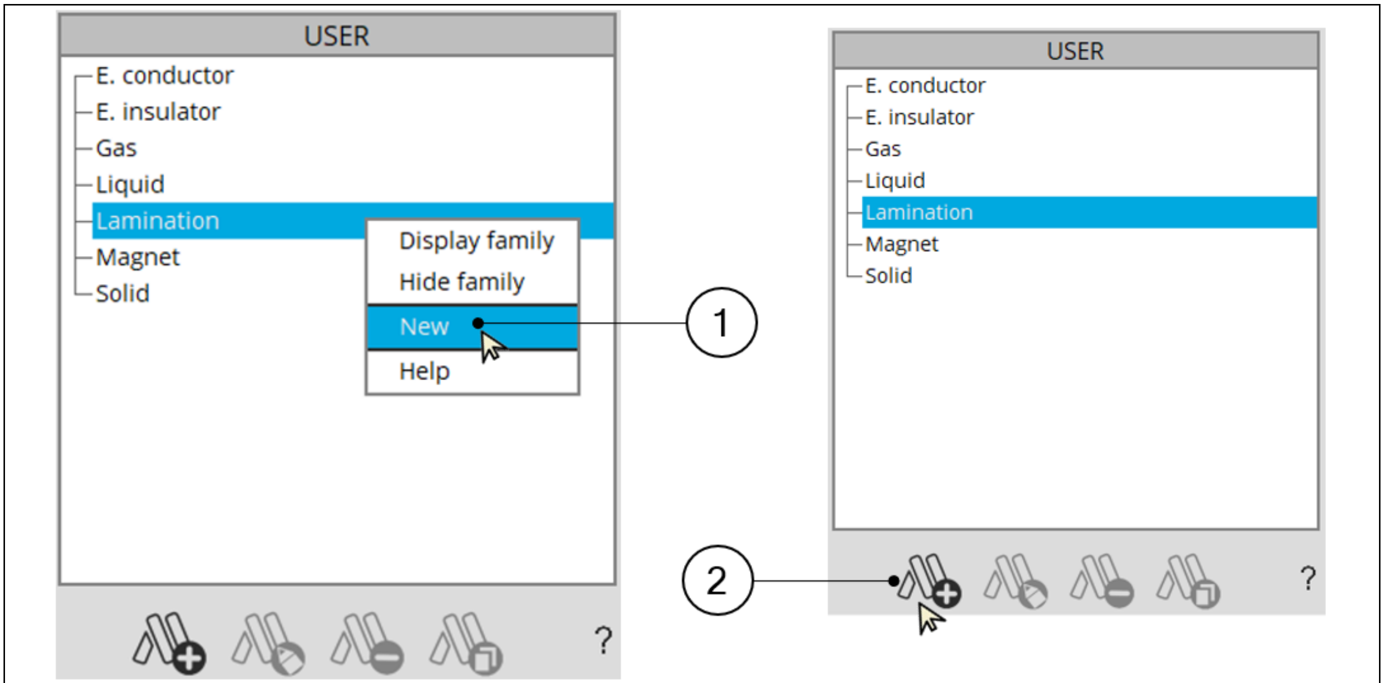
Selection of a material from the Motor Factory

1	All types of materials are displayed.
2	Only lamination materials are displayed in reference material database as well as in user material database.

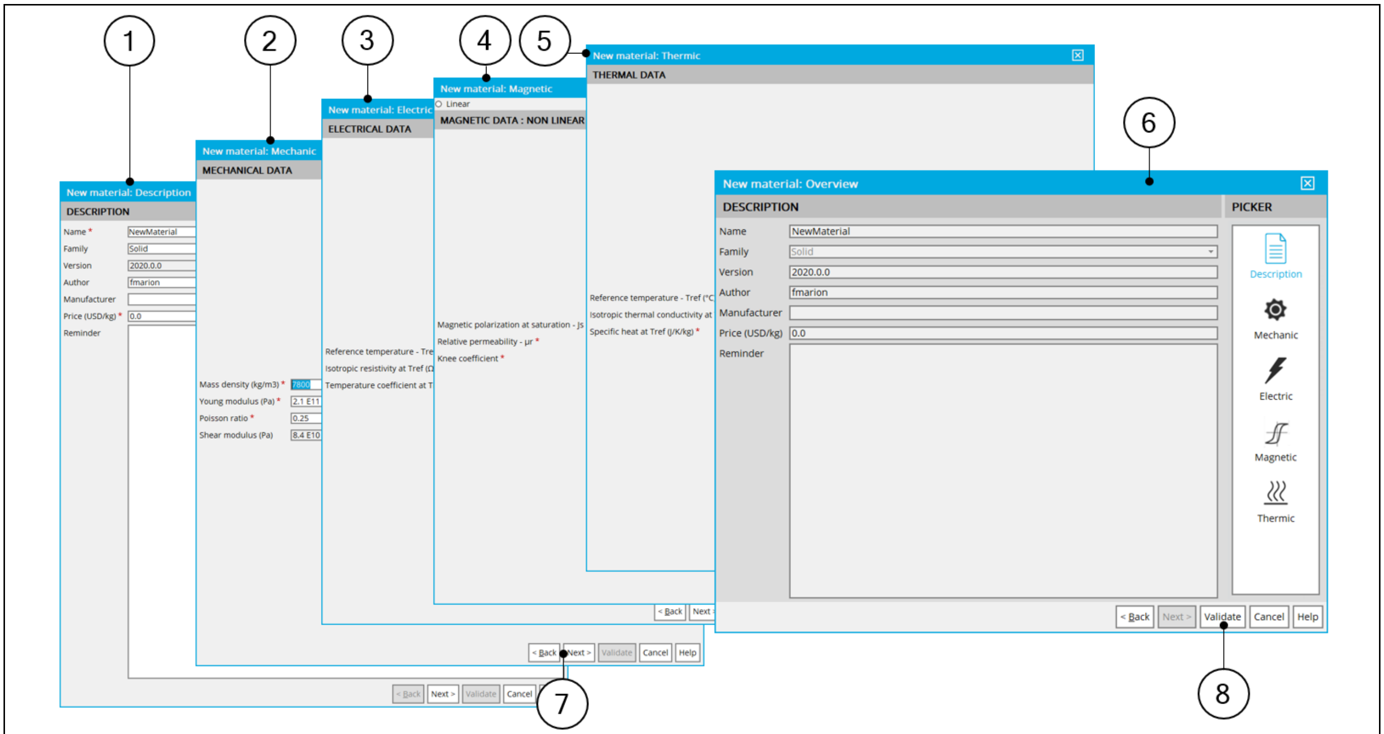
2.2 Create a new material

2.2.1 Overview

A new material can be created and is stored only in the USER material database.



How to create a new material?	
1	By using the right mouse button on one family of the user material database.
2	By clicking on the icon “New”.



Steps to create a new material

1	Dedicated dialog boxes allow defining all the physical properties of considered material. The first dialog box allows to give a general description of the new material: • Name • Family (expanding menu must be used to choose the family) • Version (imposed by the model version of the material database) • Author, manufacturer (not mandatory) • Price of the material (US dollar per kg). Not mandatory, but if this information is used, then it will be used in Motor Factory to compute the cost of materials needed to build the machine • Memo: to write a reminder if needed
2	The second dialog box allows defining the Mechanical data of the considered new material.
3	The third dialog box allows defining the Electric data of the considered new material
4	The fourth dialog box allows defining the Magnetic data of the considered new material (B(H) curve and iron losses if needed - function of the considered new material).
5	The fifth dialog box allows defining the Thermal data of the considered new material
6	The last dialog box presents a synthesis of all the physical properties described in the previous steps. The validation of these data (Button Validate) allows creating the new material.
7	Use the icons “Next” and “Back” to move forward or backward in the series of dialog boxes.
8	Button to validate the physical properties and creating of the new material.

2.2.2 Lamination data

Here are the properties needed to define a new lamination:

Category	Label	Unit
Description	Name	*
	Family	*
	Author	*
	Manufacturer	*
	Memo	*
Economic	Price	USD/kg
Mechanical data	Sheet thickness	mm
	Stacking factor	1
	Mass density	kg/m3
	Young modulus	N/m2
	Poisson ratio	1
Magnetic data	Relative permeability	1
	Magnetic polarization at saturation Js	T
	Relative permeability	1
	Knee coefficient	1
Iron Loss	Hysteresis loss coefficient (kh)	1
	Exponent of B for the hysteresis losses (αh)	1
	Exponent of f for the hysteresis losses (βh)	1
	Classical loss coefficient - Sine wave (kc x kαc)	1
	Classical loss coefficient - Any wave (kc)	1
	Exponent for the classical losses (αc)	1
	Excess loss coefficient - Sine wave (ke x kαe)	1
	Excess loss coefficient - Any wave (ke)	1
	Exponent of B for the excess losses (αe)	1
Thermal data	Reference temperature - Tref	°C
	Thermal conductivity in the lamination direction at Tref	W/K/m
	Thermal conductivity in the lamination insulation at Tref	W/K/m
	Equivalent thermal conductivity in the lamination depth at Tref	W/K/m
	Specific heat at Tref	J/K/kg

Note 1: The B(H) curve is defined with an analytical model given in the Advanced section: Create a B(H) curve.

Note 2: A stacking factor is considered to define the B(H) curve to analyze the behavior of the magnetic circuit of the machine.
The user must define the magnetic characteristics of the solid material while the magnetic characteristics of the lamination stack are automatically deduced considering the value of the stacking factor.
See Advanced section: Create a B(H) curve.

Note 3: Electric properties are defined via iron loss model.
Note 4: Iron losses are defined with an analytical model given in Advanced section: Define iron loss parameters.
Note 5: The thermal conductivity “in depth” along the stacking direction: K_d is computed as follows:

S_f	Stacking factor
K_{ins}	Thermal conductivity of the lamination insulation
K_{lam}	Thermal conductivity in the lamination

$$K_d = \frac{K_{ins} \times K_{lam}}{K_{ins} \times S_f + (1 - S_f) \times K_{lam}}$$

Note 6: The thermal conductivity of laminated regions is constant whatever is the temperature of the region.

2.2.3 Solid data

Here are the properties needed to define a new solid:

Category	Label	Unit
Description	Name	*
	Family	*
	Author	*
	Manufacturer	*
	Memo	*
Economic	Price	USD/kg
Mechanical data	Mass density	kg/m3
	Young's modulus (E)	N/m2
	Poisson's ratio (ν)	1
	Shear modulus (G)	N/m2
Electrical data	Reference temperature (Tref)	°C
	Isotropic resistivity at Tref.	Ohm*m
	Temperature coefficient at Tref.	1/K
Magnetic data	Magnetic polarization at saturation J_s	T
	Relative permeability	1
	Knee coefficient	1
Thermal data	Reference Temperature Tref	°C
	Isotropic thermal conductivity at Tref	W/K/m
	Specific heat at Tref	J/K/Kg

Note 1: The B(H) curve is defined with an analytical model as described in the Advanced section: Create a B(H) curve.

Note 2: Iron losses are not considered in solid materials.

Note 3: The relation between the electrical resistivity and the temperature is described in Advanced section: "Impact of temperature on physical properties".

Note 4: The thermal conductivity of solid regions is constant whatever is the temperature of the region.

2.2.4 Magnet data

Here are the properties needed to define a new magnet:

Category	Label	Unit
Description	Name	*
	Family	*
	Author	*
	Manufacturer	*
	Memo	*
Economic	Price	USD/kg
Mechanical data	Mass density	kg/m3
Electrical data	Reference temperature (Tref)	°C
	Isotropic resistivity at Tref.	Ohm*m
	Temperature coefficient at Tref.	1/K
Magnetic data	Reference temperature (Tref)	°C
	Remanent induction Br at Tref	T
	Reverse temperature coefficient α for Br	1/K
	Relative permeability μ_r	1
	Intrinsic Coercivity HcJ at Tref	A/m
	Reverse temperature coefficient β for HcJ	1/K
	Energy product (B.H) max	J/m3
	Normal coercivity field Hcb at Tref	A/m
	Maximum operating temperature	°C
	Curie temperature	°C
Thermal data	Reference temperature (Tref)	°C
	Isotropic thermal conductivity at Tref	W/K/m
	Specific heat at Tref	J/K/Kg

Note 1: The relations between the remanent induction, the intrinsic coercivity and the temperature are described in advanced section: “Impact of temperature on physical properties”.

Note 2: The thermal conductivity of the magnet regions is constant whatever is the temperature of the region.

2.2.5 Electric conductor data

Here are the properties needed to define a new electrical conductor:

Category	Label	Unit
Description	Name	*
	Family	*
	Author	*
	Manufacturer	*
	Memo	*
Economic	Price	USD/kg
Mechanical data	Mass density	kg/m3
Electrical data	Reference temperature Tref	°C
	Isotropic resistivity at Tref.	Ohm*m
	Temperature coefficient at Tref.	1/K
Thermal data	Reference temperature (Tref)	°C
	Isotropic thermal conductivity at Tref	W/K/m
	Specific heat at Tref	J/K/Kg

Note 1: Non-magnetic behavior.
Note 2: The relation between the electrical resistivity and the temperature is described in Advanced section: “Impact of temperature on physical properties”.

2.2.6 Electric insulator data

Here are the properties needed to define a new electrical conductor:

Category	Label	Unit
Description	Name	*
	Family	*
	Author	*
	Manufacturer	*
	Memo	*
Economic	Price	USD/kg
Mechanical data	Mass density	kg/m3
Thermal data	Reference temperature (Tref)	°C
	Isotropic thermal conductivity at Tref	W/K/m
	Specific heat at Tref	J/K/Kg

Note: Non-electrical and non-magnetic behavior.

2.2.7 Gas data

Here are the properties needed to define a new gas:

Category	Label	Unit
Description	Name	*
	Family	*
	Author	*
	Manufacturer	*
	Memo	*
Economic	Price	USD/kg
Mechanical data	Reference pressure Pref	Pa
	Mass density reference temperature TrefD	°C
	Mass density at TrefD and Pref	kg/m3
	Mass density first order temperature coefficient at TrefD and Pref	K-1
	Mass density second order temperature coefficient at TrefD and Pref	K-2
	Dynamic viscosity reference temperature - TrefV	°C
	Dynamic viscosity at TrefV	kg/m/s
	Dynamic viscosity first order temperature coefficient at TrefV	K-1
	Dynamic viscosity second order temperature coefficient at TrefV	K-2
Thermal data	Thermal conductivity reference temperature - TrefC	°C
	Thermal conductivity at TrefC	W/K/m
	Thermal conductivity first order temperature coefficient at TrefC and Pref	K-1
	Thermal conductivity second order temperature coefficient at TrefC and Pref	K-2
	Specific heat reference temperature - TrefS	°C
	Specific heat at TrefS and Pref	J/K/kg
	Specific heat first order temperature coefficient at TrefS and Pref	K-1
	Specific heat second order temperature coefficient at TrefS and Pref	K-2

Note: Gas are considered to have no electrical and no magnetic properties.

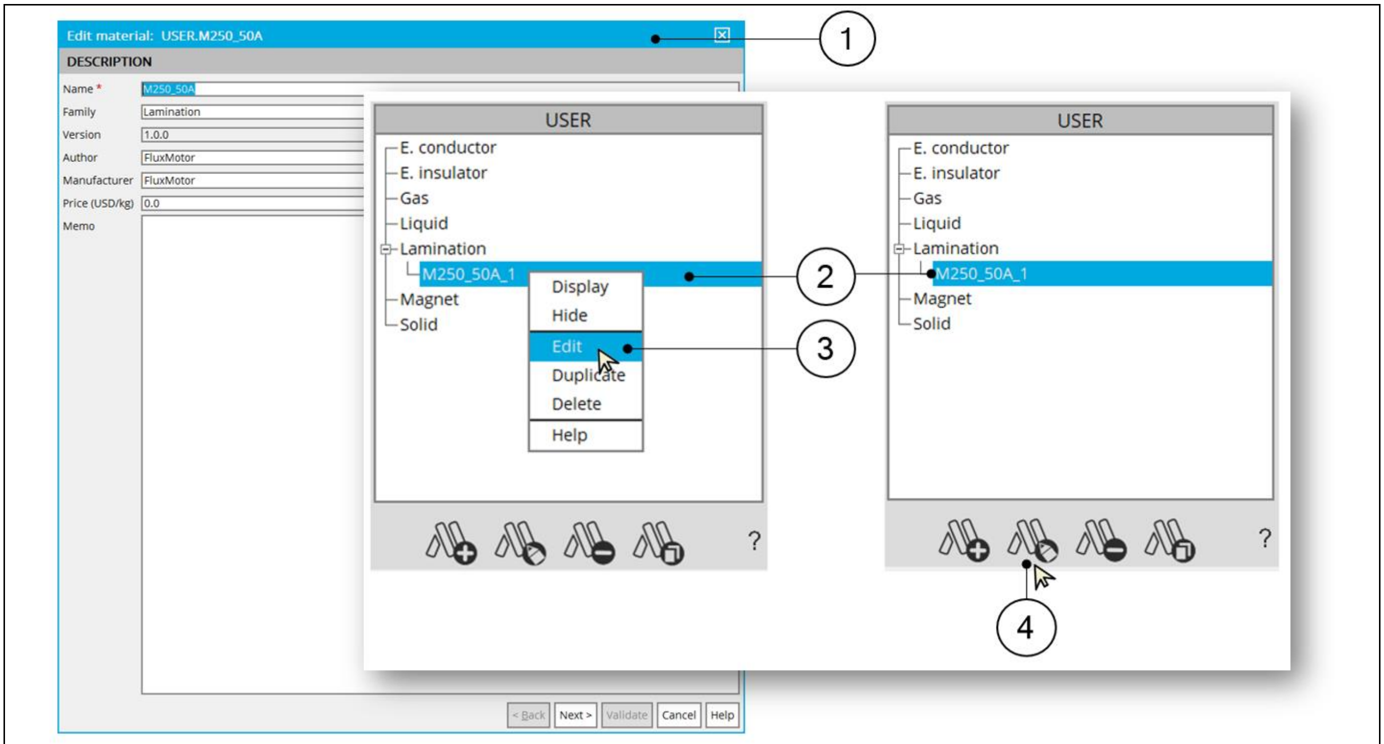
2.2.8 Liquid data

Here are the properties needed to define a new liquid:

Category	Label	Unit
Description	Name	*
	Family	*
	Author	*
	Manufacturer	*
	Memo	*
Economic	Price	USD/kg
Mechanical data	Mass density reference temperature TrefD	°C
	Mass density at TrefD and Pref	kg/m3
	Mass density first order temperature coefficient at TrefD and Pref	K-1
	Mass density second order temperature coefficient at TrefD and Pref	K-2
	Dynamic viscosity reference temperature - TrefV	°C
	Dynamic viscosity at TrefV	kg/m/s
	Dynamic viscosity first order temperature coefficient at TrefV	K-1
	Dynamic viscosity second order temperature coefficient at TrefV	K-2
Thermal data	Thermal conductivity reference temperature - TrefC	°C
	Thermal conductivity at TrefC	W/K/m
	Thermal conductivity first order temperature coefficient at TrefC and Pref	K-1
	Thermal conductivity second order temperature coefficient at TrefC and Pref	K-2
	Specific heat reference temperature - TrefS	°C
	Specific heat at TrefS and Pref	J/K/kg
	Specific heat first order temperature coefficient at TrefS and Pref	K-1
	Specific heat second order temperature coefficient at TrefS and Pref	K-2
	Thermal expansion reference temperature - TrefE	°C
	Thermal expansion coefficient at TrefE	K-1
	Thermal expansion first order temperature coefficient at TrefE	K-1
	Thermal expansion second order temperature coefficient at TrefE	K-2

2.3 Edit a material

It is possible to edit a material from the user material database by updating its properties.
Editing a material consists of opening the same dialog boxes which were used for the creation, but the fields are already filled with properties which can be modified.
Two ways are possible to edit a material. They are described below.

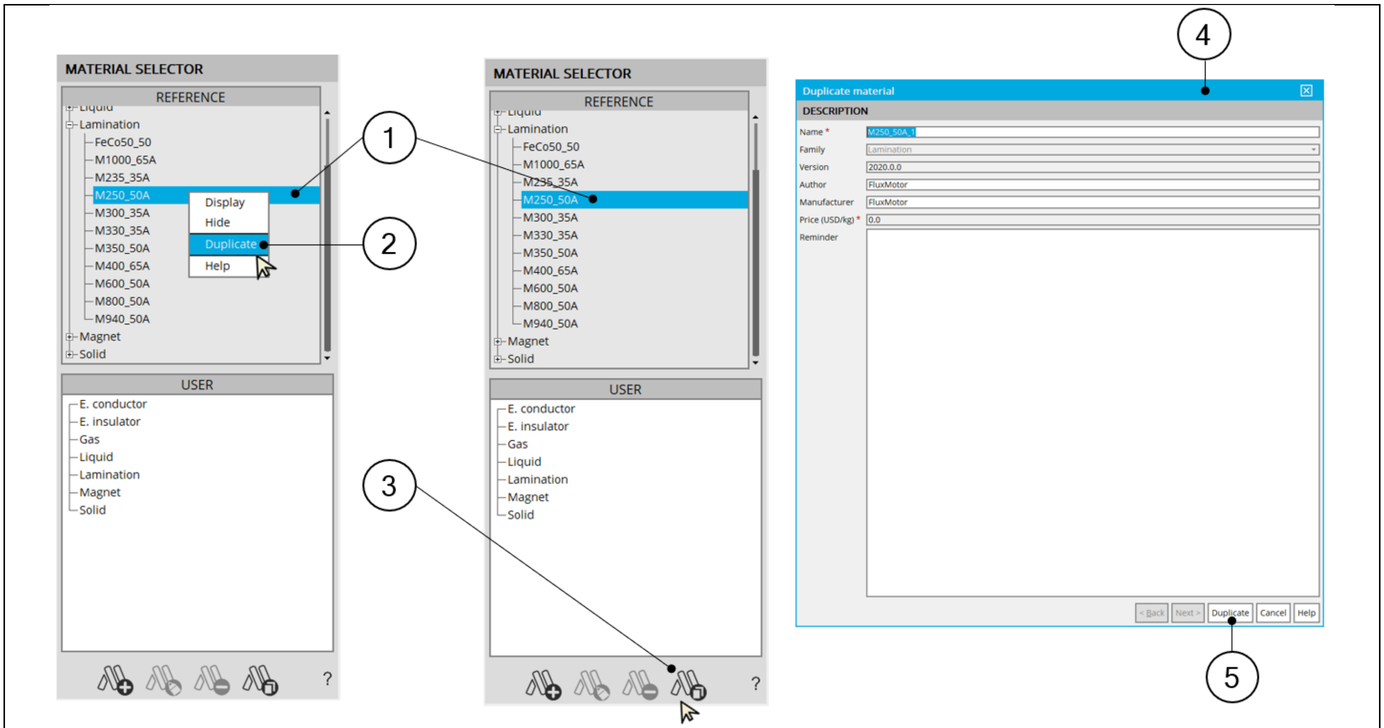


How to edit a material to update properties?	
1	Dedicated dialog box allows updating all the physical properties of the considered material.
2	In any case, one must select the name of the material properties which has to be modified.
3	The first way to edit a material consists of using the right mouse button to get the corresponding menu and clicking on the function Edit.
4	The second way to edit a material consists of clicking on the Edit button in the area where several functions are located at the bottom part of the user material database to manage the materials.

2.4 Duplicate a material

All the materials can be duplicated either from the reference material database or from the user materials database.
For any origin of the material (reference or user material database), the new material resulting from the duplication will be stored in the user material database.
Duplicate a material allows creating a new material from an original with another name. It is possible to modify (by editing it) the corresponding properties to personalize it.

Here are the ways to duplicate a material:



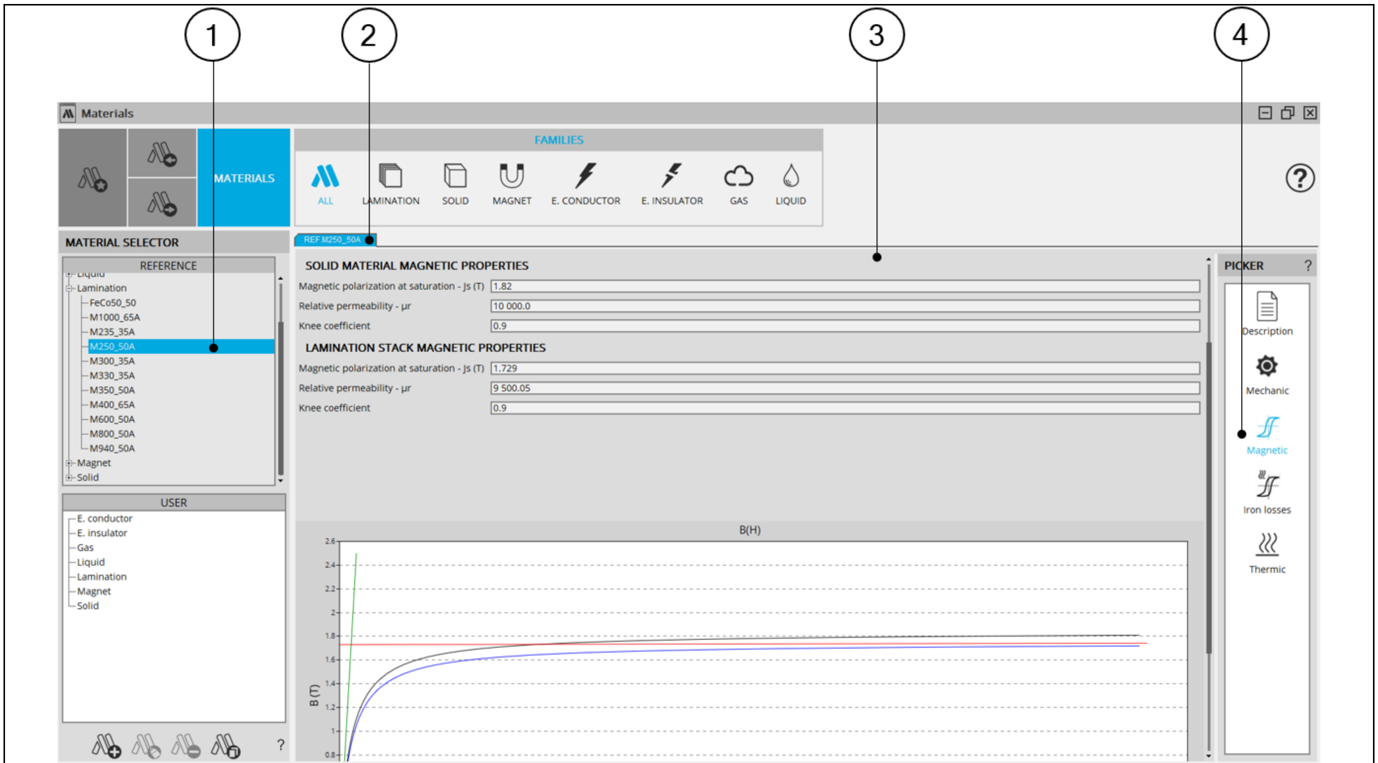
	How to duplicate a material?
1	In any case, one must select the name of the material to be duplicated.
2	The first way to duplicate a material consists of using the right mouse button to expand the corresponding menu and then clicking on the function Duplicate.
3	The second way to duplicate a material consists of clicking on the Duplicate button in the area where several functions are located at bottom part of the user material database to manage the materials.
4	A dedicated dialog box allows finalizing the creation of the new material from duplication by giving a new name and writing a memo if needed.
5	The creation of the new material is achieved when clicking on the Duplicate button. It is also possible to cancel the duplication.

2.5 Display, Hide or Delete a material

2.5.1 Display material properties

Displaying the material properties allows editing a tab in which all the properties are displayed in several chapters:

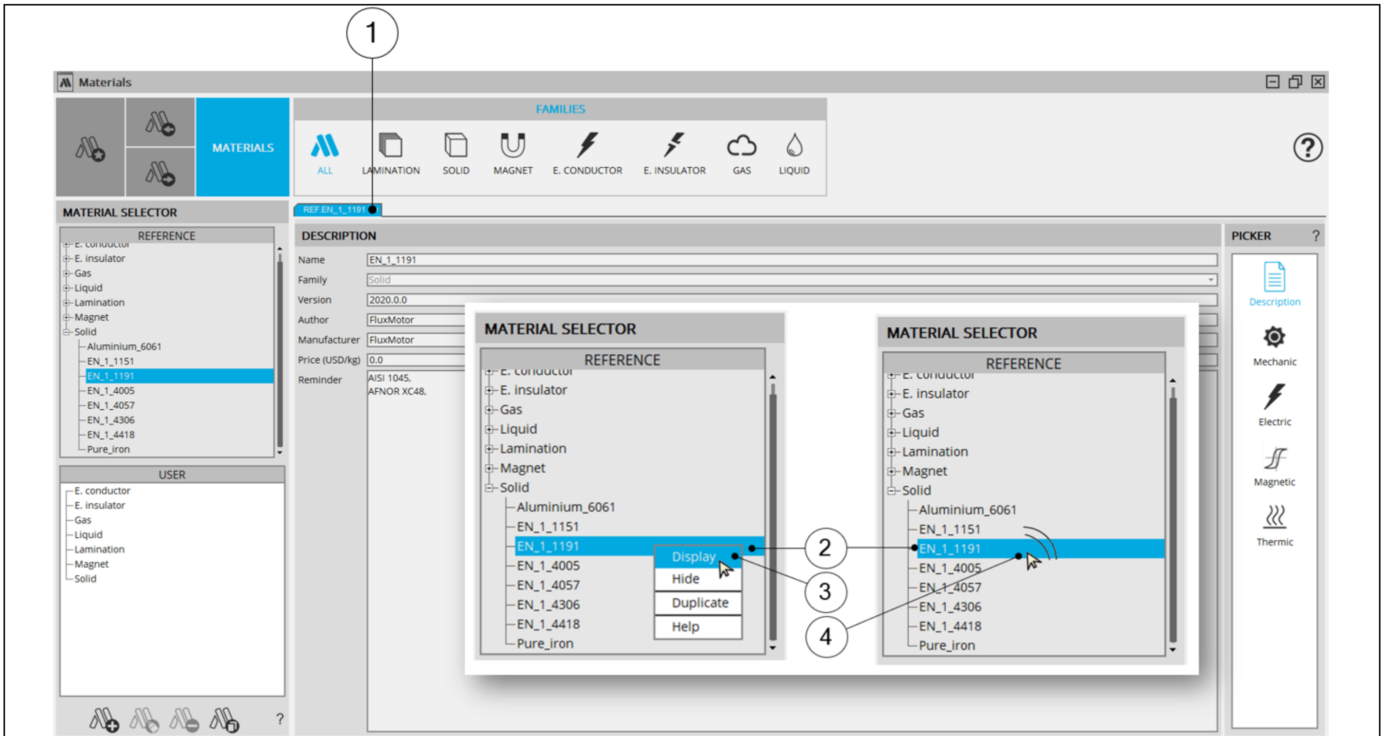
- Description for the general data (name, family, etc.)
- Mechanical data
- Electrical data
- Magnetic data (B(H) curve)
- Iron losses (If available for the considered material)



Displaying of the material properties

1	The properties of the selected material must be displayed. See below how to display the tabs where all the properties are recorded.
2	Tabs in which the physical properties of the considered material are presented.
3	All the tables can be displayed by clicking on the corresponding shortcut.
4	Shortcuts for displaying the corresponding section of the material properties.

Here are the ways to display the properties of materials:

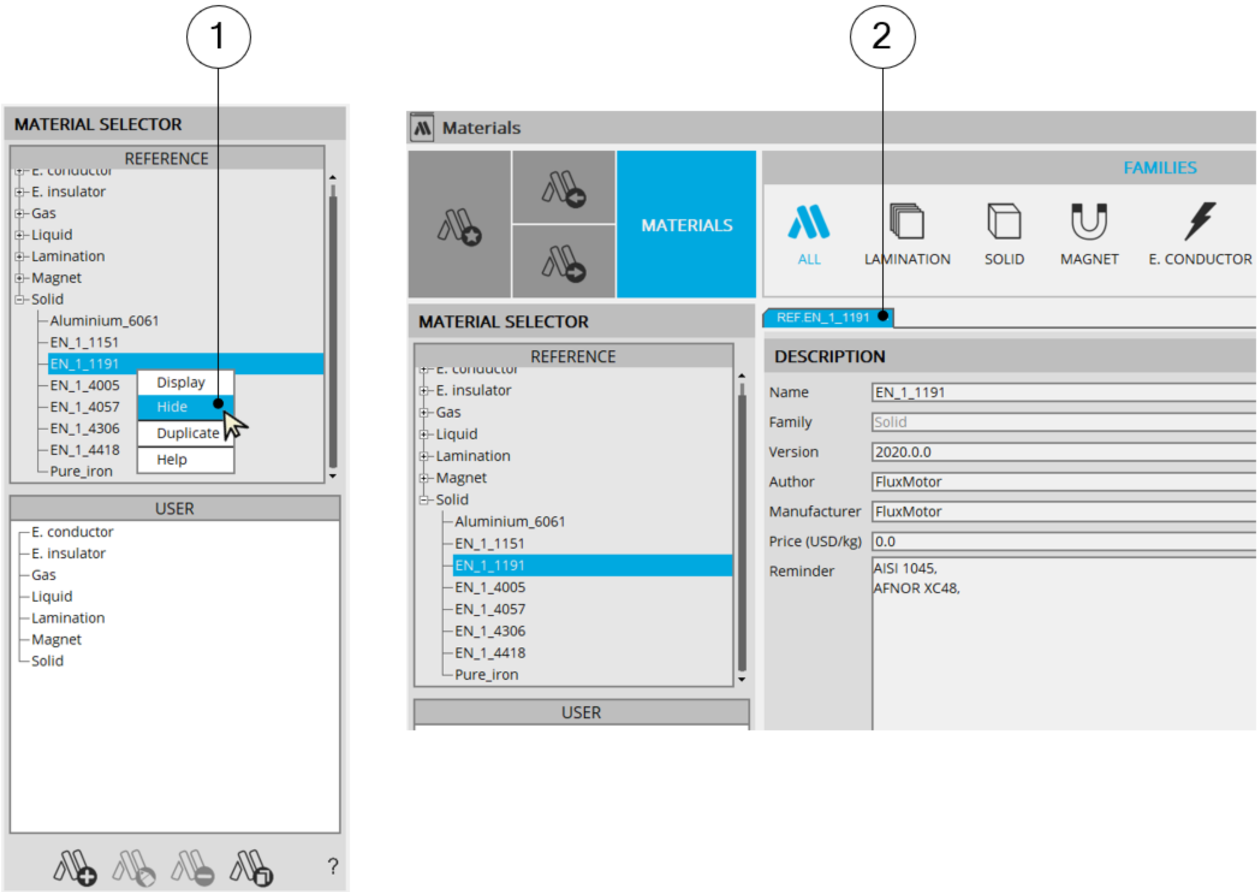


How to display the material properties?	
1	The properties of the selected material are displayed in a tab.
2	In any case, one must select the name of the material properties which have to be displayed.
3	The first way to display the properties of the selected material consists of using the right mouse button to expand the corresponding menu and clicking on the function Display.
4	The second way to display the properties of the selected material consists of double clicking on the considered material.

2.5.2 Hide material properties

Hide the material properties consists of removing the tabs in which the physical properties of the material are displayed from the central screen of the “Materials” application.
Note: The properties of the materials are hidden, but the material still exists in the material database.

Two ways are possible to hide material properties. There are described below.

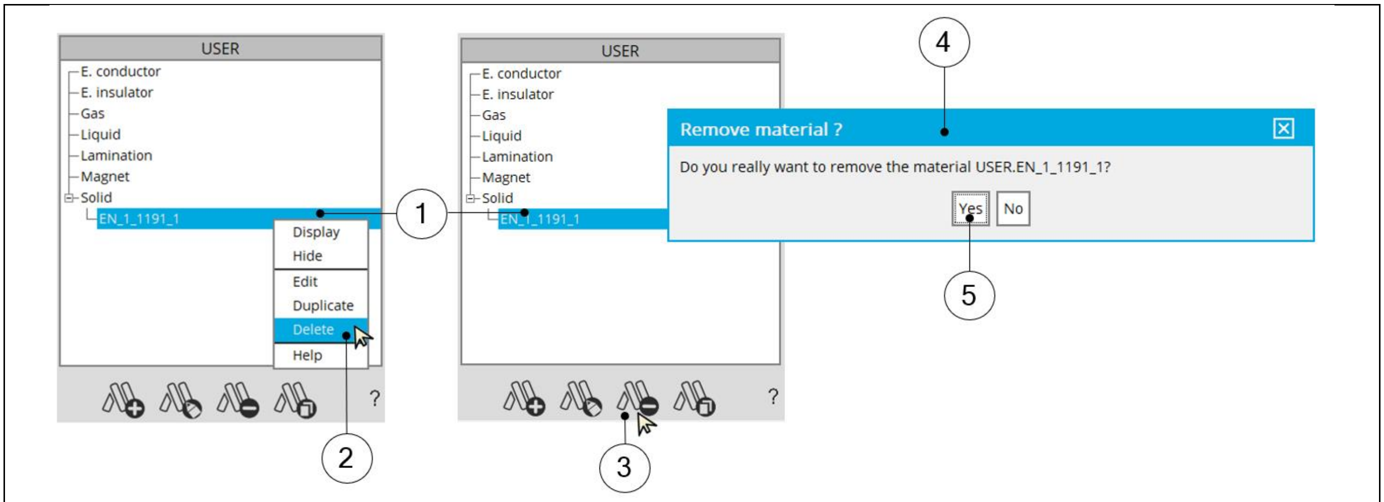


	How to hide the material properties?
1	The first way to hide the properties of the selected material consists of using the right mouse button to expand the corresponding menu and clicking on the function Hide.
2	The second way to hide the properties of the selected material consists of clicking on the cross in the top part of the displayed tab.

2.5.3 Delete a material

Delete a material means that it is removed from the material database.
Only materials from the user material database can be deleted.

Note: When deleting a material used in the design of an existing motor, the name of this material and all the corresponding physical properties are kept in the data of the motor. They are kept if the material is not changed in the motor. If the material is replaced by another one, the former material (removed from the material database) won't be usable anymore.



How to delete a material?

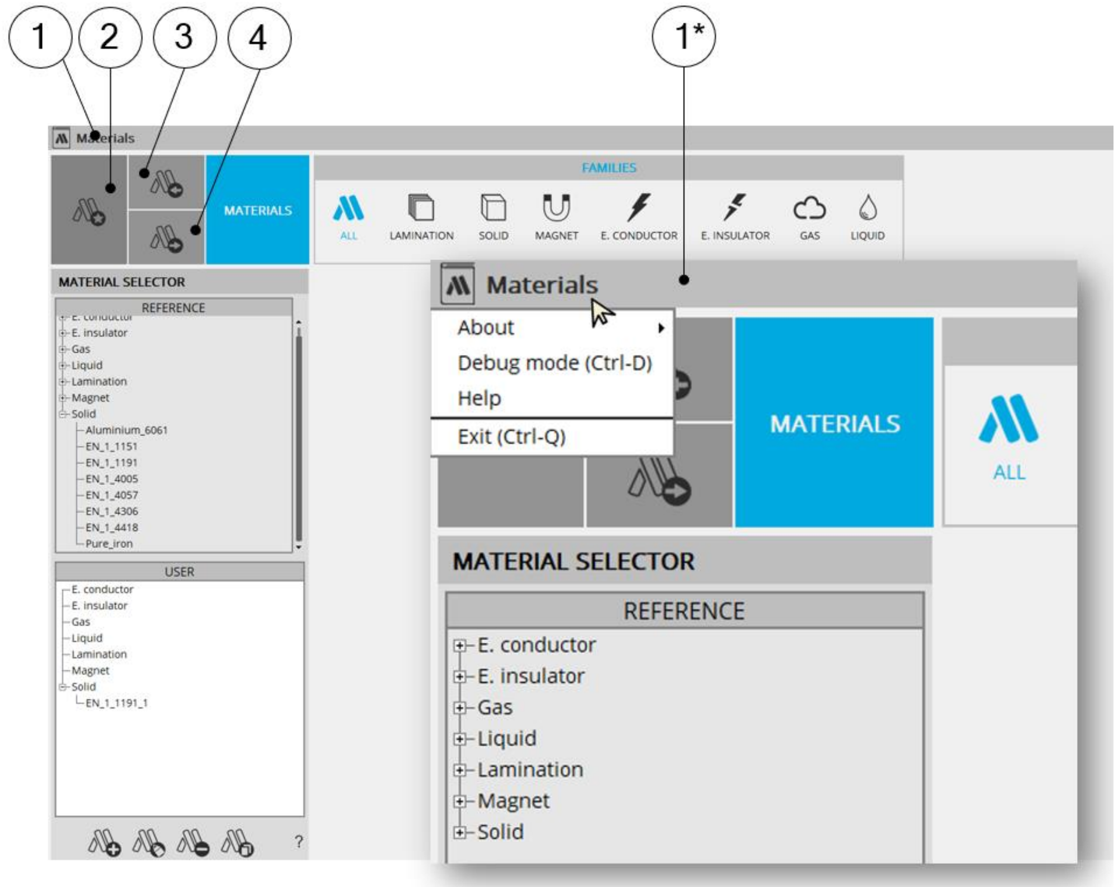
1	Select the name of the material to be deleted.
2	The first way to delete a material consists of using the right mouse button to expand the corresponding menu and clicking on the function Delete.
3	The second way to delete a material consists of clicking on the Delete button in the area where several functions are located at bottom part of the user material database to manage the materials.
4	A dedicated dialog box allows finalizing the deletion of the selected material. Note: Several materials can be selected to be deleted.
5	The deletion of the material is achieved when clicking on "Yes". Obviously, it is possible to cancel the deletion by clicking on "No".

3 SYSTEM FUNCTIONS

3.1 Overview

The main system functions are directly accessible from the “Materials” application area.
Expanding the menu in the left top part of “Materials” is also available.

Here is the presentation of these functions:

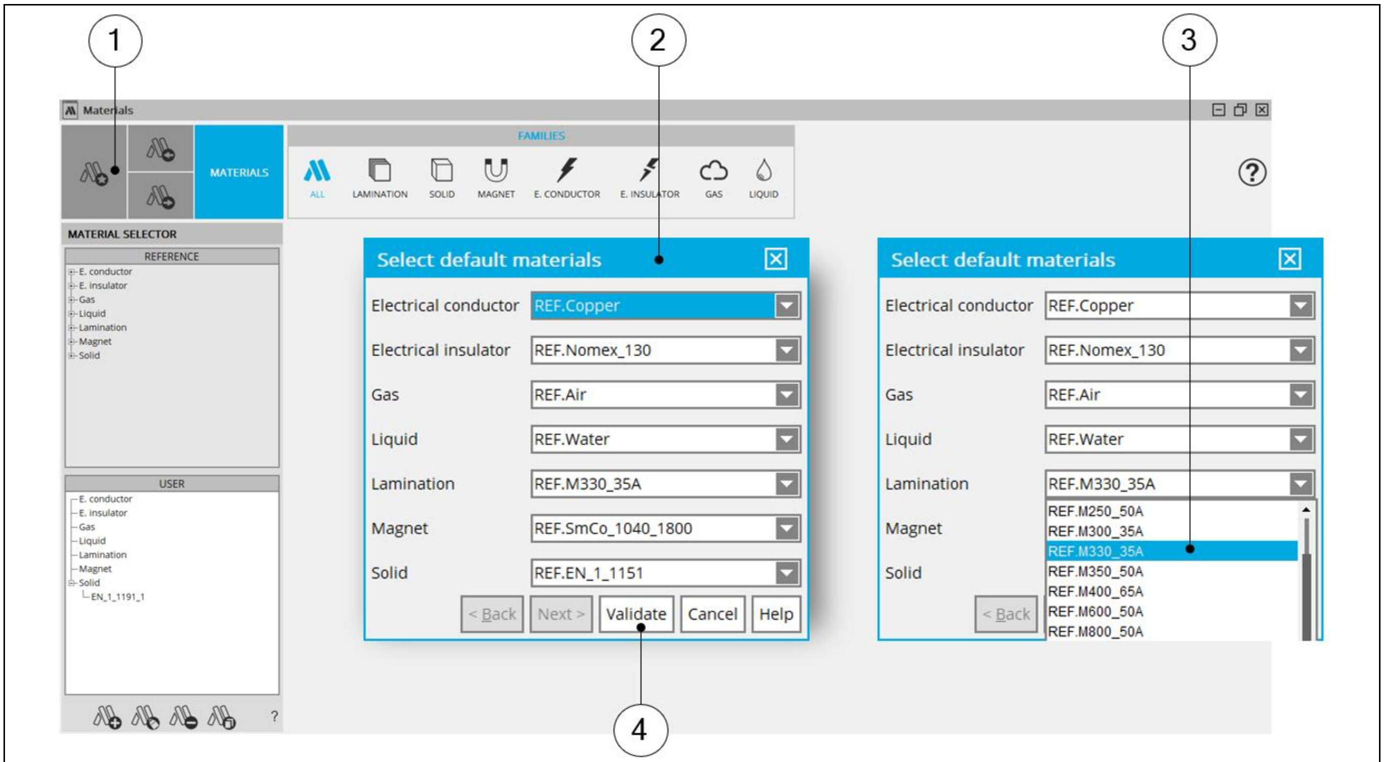


1	Access to the top menu of “Materials” area to reach functions like (1*): • About • Debug mode • Help • Exit
2	Select default materials ready to be used in Motor Factory via Quick building access.
3	Import materials from an external database.
4	Export materials to an external database.

3.2 Define default materials

The aim of this function is to declare a default material for each material family.
Each time a user creates a new machine in Motor Factory, these default materials will be automatically chosen.

Here is the way to define default materials:

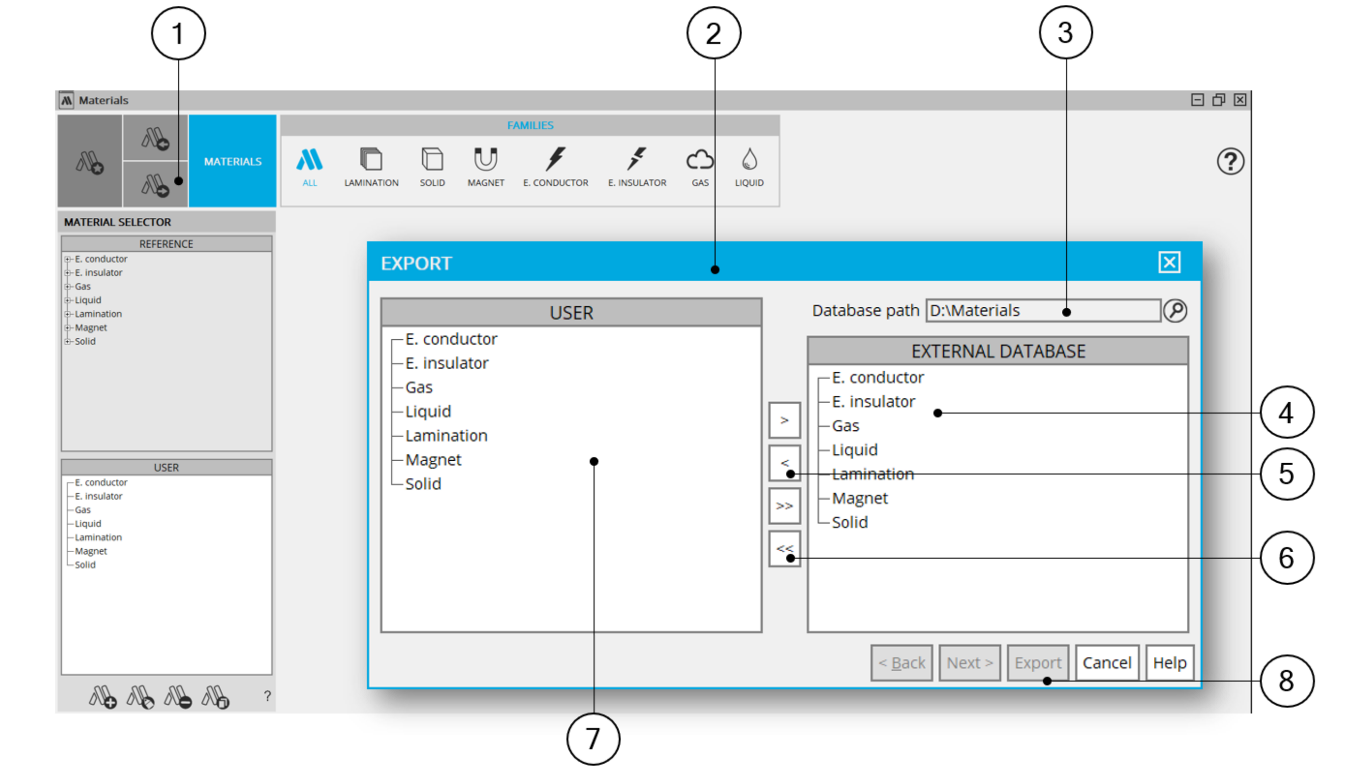


1	Main button to open the dialog box allows declaring the default materials.
2	Dialog box allows choosing one default material for each material family.
3	For each material family, expanding the menu allows choosing among all the possible materials stored in the material database (reference as well as user material database.
4	The choices of default materials are achieved when clicking on the Validate button. It is also possible to cancel the choice.

3.3 Export materials

It is possible to export materials from user material database to share them with other users.

Here is the way to export materials:

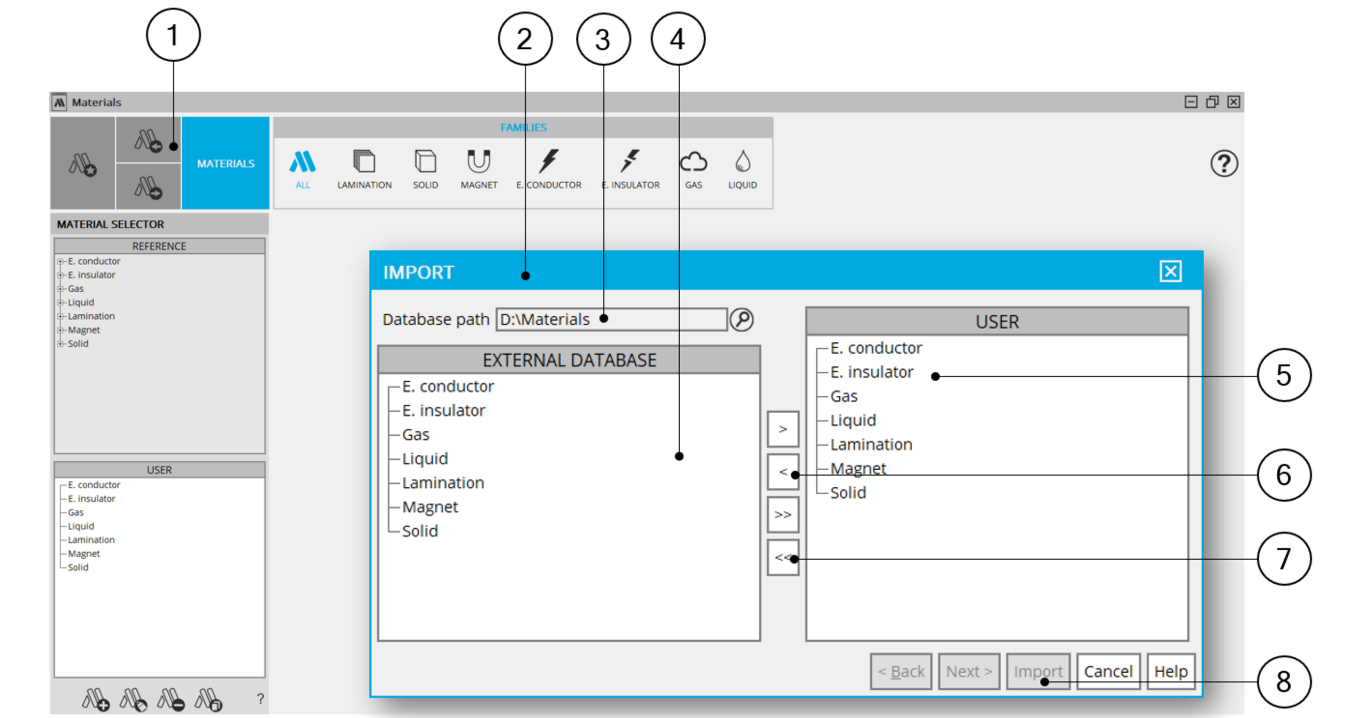


1	Main button to open the dialog box allows exporting materials.
2	Dialog box allows exporting materials from each material family. Note: Only materials from user material database can be exported.
3	Select the path where the exported materials will be stored. Note: This selection is mandatory to continue the process of exporting.
4	Select the materials to be exported in each family.
5	Choose to export the materials one by one.
6	Choose to export all the materials at the same time.
7	Visualize the materials which are already selected to be exported.
8	Exporting selected materials is achieved when clicking on the Export button. Obviously, it is possible to cancel the process of exporting.

3.4 Import materials

It is possible to import materials from external material database built by another user of FluxMotor®. All the imported materials will be stored in the user material database.

Here is the way to import materials:

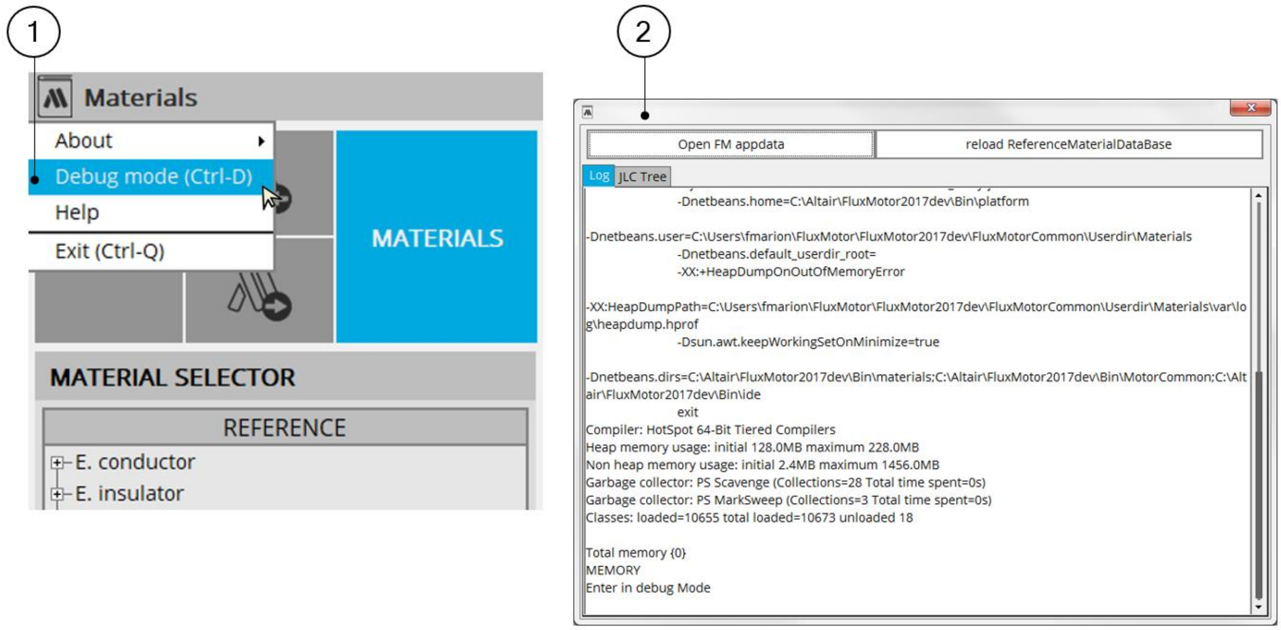


1	Main button to open the dialog box allows importing materials.
2	Dialog box allows importing materials from each material family. Note: Imported materials will be stored in user material database.
3	Select the path from which the materials must be imported. Note: This selection is mandatory to continue the process of exporting.
4	Select the materials to be imported from each family.
5	Visualize the materials which are selected for import.
6	Choose to import the materials one by one.
7	Choose to import all the materials at the same time.
8	Importing selected materials is achieved by clicking on the Import button. Obviously, it is possible to cancel the process of importing.

3.5 General functions

3.5.1 Debug mode function

The Debug mode function is dedicated for solving the problem in the use of “Materials” application.
In case of trouble, instructions will be given by our FluxMotor® support team to use this function.

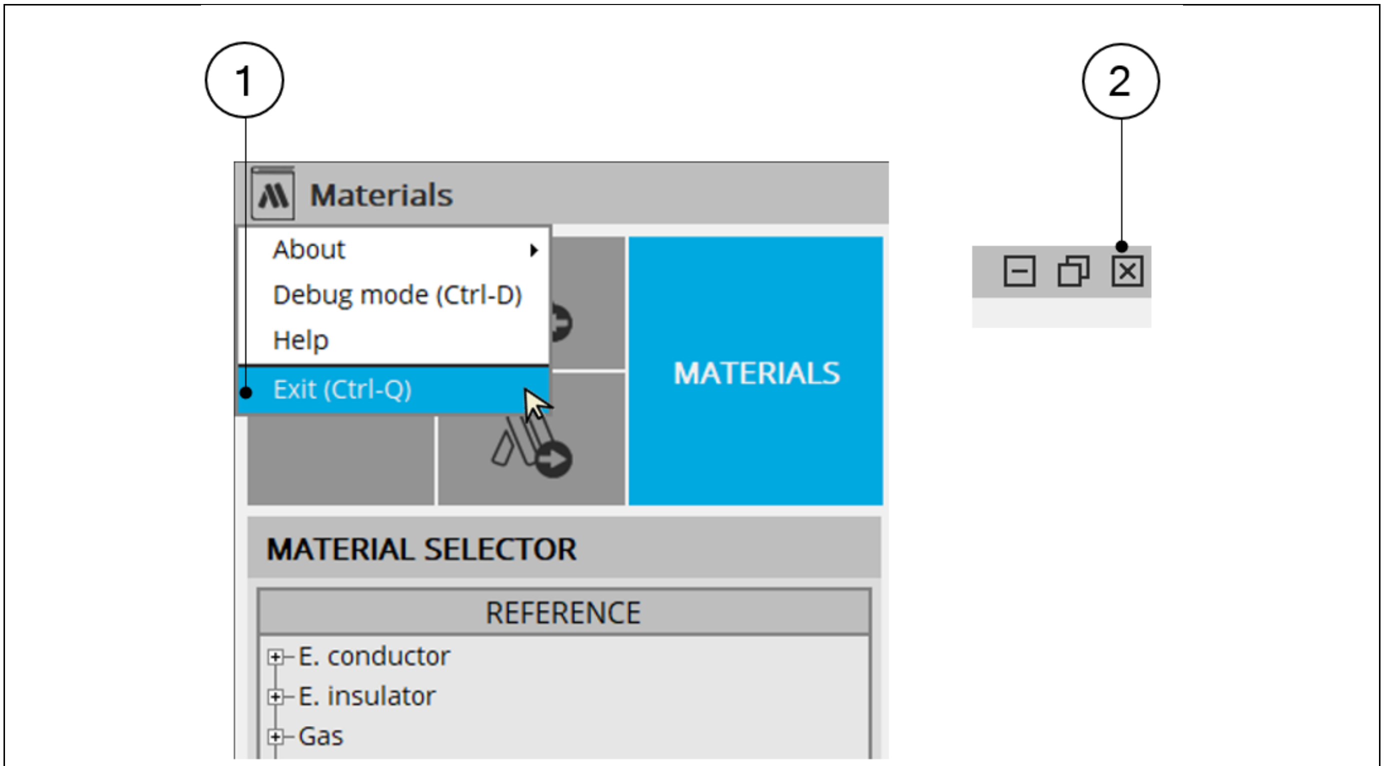


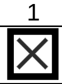
Mode debug

1	Access to “Debug mode” from the top menu of “Materials” application.
2	Dialog box corresponding to the “Debug mode” function.
*	Access to the “Debug mode” is possible by using the shortcut CTRL-D defined in the user FluxMotor® preferences. For more information, refer to the chapter “user’s preferences”.

3.5.2 Exit

Closing “Materials” application is possible



Exit – Close “Materials” application	
1	Close “Materials” application from the top menu of “Materials” application.
	Close “Materials” application by using the following icon on the right top part of the “Materials” application panel.
*	Close “Materials” application by using the shortcut CTRL-Q defined in the user FluxMotor® preferences. For more information, refer to the chapter “user’s preferences”.

4 ADVANCED

4.1 Define a B(H) curve

4.1.1 Create a B(H) curve – Main principles

The model consists of a combination of a straight line and a curve. A coefficient allows for the adjustment of the knee shape for better approximation of the experimental curve.

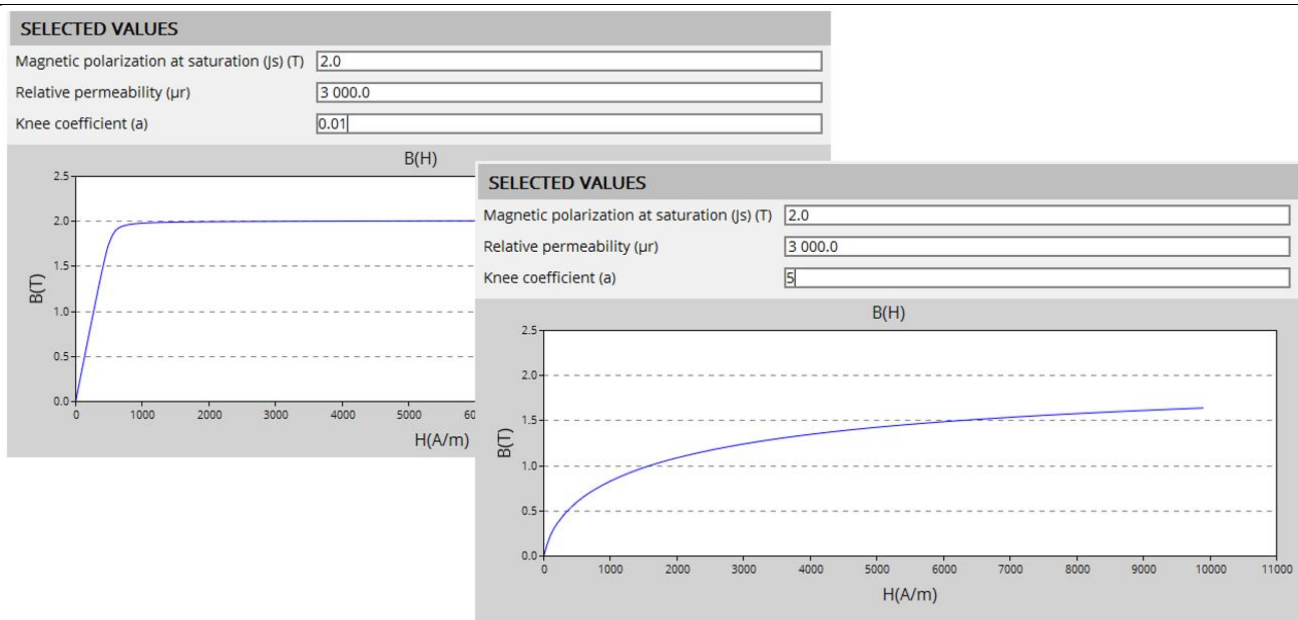
The corresponding mathematical formula is written as follows:

$$B(H) = \mu_0 \times H + J_S \times \frac{H_a + 1 - \sqrt{(H_a + 1)^2 - 4 \times H_a \times (1 - a)}}{2 \times (1 - a)}$$

with $H_a = \mu_0 \times H \times \frac{\mu_r - 1}{J_S}$

$\mu_0 = 4 \times \pi \times 10^{-7}$	Permeability of vacuum.
μ_r	Initial relative permeability of the material.
H	Magnetic field (A/m).
J_S	Magnetic polarization at saturation (T).
a	Knee coefficient of the curve $(a > 0 \quad and \quad a \neq 1)$. The smaller coefficient will give, the sharper knee point.

The impact of the knee coefficient "a" on the shape of the B(H) curve is illustrated in the below figure.



Shape of B(H) curve with the function of knee coefficient.

4.1.2 Create a B(H) curve – Process

4.1.2.1 Overview

A linear or a non-linear B(H) curve is considered.

In the first case, only the constant value of the relative permeability must be given by the user.

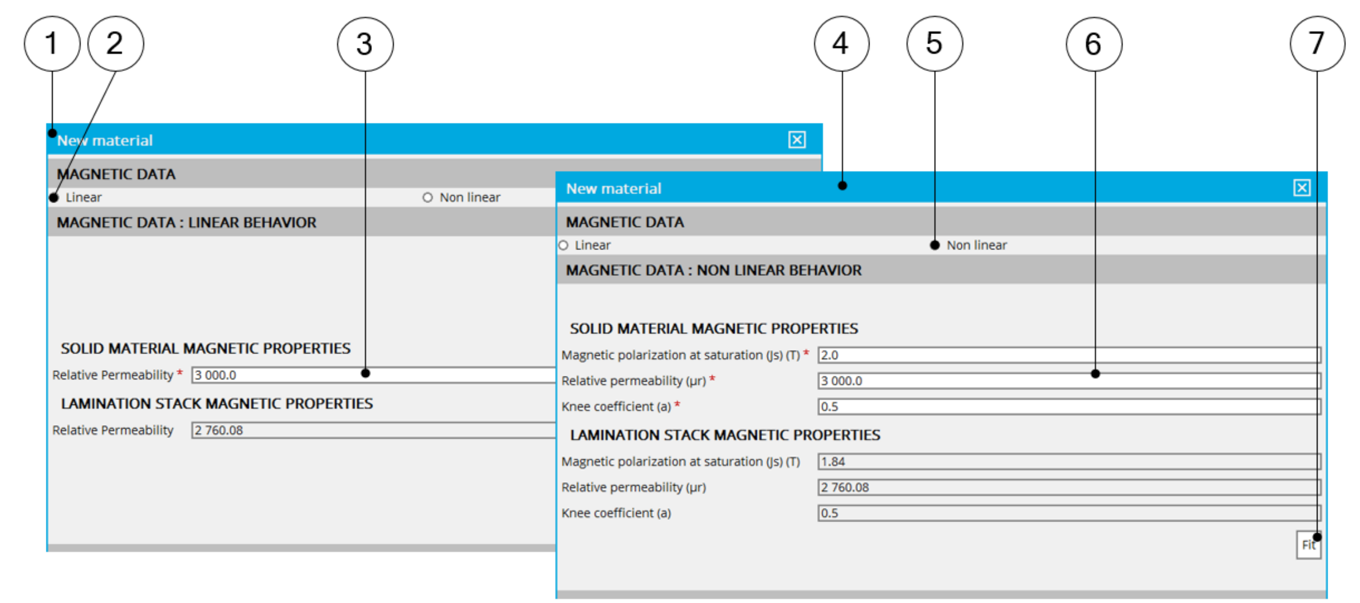
If a lamination is considered, the relative permeability of the lamination stack is automatically deduced.
If a non-linear B(H) curve is considered, these three main parameters of the magnetic characteristics must be defined:

- The magnetic polarization at saturation J_S
- The magnetic permeability (μ_r)
- And the knee coefficient a

If a lamination is considered, the corresponding magnetic characteristic is automatically deduced.

4.1.2.2 Define a B(H) curve from user input parameters

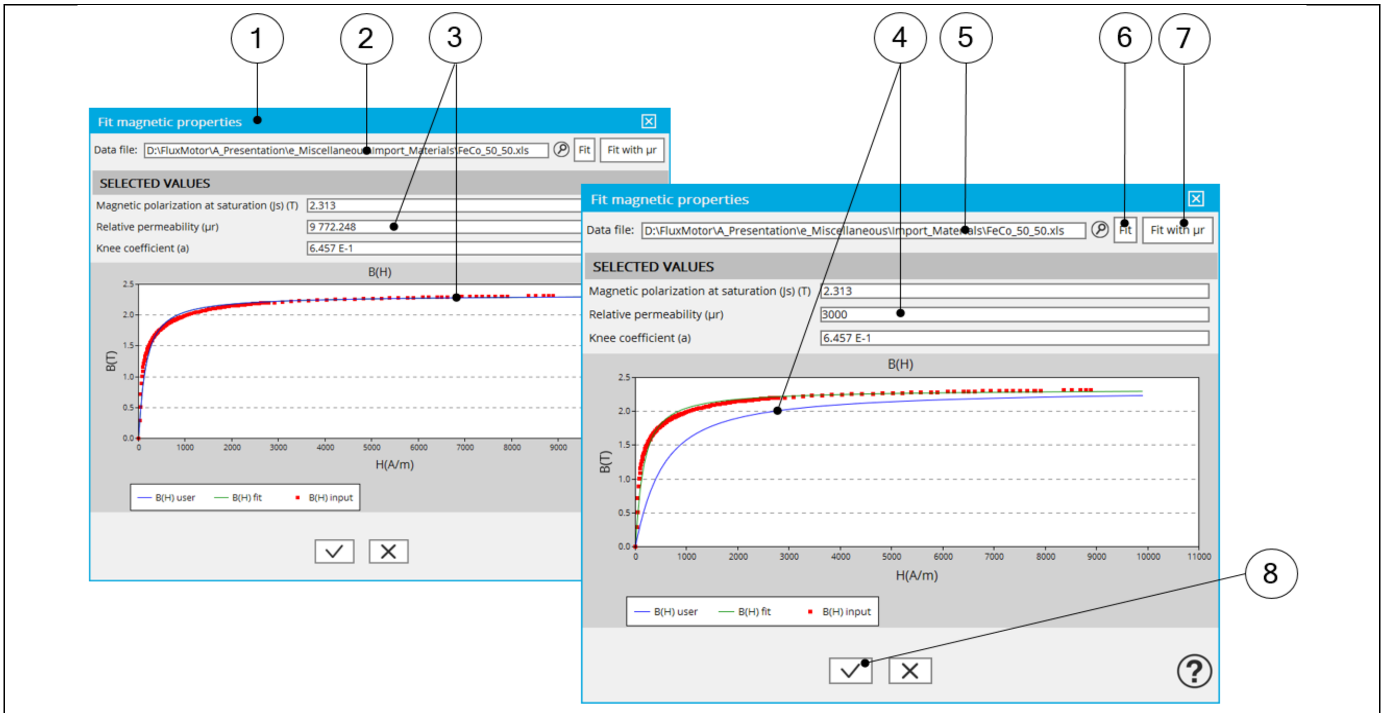
Here is the process to define the B(H) curve from the "Materials" application. In this example, it is considered that the user knows exactly the coefficients to be set.



Characterization of the B(H) curve	
1	When creating a new material or when editing the properties of an existing one, a tab is dedicated to the magnetic data.
2	In the example above, the linear B(H) characteristic of a lamination is considered
3	Only the relative permeability of the corresponding solid material is given. The resulting relative permeability of the lamination stack is automatically deduced (considering the stacking factor mentioned in the mechanical data) and displayed in a disabled field (below).
4-5	In another example, the non-linear B(H) characteristic of a lamination is considered.
6	The three main parameters of the magnetic characteristic that must be given are: • The magnetic polarization at saturation (J_S) • The magnetic permeability (μ_r) • And the knee coefficient a The resulting magnetic characteristics of the lamination stack is automatically deduced (considering the stacking factor mentioned in the mechanical data) and displayed in a disabled field (below).
7	Another method is possible to define the B(H) curve characteristics of a material. If the user has measurement or computation points representing the B(H) curve to model, it is possible to import these data to define the corresponding characteristics. This consists of importing a B(H) curve via an Excel file and identifying the three parameters J_S, μ_r and knee coefficient with an optimization process. Click on the icon "Fit" to run this process.

4.1.2.3 Define a B(H) curve from experimental data

Here is the process to define the characteristics of the B(H) curve from the importation of series of points representing the B(H) curve listed in an Excel file.



Identification of the B(H) curve characteristics	
1	Dialog box allowing the characterization of the B(H) curve imported from an Excel file
2	Path where Excel file to be imported is stored. See an example of Excel file below.
3	When importing an Excel file, points representing the B(H) curve are listed, an optimization process automatically computes and displays the corresponding characteristics Js, µr and a. At the same time three curves are displayed: Red points are the imported points (listed in the Excel file) Green curve is the resulting curve computed by the optimization process. This corresponds to the computed characteristics and displayed just after the computation. The blue curve shows modifications induced if the characteristics Js, µr and a are changed by the user.
4	Indeed, the user can adjust one or all the three main characteristics of the B(H) curve: Js, µr and a. The resulting modification is directly displayed on the graph below.
5	Field in which the path where the Excel file to be imported is stored.
6	At any time, the user can run the optimization process to get back the proposed values for Js, µr and a.
7	It is possible to run the optimization process by considering only two variables Js and a. In that case µr is imposed by the user
8	The last values of JS, µr and a, written in the input fields are validated when the user clicks on this button. Validation of the last values of Js, µr and “a” is achieved when clicking on this button. It is possible to cancel the creation of the B(H) curve model. In this case, the previous values defined before opening this dialog box are reset.

Example of an Excel file to define the B-H curves parameters.

	A	B	C	D
1				
2		BH curve		
3		Label	Magnetic field	Magnetic flux density / Vector
4		Units	A/m	T
5		Values	0,00E+00	0,00E+00
6			3,03E+01	2,88E-01
7			4,22E+01	5,06E-01
8			5,25E+01	7,19E-01
9			6,52E+01	8,86E-01
10			7,65E+01	1,01E+00
11			8,79E+01	1,09E+00
12			9,97E+01	1,16E+00
13			1,13E+02	1,22E+00
14			1,25E+02	1,26E+00
15			1,36E+02	1,30E+00
16			1,45E+02	1,33E+00
17			1,56E+02	1,37E+00
18			1,69E+02	1,39E+00
19			1,82E+02	1,42E+00
20			1,93E+02	1,45E+00
21			2,03E+02	1,47E+00
22			2,15E+02	1,49E+00
23			2,27E+02	1,51E+00
24			2,42E+02	1,53E+00
25			2,54E+02	1,55E+00
26			2,65E+02	1,57E+00
27			2,75E+02	1,58E+00
28			2,88E+02	1,58E+00
29			3,00E+02	1,61E+00

Example of an Excel file to define the B(H) curve parameters

4.2 Define iron loss parameters

4.2.1 Iron losses model - Main principles

The mathematical formula used in FluxMotor® to compute the iron losses is:

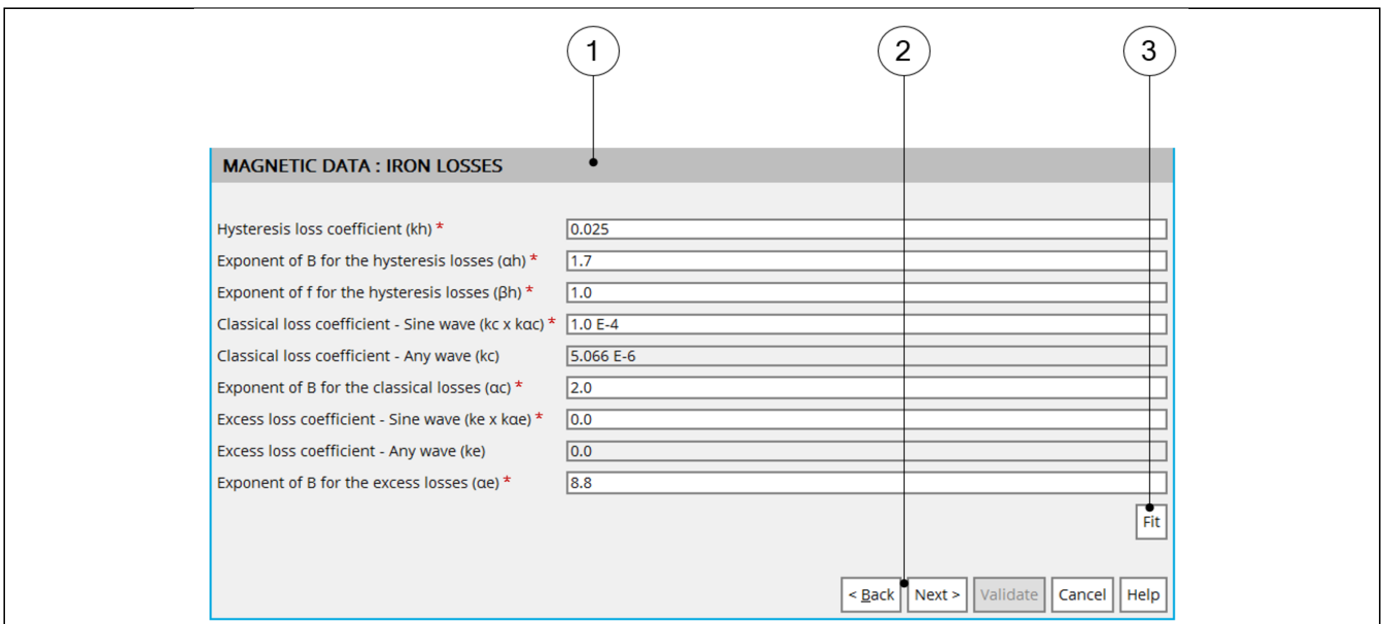
$$P = k_h \times B_{pk}^{\alpha_h} \times f^{\beta_h} + k_c \times \left(B_{pk} \times f\right)^{\alpha_c} + k_e \times \left(B_{pk} \times f\right)^{\alpha_e}$$

Note: Iron loss model is only used for lamination.

Label	Definition
k_h	Hysteresis loss coefficient.
α_h	Exponent of B for the hysteresis losses.
β_h	Exponent of f for the hysteresis losses.
k_c x k_{ac}	Classical loss coefficient – Sine wave.
k_c	Classical loss coefficient – Any wave. Automatically computed from the sine wave value – The field is grayed out.
α_c	Exponent of B and f for the classical losses.
K_e x k_{ae}	Excess loss coefficient – Sine wave.
k_e	Excess loss coefficient – Any wave Automatically computed from the sine wave value – The field is grayed out.
α_e	Exponent of B and f for the excess losses.

Note: The formula above is not homogeneous with considered the units.
Indeed, it represents a correspondence between the flux density associated with the frequency and the resulting iron loss amount.
The coefficients listed above are completely independent of units.
In FluxMotor®, P represents the amount of iron losses per cubic meter. This quantity is computed by considering B in Tesla and f in Hertz.
The coefficients are always defined by considering these reference units.
The user can use other units for defining the iron losses or flux density for example. In FluxMotor® the corresponding quantities are transformed to come back to original units (Tesla, Hz and W/m3).

When creating a new material or when editing the properties of an existing one, a tab is dedicated to the magnetic data. In this tab, iron loss coefficients must be given.



Definition of iron loss coefficients	
1	In the tab dedicated to magnetic data, a data table allows to define iron loss parameters. The users can fill this form when they know the values of the parameters.
2	It is possible to move forward or backward to other tabs describing all the physical properties of lamination.
3	When the users do not know the values of the parameters, they can use the function “Fit” to find relevant values to set. This function is described below.

4.2.2 How to define iron loss parameters?

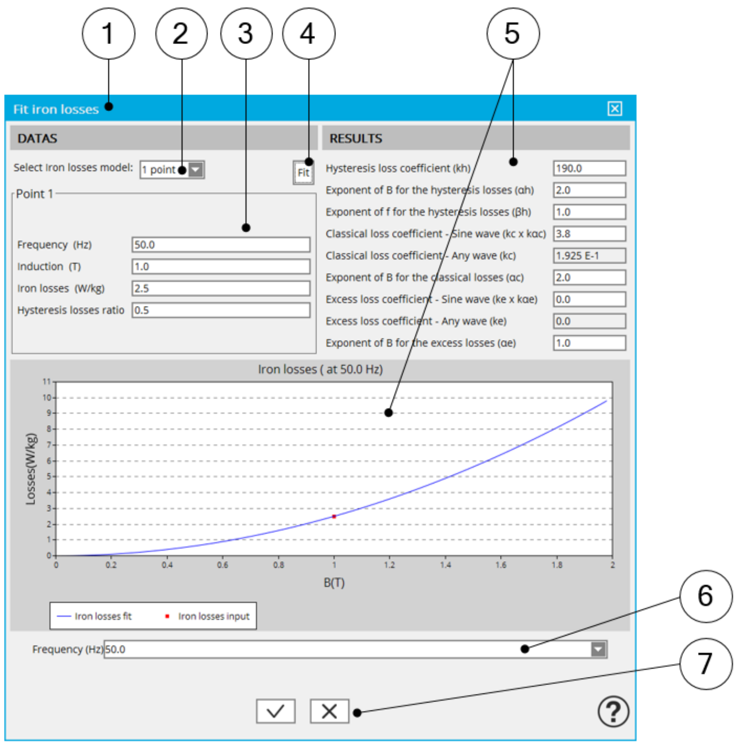
4.2.2.1 Overview

Three main methods are provided to help the users find the relevant values to consider for the iron loss parameters. The choice of the method depends on the data that the user has for the lamination to consider.

Three cases are considered:

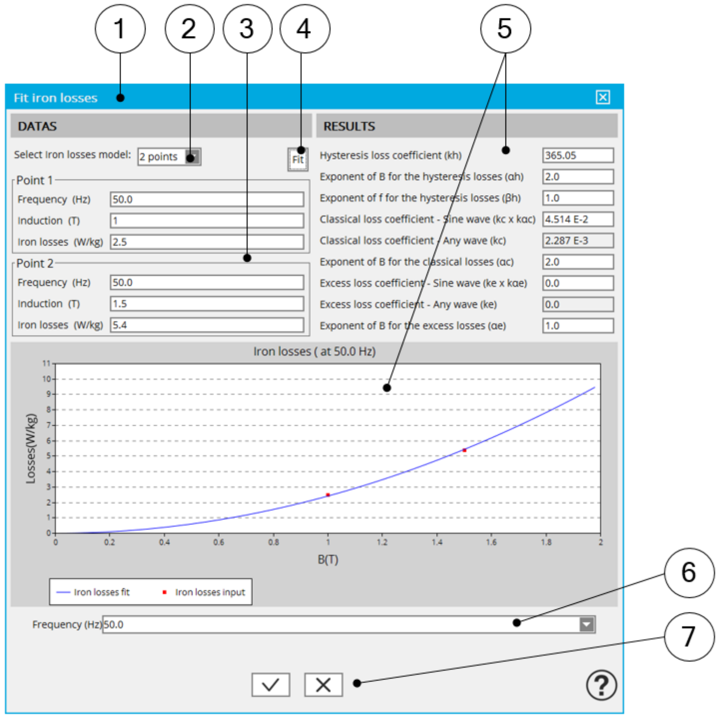
- One measurement point is characterized: Amount of iron losses corresponding to the values (frequency, induction)
- Two measurement points are characterized: Amount of iron losses corresponding to the values (frequency, induction)
- Several curves of iron losses in function of flux density for different values of frequency which corresponds to a map of Iron losses in f - B plane (where f= frequency and B=flux density)

4.2.2.2 Case 1: From one measurement point



Definition of iron loss coefficients – from one measurement point	
1	Dialog box dedicated to define the iron loss parameters. Located in the magnetic data tab when creating a new material or when editing the properties of an existing one.
2	Choice of the method to find iron loss parameters (1 point in this example).
3	Measurement characteristics: • Frequency, • Induction (magnetic flux density B), • Iron losses (amount of iron losses) • Hysteresis loss ratio. Note: Hysteresis loss ratio is the ratio between the hysteresis losses and the total amount of iron losses.
4	When input parameters characterizing the measurement point are defined, click the button Fit to run the optimization process. This process computes the set of iron loss parameters that allow targeting the considered measurement point.
5	The resulting iron loss input parameters are deduced and displayed in the result table and the corresponding curve Losses versus B (magnetic flux density) is displayed. Note: The values can be modified inside the table and the resulting curve is displayed below.
6	It is possible to select a frequency to visualize the behavior of the resulting iron loss curve. Note 1: Write a new frequency or user can select the frequency by expanding the menu. Note 2: In the current example, the selected frequency equals the frequency set as input. The targeted measurement point (in red) is superimposed to the resulting iron loss curve.
7	Validation of iron loss parameters is achieved when clicking on this button. it is possible to cancel the computation of iron loss parameters.

4.2.2.3 Case 2: From two measurement points



Definition of iron loss coefficients – from two measurement points	
1	Dialog box dedicated to defining the iron loss parameters. Located in the magnetic data tab when creating a new material or when editing the properties of an existing one.
2	Choice of the method to find iron loss parameters (2 points in this example).
3	Measurement characteristics to give for each measurement point: • Frequency (It is highly recommended to take 2 different frequencies as boundaries of the working area) • Induction (magnetic flux density B) • Iron losses (amount of iron losses)
4	When input parameters characterizing the two measurement points are defined, click on the Fit button to run the optimization process. This process computes the set of iron loss parameters that allow targeting the considered measurement points.
5	The resulting iron loss input parameters are deduced and displayed in the result table and the corresponding curve Losses versus B (magnetic flux density) is displayed.
6	It is possible to select a frequency to visualize the behavior of the resulting iron loss curve. In the current example, the selected frequency equals the frequency set as input. The targeted measurement points (in red) are superimposed on the resulting iron loss curve.
7	Validation of iron loss parameters is achieved when clicking on this button. It is possible to cancel the computation of iron loss parameters.

Warning: When characterizing the iron loss parameters by using the method with two measurement points there are two things to be known:

1) Firstly, our internal process uses a genetic algorithm to compute the iron loss parameters.

   When the same frequency is considered for the two targeted points, this can lead to a disparity on the resulting iron loss parameters. It means that the same set of inputs provide sets of iron loss parameters which can be different. However, the resulting iron loss model give the same total amount of iron losses.

   Note: The best way to use the method with two measurement points, is to consider two different frequencies. Thus, there is only one resulting set of iron loss parameters.

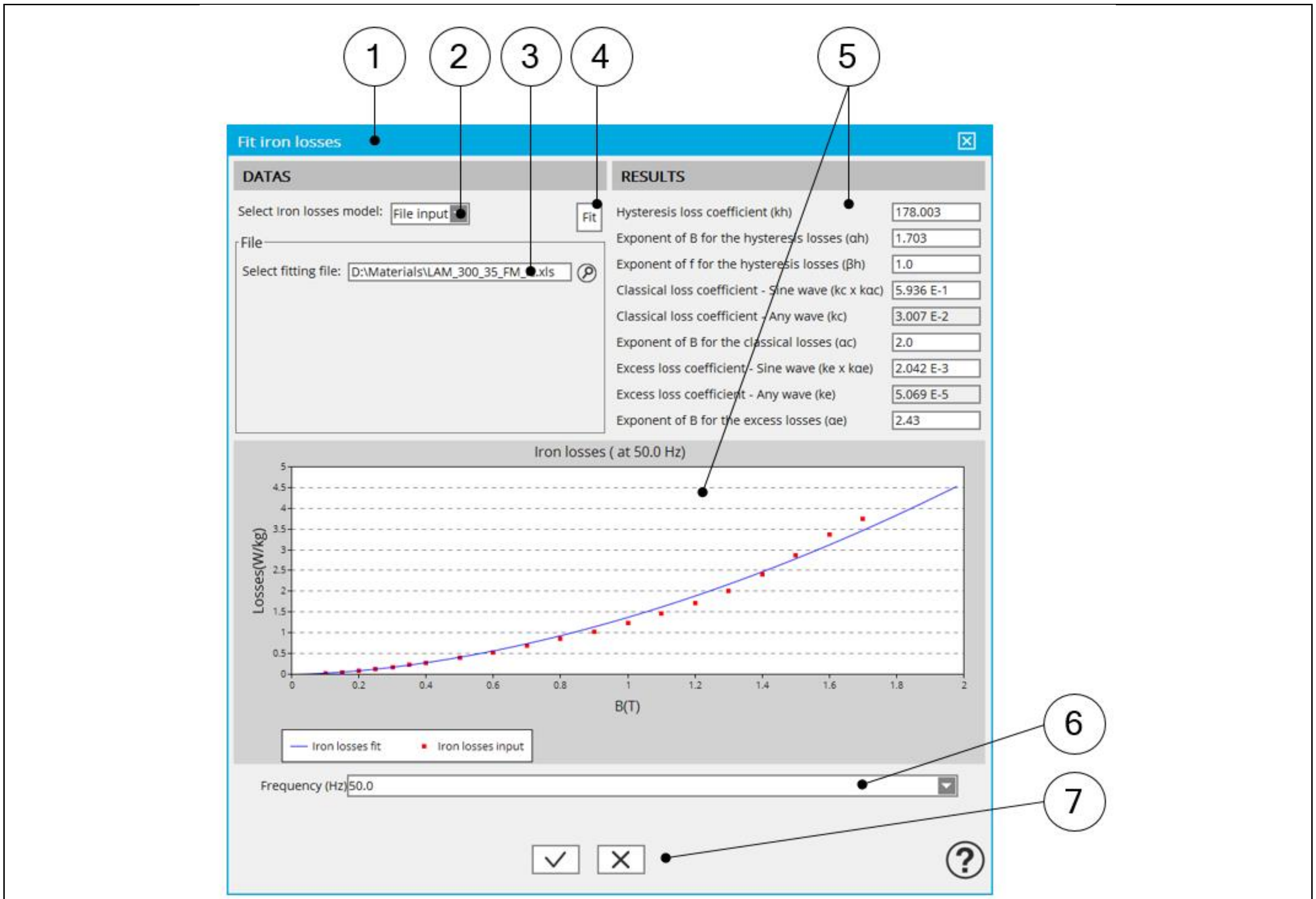
   It is highly recommended to take 2 different frequencies as boundaries of the working area.

Moreover, check that the classical losses coefficient is positive before using the resulting iron loss model. If this coefficient is negative, please, check the relevance of the original data.

2) Secondly, defining the iron loss parameters, with frequency very different from the one which is considered for the computation of a working point in Motor Factory, can lead to wrong results.

The most accurate way to compute iron loss parameters is to use a map of iron losses in f - B plane (f= frequency and B=flux density) where iron losses are defined in function of flux density for different values of frequency. Note that to be accurate the frequency and the flux density of the working point to be computed must be respectively in the range of frequencies and flux densities used to identify the iron loss parameters.

4.2.2.4 Case 3: From a map (file input)



Definition of iron loss coefficients – from a map	
1	Dialog box dedicated to defining the iron loss parameters. Located in the magnetic data tab when creating a new material or when editing the properties of an existing one.
2	Choice of the method to find iron loss parameters (from a file input (map) in this example).
3	Select the Excel file inside of which several curves of iron losses with flux density functions are available for different values of frequency are defined. An example of file is shown below.
4	When the Excel file is selected, click on the Fit button to run the optimization process. This process computes the set of iron loss parameters targeting the considered measurement points.
5	The resulting iron loss input parameters are deduced and displayed in the result table and the corresponding curve Losses versus B (magnetic flux density) is displayed.
6	It is possible to select a frequency to visualize the behavior of the resulting iron loss curve in a wider range of frequencies. In the current example, the selected frequency equals the frequency considered in the Excel file. The targeted measurement points (in red) are superimposed on the resulting iron loss curve.
7	Validation of iron loss parameters is achieved when clicking on this button. It is possible to cancel the computation of iron loss parameters.

Example of an Excel file to define the curves of iron losses in function of flux density for different values of frequency.
This corresponds to a map of Iron losses in f - B plane (where f= frequency and B=flux density).

	A	B	C	D	E	F	G	H	I
1									
2		**Iron losses**							
3		**Label**	**Units**	**Values**					
4		Frequency	Hz		**50**	**100**	**200**	**400**	**700**
5		Magnetic induction B	T	**0,10**	0,022	0,049	0,115	0,304	0,699
6		Core loss	W/kg	**0,15**	0,049	0,110	0,260	0,673	1,530
7				**0,20**	0,084	0,188	0,447	1,157	2,624
8				**0,25**	0,125	0,282	0,671	1,739	3,947
9				**0,30**	0,171	0,387	0,926	2,388	5,435
10				**0,35**	0,221	0,503	1,212	3,140	7,165
11				**0,40**	0,276	0,631	1,527	3,977	9,091
12				**0,50**	0,397	0,915	2,235	5,895	13,427
13				**0,60**	0,532	1,237	3,057	8,086	18,697
14				**0,70**	0,683	1,597	3,991	10,683	24,949
15				**0,80**	0,849	2,000	5,017	13,651	32,204
16				**0,90**	1,031	2,442	6,184	17,030	40,521
17				**1,00**	1,234	2,932	7,481	20,810	50,067
18				**1,10**	1,458	3,470	8,894	25,016	60,873
19				**1,20**	1,713	4,086	10,478	29,673	73,213
20				**1,30**	2,014	4,806	12,299	34,904	91,388
21				**1,40**	2,397	5,697	14,557	41,142	118,032
22				**1,50**	2,867	6,852	17,551	49,656	128,825
23				**1,60**	3,368	7,993	20,889	59,960	
24				**1,70**	3,746	8,932	24,808	73,161	
25									

Example of an Excel file to define iron loss parameters from a map

Notes:

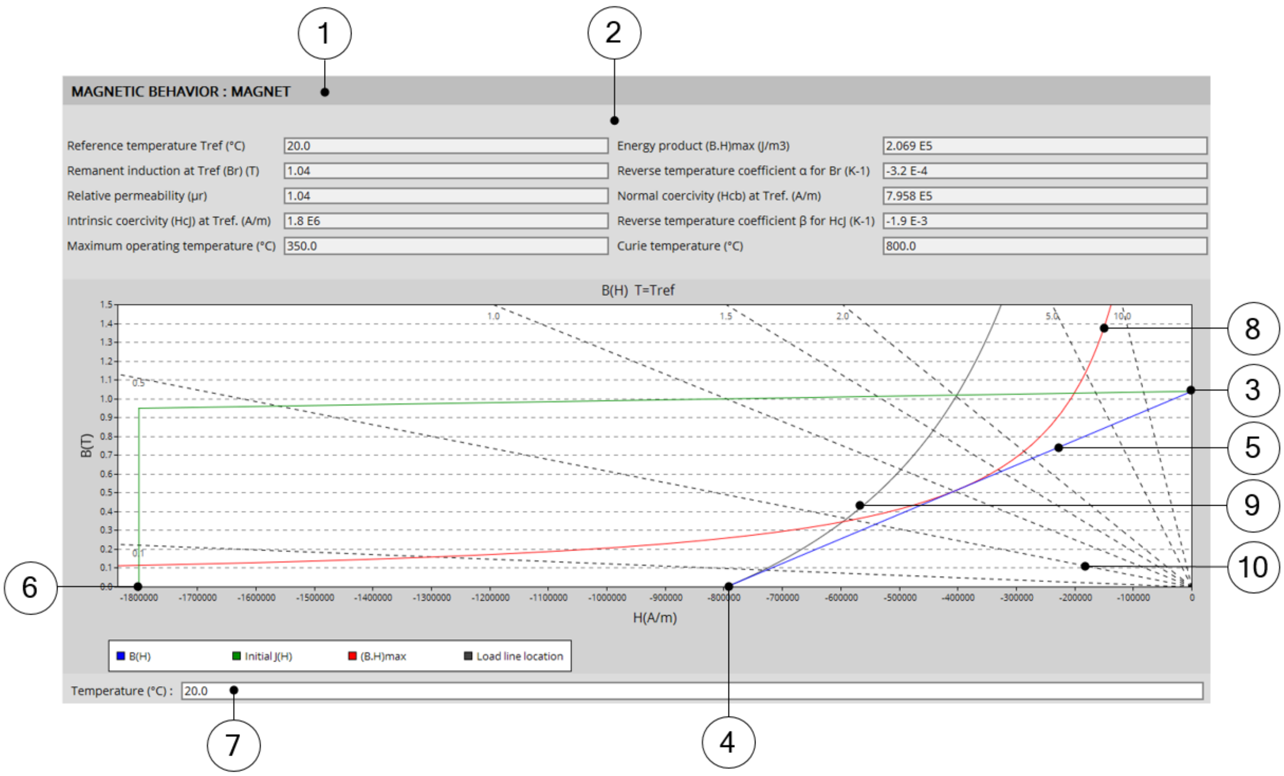
- The columns with the larger number of rows must be written first. At least three columns with the same number of rows must be written. In the example above, there are four columns with twenty rows.

- The exponent of B for the excess losses is set to 1.5 in our optimization process.

4.3 Manage magnet parameters

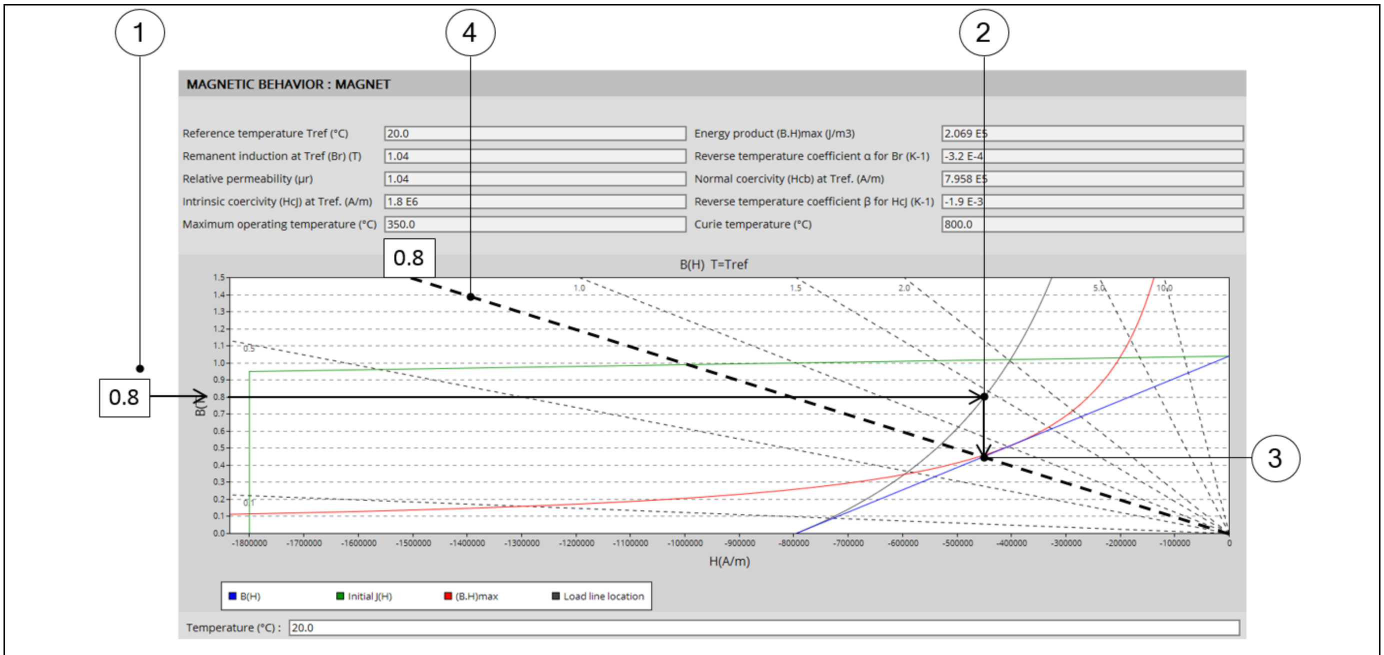
Here is the list of user parameters related to the magnetic behavior of magnets:

Label	Definition
T_{REF}	Reference temperature.
Br at T_{REF}	Remanent induction at T_{REF}.
α	Reverse temperature coefficient for Br.
μ_r	Relative permeability.
HcJ	Intrinsic coercivity at T_{REF}.
β	Reverse temperature coefficient for HcJ.
$(B.H)_{max}$	Energy product. Disabled input field, value deduced from other inputs.
Hcb	Normal coercivity at T_{REF}. Disabled input field, value deduced from other inputs.
*	Maximum operating temperature. Just for information, not used in computations.
*	Curie temperature. Just for information, not used in computations.



Presentation of the magnet properties in “Materials” application

1	Dialog box dedicated to the definition of magnet parameters. Located in the magnetic data tab when creating a new material or when editing the properties of an existing one.
2	Input parameters are written in this header and are defined for the reference temperature T_{REF} written in the first cell of the table.
3	Remanent induction at T_{REF} (B_r).
4	Normal coercivity at T_{REF} (Hcb).
5	B(H) curve for the magnet.
6	Intrinsic coercivity at T_{REF} (HcJ).
7	The curves displayed depend on the operating temperature defined in this field. The default value corresponds to the reference value. The user can modify this value and visualize the changes on graph.
8	$(B.H)_{max}$ curve.
9	Load line location. See illustration on how to use it below.
10	Load lines.



How to use the load line location?	
1	Target a load point.
2	Draw a horizontal line till the intersection with the load line curve.
3	Then, draw a vertical line from the previous intersection till the intersection with the B(H) curve.
4	The new intersection point allows drawing the targeted load line as shown on the graph above.

4.4 Thermal impact on quantities computations

4.4.1 Electrical resistivity

Note 1: Only isotropic materials are considered.
Note 2: Resistivity ρ (rho) is a linear function of temperature.

The corresponding mathematical formula for electrical resistivity is:

$$\rho_T = \rho_{REF} \times \left(1 + a \times (T - T_{REF})\right)$$

ρ_T	Resistivity to be defined at a temperature T. Linear function of the temperature for an isotropic or anisotropic material.
T_{REF}	Reference temperature.
T	T is the temperature for which the resistivity must be computed.
ρ_{REF}	Resistivity of the material at T_{REF}.
a	Temperature coefficient at T_{REF}.

4.4.2 Thermal conductivity for all materials except gas and liquid

The thermal conductivity is defined at a reference temperature and is considered as constant for all thermal computations.
The reference temperature is then only a memo, to keep in mind the temperature corresponding to the indicated thermal conductivity.

Symbol	Definition	Unit
T_{ref}	Reference temperature (Tref)	°C
K_{ref}	Isotropic thermal conductivity at Tref W/K/m)	W/K/m

4.4.3 Specific heat variation versus temperature – For all material except gas and liquid

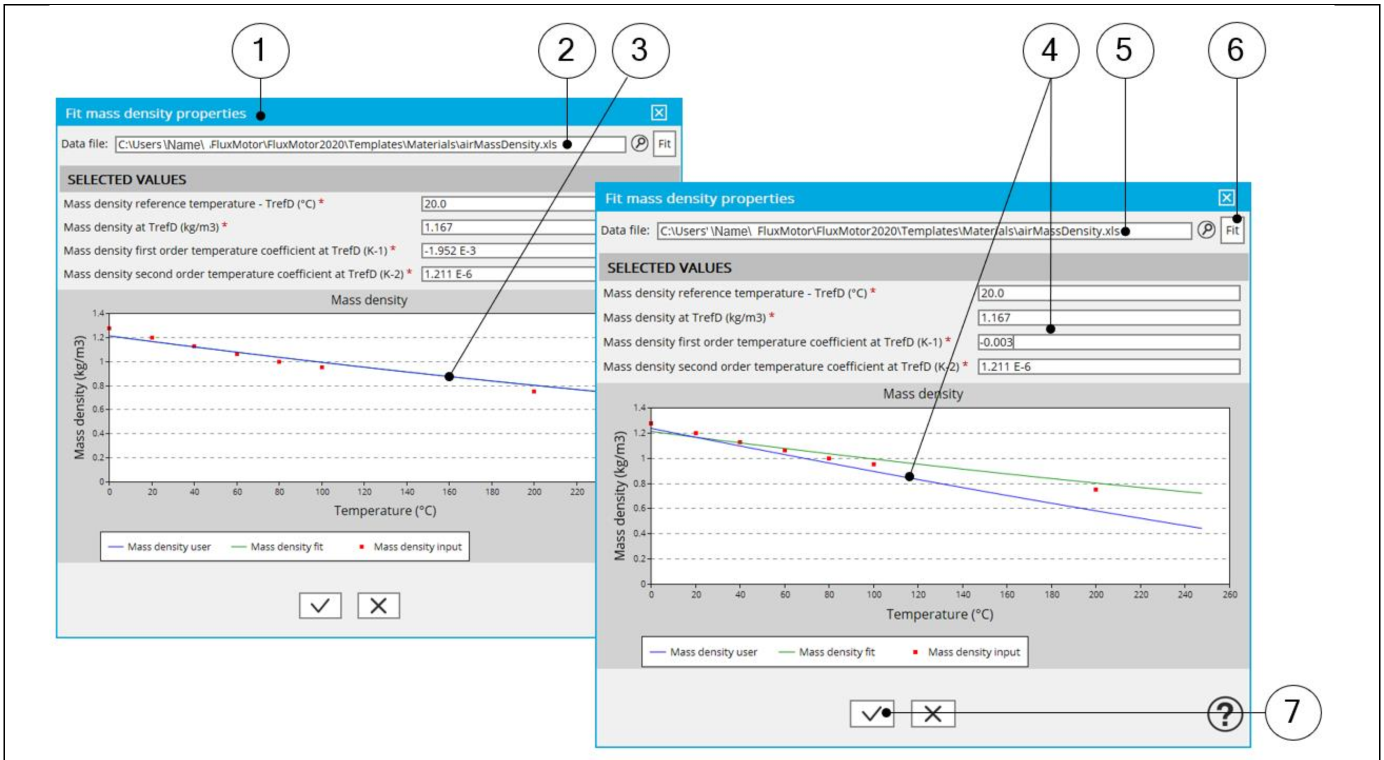
The specific heat is defined at a reference temperature and is considered as constant for all thermal computations.
The reference temperature is then only a memo, to keep in mind the temperature corresponding to the indicated specific heat.

Symbol	Definition	Unit
T_{ref}	Reference temperature (Tref)	°C
C_{ref}	Specific heat at Tref (J/K/Kg)	J/K/Kg

4.4.4 Gaz properties

4.4.4.1 Introduction

Here is the process to define the gas thermal characteristics from the importation of series of points representing the considered quantity curve listed in an Excel file. In the following example air mass density is considered, however the same principle is applied for all other gas thermal quantity which are defined below.



Identification of the air mass density curve characteristics (for instance)	
1	Dialog box allowing the characterization of the density curve imported from an Excel file
2	Path where Excel file to be imported is stored. See an example of Excel file below.
3	When importing an Excel file, points representing the density curve are listed, an optimization process automatically computes and displays the corresponding characteristics. At the same time three curves are displayed: Red points are the imported points (listed in the Excel file) Green curve is the resulting curve computed by the optimization process. This corresponds to the computed characteristics and displayed just after the computation. The blue curve shows modifications induced when the characteristics are changed by the user.
4	Indeed, the user can adjust one or all the three main characteristics of the density curve. • The density at reference temperature • The density first order temperature coefficient • The density second order temperature coefficient
5	Field in which the path where the Excel file to be imported is stored.
6	At any time, the user can run the optimization process to get back the proposed values.
7	The last parameter values, written in the input fields are validated when the user clicks on this button. Validation of the last parameter values is achieved when clicking on this button. It is possible to cancel the creation of the density curve model. In this case, the previous values defined before opening this dialog box are reset.

Example of an Excel file to define the mass density curve parameters.

Mass density curve		
Label	Temperature	Mass density
Units	K	kg/m3
Values	273,15	1,2759
	293,15	1,2
	313,15	1,13
	333,15	1,06
	353,15	1
	373,15	0,95
	473,15	0,75
	773,15	0,46
	1273,15	0,28

Example of an Excel file to define the air mass density curve parameters

4.4.4.2 Mass density

$$\rho_T = \rho_{ref} \times (1 + a \times (T - T_{refD}) + b \times (T - T_{refD})^2)$$

Symbol	Definition	Unit
P_{ref}	Reference pressure	Pa
T_{refD}	Mass density reference temperature T_{refD}	°C
ρ_{ref}	Mass density at T_{refD} and P_{ref}	kg/m3
a	Mass density first order temperature coefficient at T_{refD} and P_{ref}	K-1
b	Mass density second order temperature coefficient at T_{refD} and P_{ref}	K-2

Note 1: The reference pressure mentioned in the previous table is also the one considered for defining the gas specific heat.

Note 2: For a given temperature, the gas density (kg/m^3) changes with the pressure following the perfect gas law.

The mass density ρ computed at a pressure P is computed as below:

$$\rho_P = \frac{P}{P_{ref}} \times \rho_{P_{ref}}$$

4.4.4.3 Dynamic viscosity

$$\mu_T = \mu_{ref} \times (1 + a \times (T - T_{refV}) + b \times (T - T_{refV})^2)$$

Symbol	Definition	Unit
T_{refV}	Dynamic viscosity reference temperature	°C
μ_{ref}	Dynamic viscosity at T_{refV}	kg/m/s
a	Dynamic viscosity first order temperature coefficient at T_{refV}	K-1
b	Dynamic viscosity second order temperature coefficient at T_{refV}	K-2

Note: The model does not consider any variation of the gas dynamic viscosity with the gas pressure.

4.4.4.4 Thermal conductivity

$$K_T = K_{ref} \times (1 + a \times (T - T_{refC}) + b \times (T - T_{refC})^2)$$

Symbol	Definition	Unit
T_{refC}	Thermal conductivity reference temperature	°C
K_{ref}	Thermal conductivity at T_{refC}	W/K/m
a	Thermal conductivity first order temperature coefficient at T_{refC}	K-1
b	Thermal conductivity second order temperature coefficient at T_{refC}	K-2

Note: The model does not consider any variation of the gas thermal conductivity in function with the gas pressure.

4.4.4.5 Specific heat

$$C_T = C_{ref} \times (1 + a \times (T - T_{refS}) + b \times (T - T_{refS})^2)$$

Symbol	Definition	Unit
T_{refS}	Specific heat reference temperature	°C
C_{ref}	Specific heat at T_{refS} and P_{ref}	J/K/Kg
a	Specific heat first order temperature coefficient at T_{refS} and P_{ref} (K-1)	K-1
b	Specific heat second order temperature coefficient at T_{refS} and P_{ref} (K-2)	K-2

Note 1: All the parameters defined is the previous table are defined for the reference pressure P_{ref} mentioned in the gas mass density section.

Note 2: For a given temperature, the gas specific heat (J/K/kg) changes with the pressure following the perfect gas law.

The specific heat C computed at a pressure P is computed as below:

$$C_P = \frac{P}{P_{ref}} \times C_{P_{ref}}$$

Symbol	Definition	Unit
P_{ref}	Reference pressure	Pa
C_P	Specific heat at the pressure P	J/K/Kg
C_{Pref}	Specific heat at the pressure P_{ref}	J/K/Kg

4.4.4.6 Thermal expansion

The gas property changes with the temperature according to the perfect gas law and is automatically applied in internal processes with the following formula:

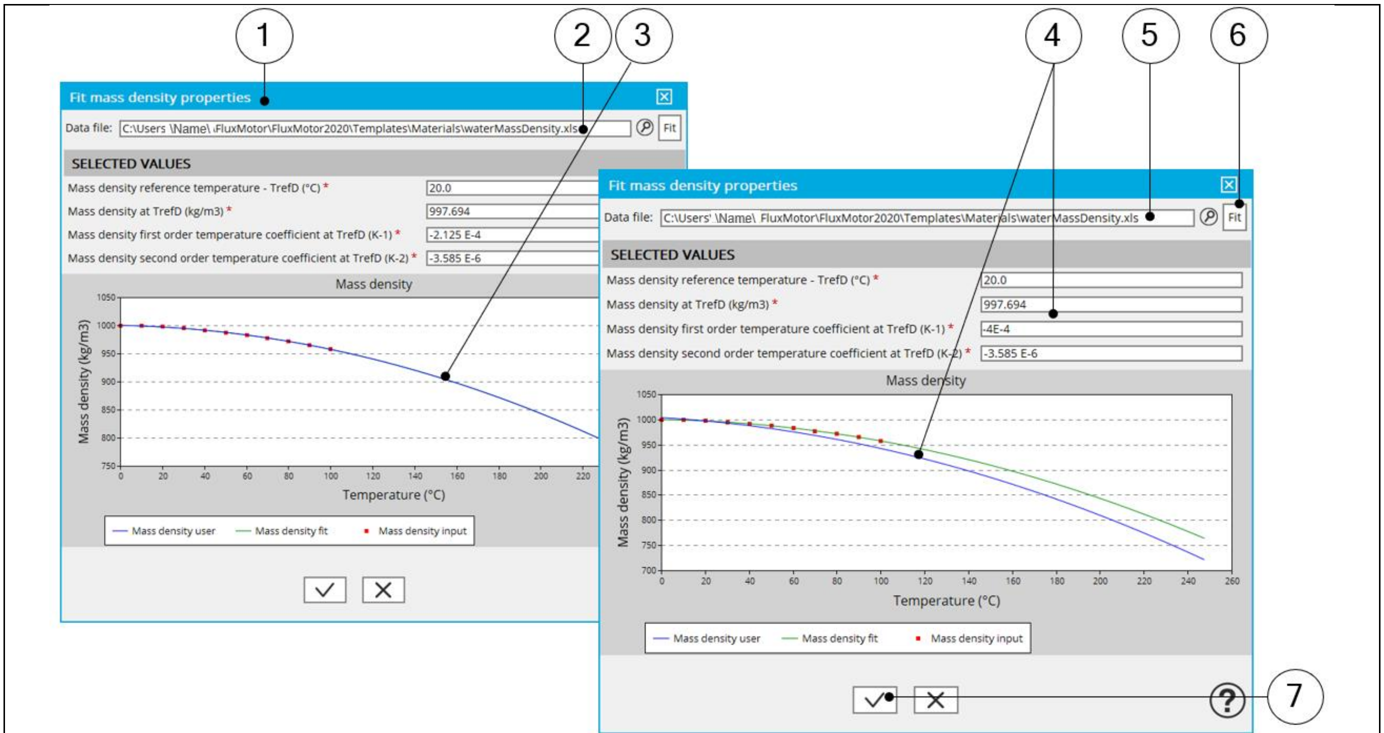
$$\beta_T = \frac{1}{T}$$

Symbol	Definition	Unit
T_{refE}	Temperature at which the thermal expansion must be considered	K
β_T	Thermal expansion coefficient at the temperature T	K-1

4.4.5 Liquid properties

4.4.5.1 Introduction

Here is the process to define the liquid thermal characteristics from the importation of series of points representing the considered quantity curve listed in an Excel file. In the following example water mass density is considered, however the same principle is applied for all other gas thermal quantity which are defined below.



Identification of the water mass density curve characteristics (for instance)	
1	Dialog box allowing the characterization of the density curve imported from an Excel file
2	Path where Excel file to be imported is stored. See an example of Excel file below.
3	When importing an Excel file, points representing the density curve are listed, an optimization process automatically computes and displays the corresponding characteristics. At the same time three curves are displayed: Red points are the imported points (listed in the Excel file) Green curve is the resulting curve computed by the optimization process. This corresponds to the computed characteristics and displayed just after the computation. The blue curve shows modifications induced when the characteristics are changed by the user.
4	Indeed, the user can adjust one or all the three main characteristics of the density curve. • The density at reference temperature • The density first order temperature coefficient • The density second order temperature coefficient
5	Field in which the path where the Excel file to be imported is stored.
6	At any time, the user can run the optimization process to get back the proposed values.
7	The last parameter values, written in the input fields are validated when the user clicks on this button. Validation of the last parameter values is achieved when clicking on this button. It is possible to cancel the creation of the density curve model. In this case, the previous values defined before opening this dialog box are reset.

Example of an Excel file to define the water mass density curve parameters.

Mass density curve		
Label	Temperature	Mass density
Units	K	kg/m3
Values	273,15	999,9
	283,15	999,6
	293,15	998,2
	303,15	995,6
	313,15	992,3
	323,15	988
	333,15	983,2
	343,15	977,7
	353,15	971,8
	363,15	965,3
	373,15	958,3

Example of an Excel file to define the water mass density curve parameters

4.4.5.2 Mass density

$$\rho_T = \rho_{ref} \times (1 + a \times (T - T_{refD}) + b \times (T - T_{refD})^2)$$

Symbol	Definition	Unit
T_{refD}	Mass density reference temperature T_{refD}	°C
ρ_T	Mass density at T_{refD}	kg/m3
a	Mass density first order temperature coefficient at T_{refD}	K-1
b	Mass density second order temperature coefficient at T_{refD}	K-2

Note 1: Liquids are considered as incompressible in FluxMotor®. Their properties are constant versus the pressure.

4.4.5.3 Dynamic viscosity

$$\mu_T = \mu_{ref} \times (1 + a \times (T - T_{refV}) + b \times (T - T_{refV})^2)$$

Symbol	Definition	Unit
T_{refV}	Dynamic viscosity reference temperature	°C
μ_{ref}	Dynamic viscosity at T_{refV}	kg/m/s
a	Dynamic viscosity first order temperature coefficient at T_{refV}	K-1
b	Dynamic viscosity second order temperature coefficient at T_{refV}	K-2

4.4.5.4 Thermal conductivity

$$K_T = K_{ref} \times (1 + a \times (T - T_{refC}) + b \times (T - T_{refC})^2)$$

Symbol	Definition	Unit
T_{refC}	Thermal conductivity reference temperature	°C
K_{ref}	Thermal conductivity at T_{refC}	W/K/m
a	Thermal conductivity first order temperature coefficient at T_{refC}	K-1
b	Thermal conductivity second order temperature coefficient at T_{refC}	K-2

Note 1: Liquids are considered as incompressible in FluxMotor®. Their properties are constant versus the pressure.

4.4.5.5 Specific heat

$$C_T = C_{ref} \times (1 + a \times (T - T_{refS}) + b \times (T - T_{refS})^2)$$

Symbol	Definition	Unit
T_{refS}	Specific heat reference temperature - T_{refS} (°C)	°C
C_{ref}	Specific heat at T_{refS}	J/K/Kg
a	Specific heat first order temperature coefficient at T_{refS}	K-1
b	Specific heat second order temperature coefficient at T_{refS}	K-2

Note 1: Liquids are considered as incompressible in FluxMotor®. Their properties are constant versus the pressure.

4.4.5.6 Thermal expansion

$$\beta_T = \beta_{ref} \times (1 + a \times (T - T_{refE}) + b \times (T - T_{refE})^2)$$

Symbol	Definition	Unit
T_{refE}	Thermal expansion reference temperature	°C
β_{ref}	Thermal expansion coefficient at T_{refE}	K-1
a	Thermal expansion first order temperature coefficient at T_{refE}	K-1
b	Thermal expansion second order temperature coefficient at T_{refE}	K-2

4.4.6 Magnet properties

4.4.6.1 Remanent induction of magnets

Note 1: Only isotropic magnet is considered.
Note 2: Remanent induction (Br) is a linear function of the temperature.

The corresponding mathematical formula is:

$$\mathrm{Br}_T = \mathrm{Br}_{ref} \times \left(1 + \mathrm{a} \times (\mathrm{T} - \mathrm{T}_{\mathrm{ref}})\right)$$

Br_{rT}	Remanent induction to be defined at a temperature T. Linear function of the temperature for an isotropic or anisotropic material.
T_{ref}	Reference temperature.
T	T is the temperature for which the remanent induction must be computed.
Br_{ref}	Remanent induction of the magnet at T_{REF}.
a	Reverse temperature coefficient for Br at T_{REF}.

4.4.6.2 Intrinsic coercivity

Note 1: Only isotropic magnet is considered.
Note 2: Intrinsic Coercivity (HcJ) is a linear function of the temperature.

The corresponding mathematical formula is:

$$\mathrm{HcJ}_T = \mathrm{HcJ}_{ref} \times \left(1 + \mathrm{a} \times (\mathrm{T} - \mathrm{T}_{\mathrm{ref}})\right)$$

HcJ_T	Intrinsic Coercivity to be defined at a temperature T. Linear function of the temperature for an isotropic or anisotropic material.
T_{REF}	Reference temperature.
T	T is the magnet temperature for which the Intrinsic Coercivity must be computed.
HcJ_{ref}	Intrinsic Coercivity of the magnet at T_{REF}.
a	Reverse temperature coefficient for HcJ at T_{REF}.