

CIMNE

Industrial Training

Work plan

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Abstract

The present documents aims to describe the different tasks that Rafael Pacheco has developed during his industrial training.

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INTRODUCTION

This document explains the sort of several tasks which Rafael Pacheco (the proposer) will be undertaking during the industrial training placement in a fairly major way.

The industrial training will be taking part inside the Centro Internacional de Metodos Numéricos en Ingeniería (in short CIMNE), within the H2020 research project Engineering, production and life-cycle management for the complete construction of large-length FIBRE-based SHIPs (FIBRESHIP). In the framework of this project, the proposer will also be collaborating with the company Compass IS. also a partner in the aforementioned project FIBRESHIP.

The following sections shall state the tasks which will be carried out within this Industrial Training, with a description of them. A Gant diagram is enclosed at the end.

The final goal of the industrial training proposal is the implementation and validation of what is called a "Rule of Mixture Serial/Parallel discrete-Kirchhoff triangle" which is an element designed for composite non-linear triangle shells. This methodology will be implemented within the structural analysis software Ramseries, developed and commercialized by Compass IS. This implementation is a first step to interconnect this software tool with the Structural Health Monitoring tools to be developed in FIBRESHIP. This final implementation is out of the scope of this proposal.

I - TASK 0 - LEARNING

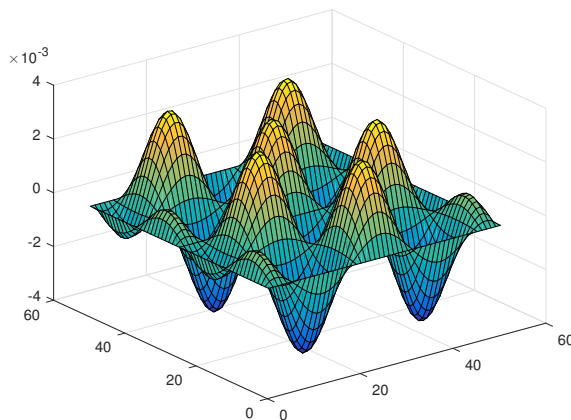
1 - 1 SCRIPTING LEARNING

In order to be able to work inside Ramseries Framework, it is mandatory to have a basic knowledge of C++.

GOAL: Code in C++ a 2D Poisson problem with only a source term and Dirichlet boundary conditions, using Ramseries vector and matrix environment.

RESULT: The problem is the following:

$$\nabla u = f \quad , \quad f(x) = \sin(4\pi x)\cos(4\pi y) \quad , \quad u(x)_D = 0 \quad \forall x, y \in \partial\Omega \quad (1.1)$$



The problem was successfully coded and the result show how the imposed boundary conditions are 0 among the outer boundary and that the independent term $f(x)$ generates this sinusoidal results.

Figure 1.1-1: Solution to Eq. (1.1), represents $u(x,y)$

1 - 2 COMPOSITE FEM THEORY

The main purpose of this industrial training is to create an element which can combine the Discrete Kirchhoff Triangle formulation together with a composite constitutive material. Hence, a series of literature about these two topics has to be carefully reviewed.

RESULT: All the literature below has been reviewed.

1 - 2.1 General Theory

GOAL: Read and comprehend the book: "Structural Analysis with the Finite Element Method - Linear Statics" by Eugenio Oñate, "Vol. 2 - Beams, Plates and Shells". Paying special attention to the formulation of shells of composite materials.

1 - 2.2 RoM S/P Theory

GOAL: The basic algorithm to be included inside Ramseries Framework is the Serial/Parallel Rule of Mixture. In order to understand the algorithm, the proposer has to review different references, amongst them:

- Rastellini, F, Oller, S., Salomón, O., & Oñate, E. (2008). Composite materials non-linear modelling for long fibre-reinforced laminates - Continuum basis, computational aspects and validations. *Elsevier-Computers and Structures*, 89, 879-896.
- Almeida, F.S., & Awruch, A.M. (2011). Corotational nonlinear dynamic analysis of laminated composite shells. *Elsevier-Finite Elements in Analysis and Design*, 47, 1131-1145.
- Felippa, C.A. (2003). A study of optimal membrane triangles with drilling freedoms. *Elsevier-Comput. Methods Appl. Mech. Engrg.*, 192, 2125-2168.
- Car, E. (2000). Tratamiento numérico de los materiales compuestos. *CIMNE*, 57.
- Martínez, X. (2008). PhD Thesis: Micro-mechanical simulation of composite materials using the serial/parallel mixing theory. *Universitat Politècnica de Catalunya*.
- Rastellini, F. (2006). PhD Thesis: Modelación numérica de la no-linealidad constitutiva de laminados compuestos. *Universitat Politècnica de Catalunya*.

1 - 2.3 RoM S/P Solid

GOAL: The Rule of Mixtures Serial/Parallel has already been coded in Ramseries Framework for Solid elements. The proposer shall study this code to see the syntax and structure used inside Ramseries Framework.

II - TASK 1 - ANALYSIS

2 - 1 COMPOSITE FEM APPS

The second task would be an analysis of the current composite theories used in commercial software products. Different software products should be analysed and tested, paying special attention to their local axis feature. This study will be focused on the strengths and weaknesses of the current local axis definition tool of Ramseries (based on GiD tools).

RESULT: The complete results were detailed in a separate document ANALIZAR_CODIGOS_COMERCIALES -DEFINICION_DE_EJES.PDF .

2 - 1.1 Commercial Soft.

GOAL: To test and analyse the commercial software products:

- FeMap.

RESULT: Use of the Rule of Mixtures and poor Custom Coordinates System type to orient the elements.

- ABAQUS.

RESULT: Use of the Rule of Mixtures and poor Custom Coordinates System type to orient the elements.

- ANSYS.

RESULT: Use of the Rule of Mixtures and use of a Rossete(s) system to orient the elements. Serial/Parallel Rule of mixtures using Ramseries Framework.

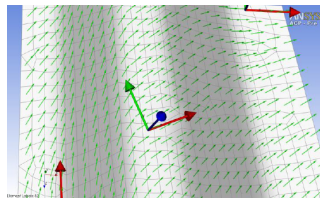


Figure 2.1-1: Local axis definition for ANSYS by means of multiple rossete system

- GID.

RESULT: Use of direction line(s) system to orient the elements.

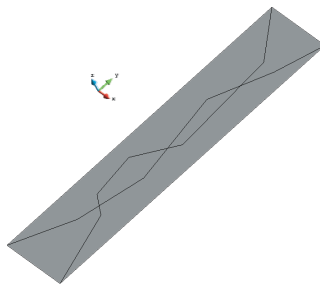


Figure 2.1-2: Local axis definition for GID by means of direction line system

2 - 1.2 GID Local Axis

GOAL: Test the feature *Direction Lines* from GID and spot potential bugs.

RESULT1: GID definitions of local axis by means of simple direction lines is outstanding.

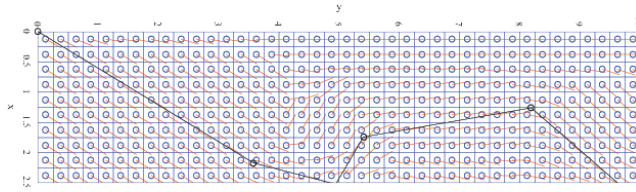


Figure 2.1-3: Local X-axis definition for GID by means of direction line system

RESULT2: Major bug found regarding the local axis generation for circumferences, where they need to be divided into more than 4 divisions to avoid ill definition of the axis.

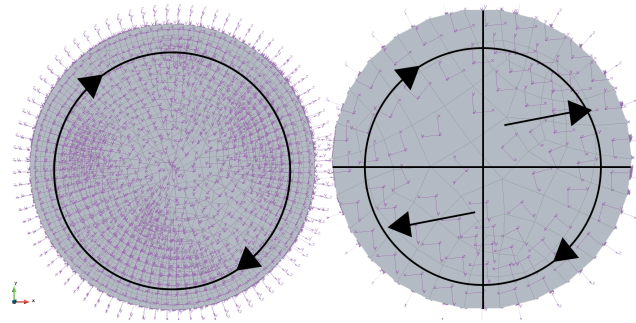


Figure 2.1-4: Local axis definition for GID by means of direction line system on a circumference.

III - TASK 2 - DEVELOPMENT

3 - 1 RAMSERIES FRAMEWORK

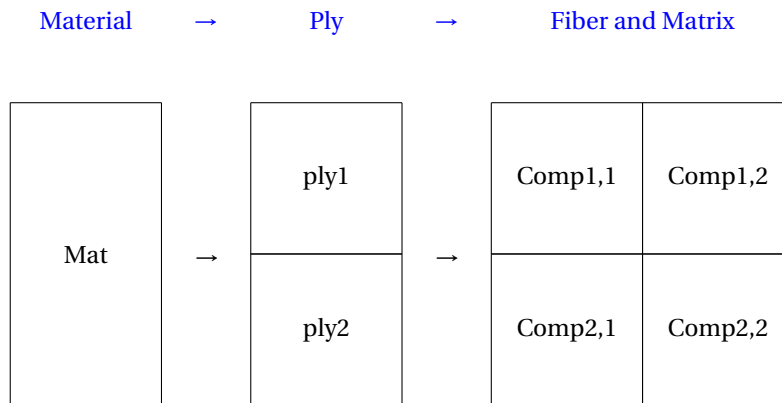
Ramseries framework is a unique material oriented framework, therefore it is mandatory that before any implementation is done, a re-organization of the material database should be completed.

3 - 1.1 Composite Material

GOAL: Definition and implementation of multiple material oriented framework.

RESULT: The structure for the material is divided in 3 levels:

- 1 Regular Materials (any material desired).
- 2 Layer Material (Combination of two or more Regular Material - fibre and matrix).
- 3 Composite Material (Stacks of Layer Material).



3 - 2 DKT

The major and crucial goal of this industrial training is to be able to implement the Serial/Parallel algorithm for a Discrete Kirchhoff Triangle (in short DKT). This task will focus first on the implementation of the classical Rule of Mixture and later extend it to the Serial/Parallel.

3 - 2.1 Parametrize

GOAL: Implement a compact Composite module that operates with solids and shells.

RESULTS: Ramseries framework has unique member function to evaluate the stress for non-linear constitutive materials. Therefore implementing the RoM/SPRoM inside this function is mandatory. Also two similar implementations have to be done for the stiffness for DKT and the previous implemented Solid element. Thus the algorithm for all these functions is in the form:

```
1  if (is_Material? == Composite_Stack_MT)
2  {
3   $\Phi^{Stack} = 0$ 
```

```

4  for ( i ∈ ℤ , iPlystart ≤ iPlyend , i++ ) do
5  {
6    while (ΔΦs == 0)
7    {
8      ΦPly = 0
9      for ( j ∈ ℤ , jComponentstart ≤ jComponentend , j++ ) do
10     {
11       ΦComponent = 0
12       CALCULATE: Φcomponenti,j(εi,j)
13       switch (type_of_element?)
14       {
15         case Shell:
16           ΦPly = ΦPly + ki,j · Φcomponenti,j
17         case Solid:
18           ΦPly = ΦPly + ki,j · ki · Φcomponenti,j
19       }
20     }
21     ΦStack = ΦStack + ΦStack
22   }
23 }
24 }

```

Where $\Phi^{(\cdot)}$ can be $\sigma^{(\cdot)}$ or $K^{(\cdot)}$, the key features for this parametric algorithm reside on the fact that the loop over plies is set from i_{start}^{Ply} to i_{end}^{Ply} , which indeed are functions that return integers. Once the functions are called, they intrinsically check whether or not this is a S/P RoM or just a RoM material and set the ranges of the component loop from $i_{start}^{Component}$ to $i_{end}^{Component}$.

The enclosed equation $\Delta\Phi_s == 0$ - which indeed only applies if it is $\sigma^{(\cdot)}$, is fulfilled always for a RoM material, whilst for S/P RoM materials it will depend on the convergence of that equation. Finally, the step CALCULATE: $\Phi_{i,j}^{component}(\epsilon_{i,j})$ changes depending of the type of the composite material and the addition of that calculated variables will be homogenized differently if it a Shell element (ply level homogenization $k_{i,j}$) or a Solid element (Component level homogenization $k_{i,j} \cdot k_i$)

3 - 2.2 RoM DKT

GOAL: Implement the Rule of Mixtures for the discrete-Kirchhoff triangle.

RESULTS: The algorithm shown in the parametric section is the one used for a simple rule of mixture. The rule of mixture is a simple homogenization equation such as:

$$\Phi^c = \sum_{i=1}^n k_i \cdot \Phi^i \quad (3.1)$$

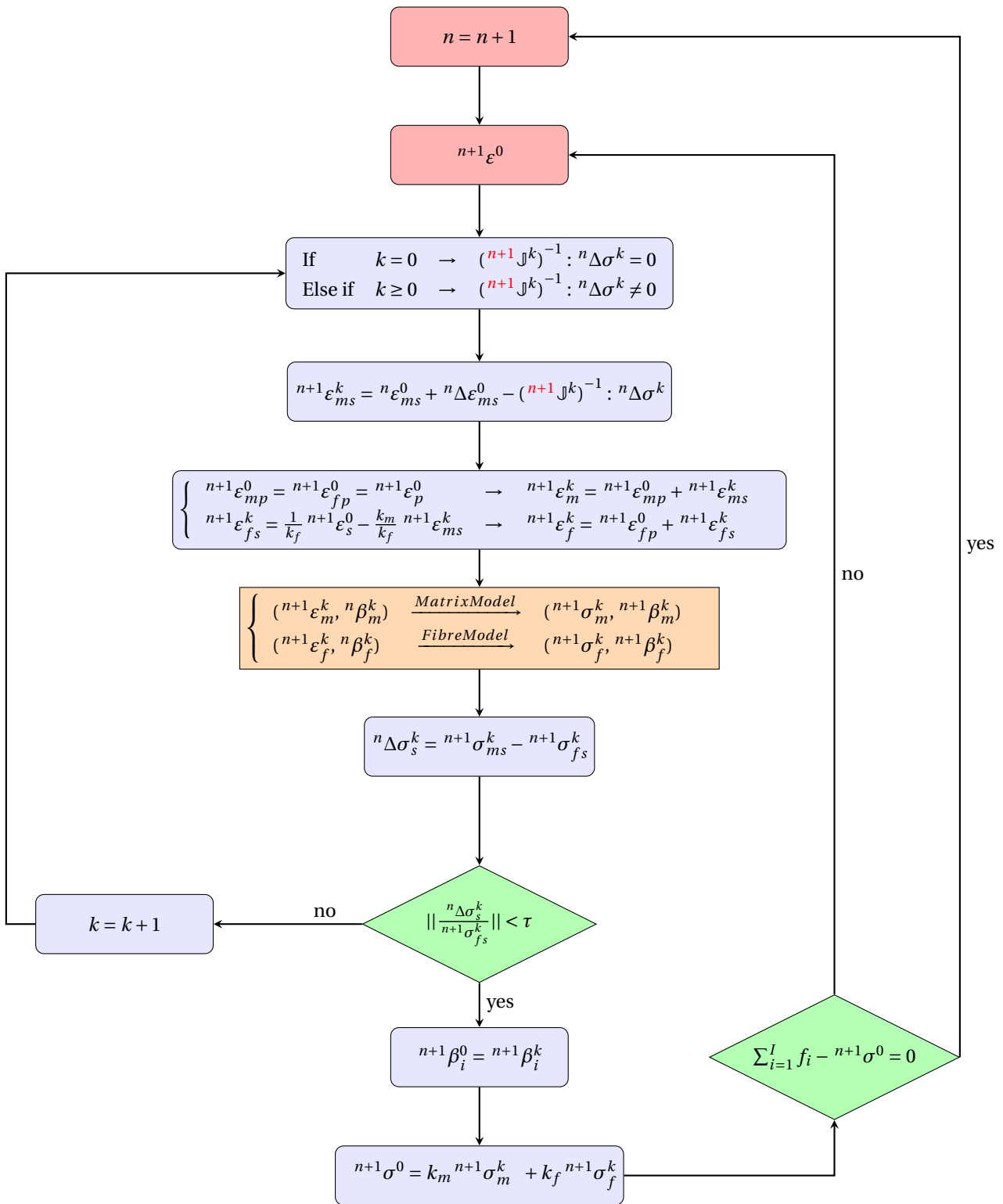
This is what is coded previously after CALCULATE: $\Phi_{i,j}^{component}(\epsilon_{i,j})$.

3 - 2.3 RoM S/P DKT

GOAL: Implement the Serial/Parallel Rule of Mixtures for the discrete-Kirchhoff triangle.

RESULTS: This is coded inside CALCULATE: $\Phi_{i,j}^{component}(\epsilon_{i,j})$. This function is a virtual function and depending if the layer has assigned a S/P RoM constitutive equation or RoM, it will perform one calculation or the other.

The S/P RoM can be explained with the following local evaluation of the stress diagram:



3 - 3 SHM TOOLS

As a parallel main goal, the proposer is requested to interconnect Ramseries software with the *Structural Health Monitoring* tools. Once the coupling between Ramseries software and the optimiser is done, different test models will be prepared in order to assess the performance of the optimiser algorithm.

RESULTS: The implementation has been done inside ramseries, the optimisation algorithm is an evolutive one, but gradient methods are to be used as well. The problem is based on optimising a structure based on its initial frequency modes and compare with the present frequency modes obtained from sensors. The objective function chosen is the following:

$$r = \frac{(f_{calc} - f_{ref})^2}{f_{ref}} \quad (3.2)$$

At the end, it might turn out that this function is not the most wisely chosen, since the optimiser is having trouble to find the current state of the structure.

3 - 3.1 Modal Analysis Plate

GOAL: Prepare a shell model of a plate divided into 4 regions with different Young's modulus applied on these regions and verify the correct optimiser tool.

RESULT: The model has been prepared and send to test, the feedback is that the optimiser is not able to find the optimal values. It might be because of the square relative error objective function chosen. As future work, revising some literature regarding this topic is highly recommendable.

3 - 3.2 Modal Analysis Beam Ship

GOAL: Prepare a beam-ship model for the optimiser to calculate the shape modes of 100m - 150m container ship and verify the correct functionality of the optimiser tool.

RESULTS: The model has been prepared but not send to test since the previous model has not obtained satisfactory results.

IV - TASK 3 - VALIDATION AND VERIFICATION

In order to validate and verify the implementations, there will be three different methods:

- Validate

Use of experimental and validation cases from NAFEMS on-line publications.

- Verification

Use of literature - from section **Composite Fem Theory** - to verify the mathematical model and compare between a unique material to a composite unique material to check the correctness of the algorithm.

4 - 1 RULE OF MIXTURES

4 - 1.1 V&V RoM DKT

GOAL: To compare a unique material to a RoM layered unique material composite to verify the algorithm. Use of literature or references to validate cases.

RESULT VERIFICATION: To verify the implementation of the RoM DKT, since only the constitutive part has been modified, thus the DKT model is intact and there is no need to perform a patch test or single element test. Thus, benchmark problems will be carried out to verify the correctness of the RoM algorithm by comparing unique materials with unique laminate materials (composite material composed of a single same material). E.g.:

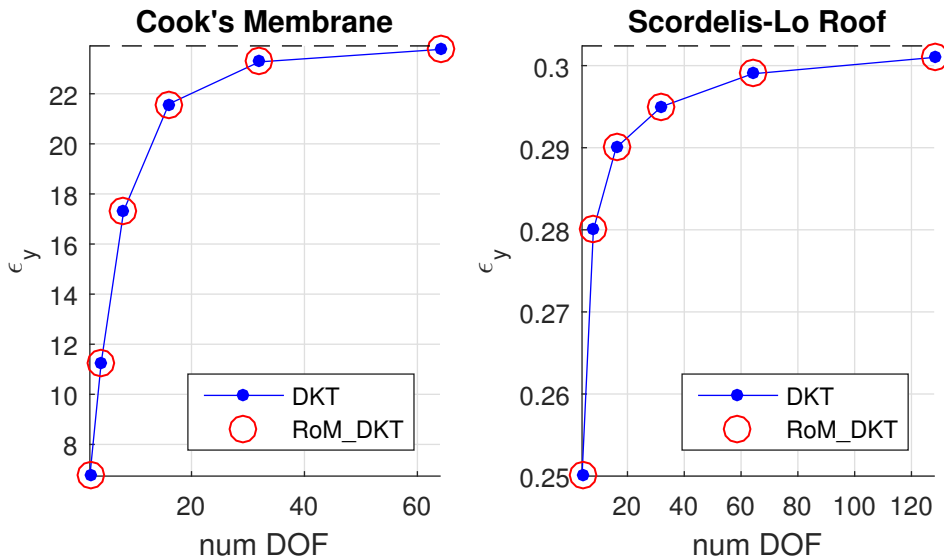


Figure 4.1-1: Benchmark results for RoM DKT.

RESULT VALIDATION: Same results between a unique material and a composed unique material, meaning the rule of mixtures is verified and validated.

4 - 2 SERIAL/PARALLEL RULE OF MIXTURES

4 - 2.1 V&V RoM S/P DKT

GOAL: To compare a unique material to a SPRoM layered unique material composite and Compare a fully iso-deformation SPRoM to a RoM case in order to verify the algorithm. Use of literature or references to validate cases.

RESULT VERIFICATION: First the same verification for RoM DKT will be performed. Second a graph showing the parallel-serial behaviour will be presented and last the transversal ratio of the fibre/matrix Young's modulus vs different volumetric participation.

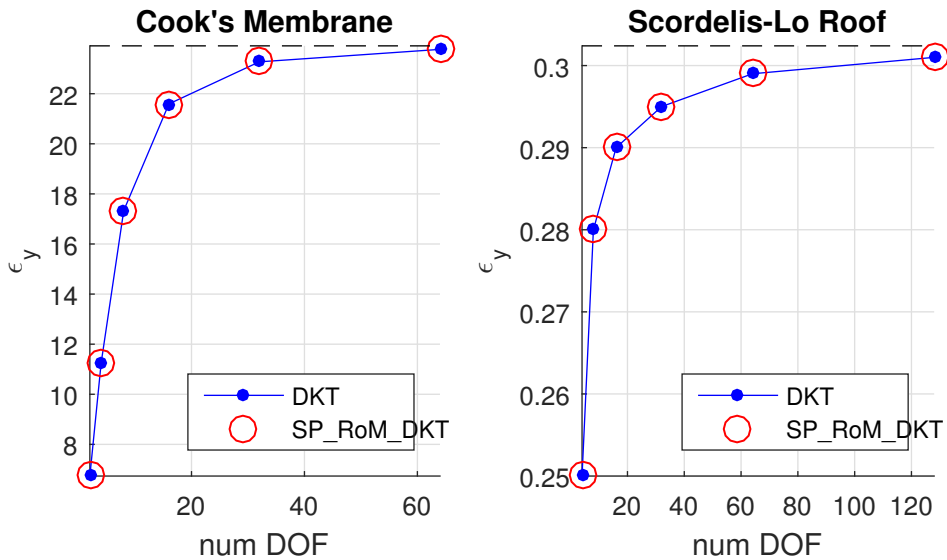
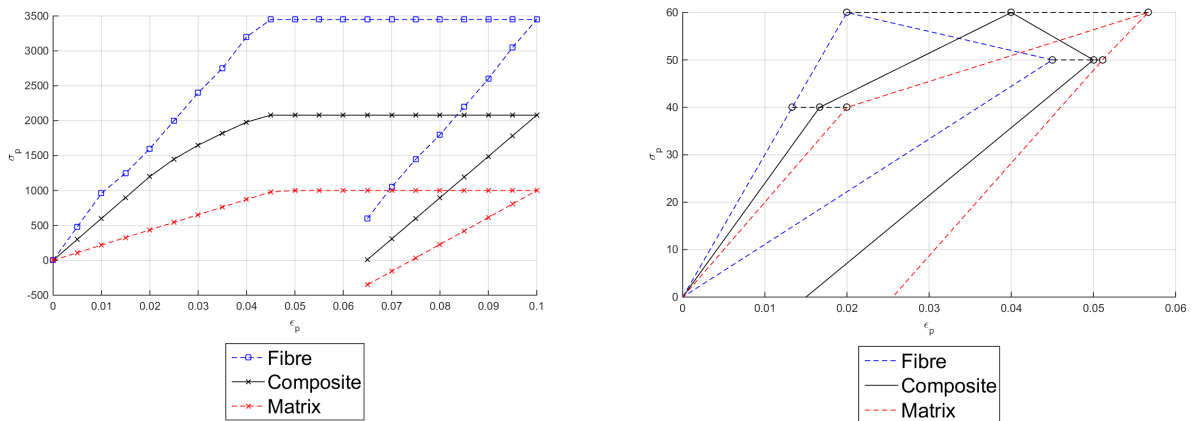


Figure 4.2-2: Benchmark results for SPRoM DKT.

Same results obtained as for the RoM case, which mean the algorithm is verified.



(a) Parallel Behaviour.

(b) Serial Behaviour.

Same results according to the Rule of Mixtures theory (4.2-3a) and same results for the Serial-Parallel Rule of Mixtures theory (4.2-3b).

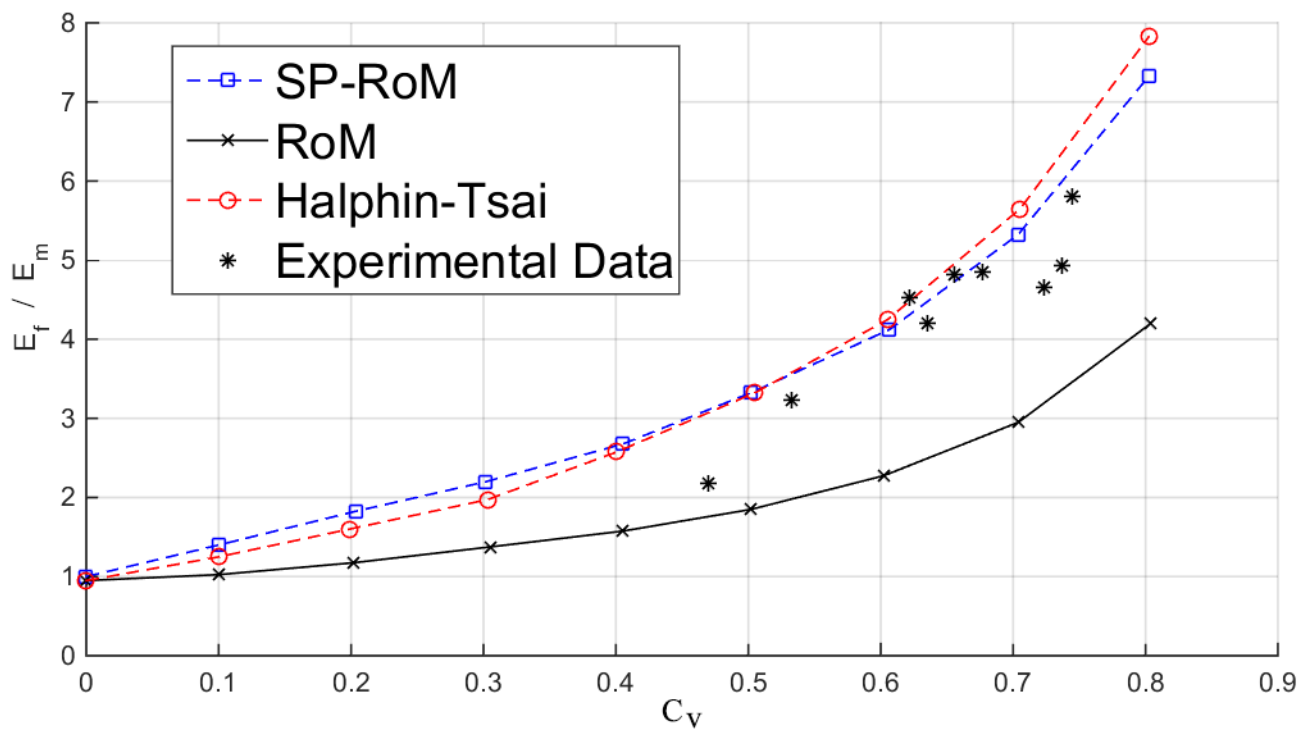
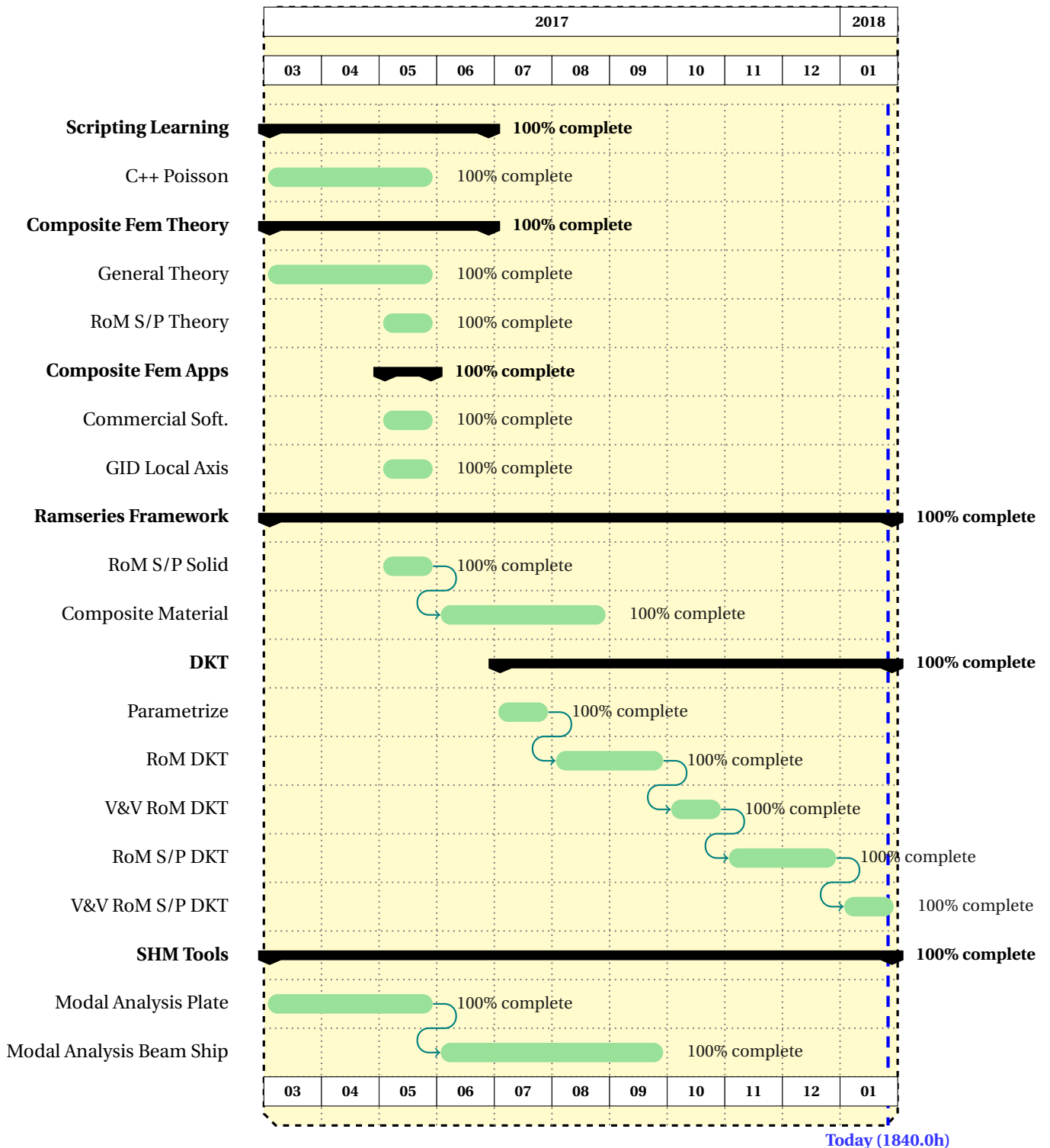


Figure 4.2-4: Transversal ratio against volumetric participation of the fibre component..

RESULT VALIDATION: Validation is correct comparing to the results from empirical formulation (Halphin-Tsai) and experimental Data from Barbero[[1], p. 72].

V - GANTT DIAGRAM



REFERENCES

- [1] Barbero EJ. *Introduction to composite materials design*. London, Taylor & Francis; 1998.