# METHODOLOGY OF DRY AND WET COMPRESSIBILITY MEASUREMENT

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## Introduction

This paper describes the methodology to obtain and analyse data in composite reinforcement fabric compaction tests in dry and wet condition on a standard electromechanical test machine using a non-direct thickness measurement method. Diverse examples of dry fabrics compression tests using non-direct thickness measurement methods can be found in [1-5]. The methodology accounts for the test setup compliance and evaluates of tens of microns-scale errors in the fabric thickness measurements, especially during the fabric relaxation test phase. The relaxation test constitutes of one compression cycle with a relaxation stage of 30 minutes between loading and unloading performed at 1 bar in wet conditions (maximum pressure available for infusion). Additional tests without relaxation stage were performed in both dry and wet conditions up to a pressure of 10 bar (for a greater behavior characterization). For dry compression, the fabric layers are simply cut in square samples (width 90 mm) and stacked. However, contrary to the typical wet compaction were the fluid is injected into the fabrics through a central injection gate [6], in this case, the wet compression is achieved by individually submerging the layers in oil and draining its excess in a mesh-houlder before stacking.

## Materials and methods

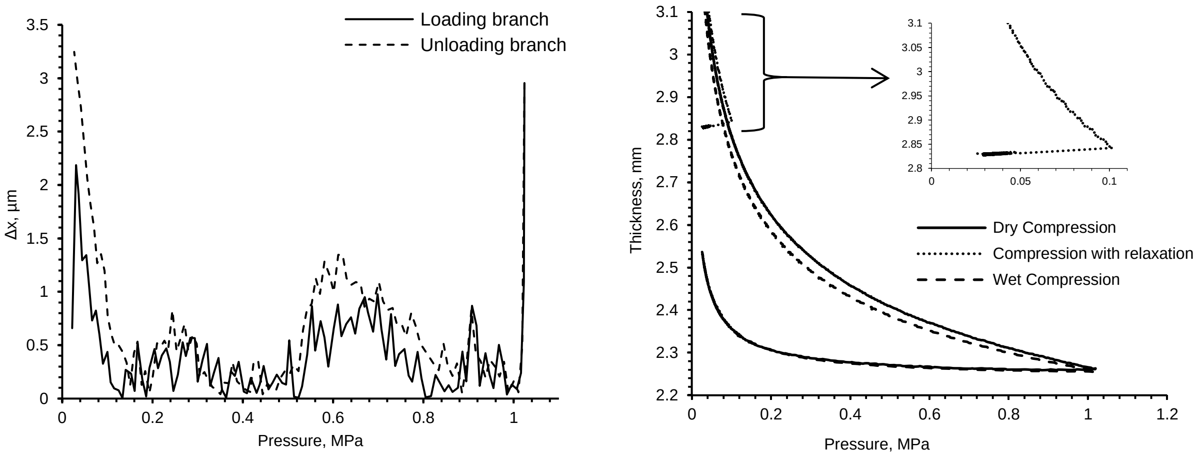
The fabric used in the tests is a plain weave carbon fabric with an areal density of 240 g/m², woven from 3K tows with ends/picks counts of 3 yarns/cm. The tests were performed using stacks of 10 samples having a square shape of side 90 mm (± 5 mm). All layers in a stack have the 0° (warp) direction coinciding, the same surface facing upwards and the stacks were placed centrally in the press. The wet compression is achieved by submerging layers of fabric for at least 15 minutes in oil and draining its excess for 15 minutes in a mesh-houlder before stacking.

The compression tests with relaxation were performed on a displacement-controlled testing machine Instron 4467 using a 5 kN load cell at a constant test speed 1 mm/min until the desired pressure (1 or 10 bar). To ensure the absence of precompression, the fabrics were compacted with an initial clearance of 10 mm. A round self-aligning pivot (fixed bottom compression plate) with a diameter of 70 mm is used to ensure the correct alignment of the compression planes during tests without samples in the free compression tests required for the indirect thickness measurement method. In dry compression these tests are performed only before and after the compression of 5 stacks. On the other hand, in wet compression the calibration tests are performed between changing of the stacks. A pivot is placed on the top of a column for greater stability and the load cell is attached to a steel plate with a diameter of 80 mm. In wet compression, the setup is placed inside a rigid metal box with grooves in the bottom which prevents oil accumulation under the steel cylinder. The test with relaxation constitutes one compression cycle with a relaxation stage of 30 minutes between loading and unloading at 1 bar. The maximum load of 392 N (± 0.98 N), corresponds to a compressed stack thickness of 2.8 mm (± 0.05 mm). Regarding the tests without relaxation, these are performed up to a load of 3921 N (± 5.9 N) which corresponds to a thickness of 2.23 mm (± 0.026 mm) in both dry and wet conditions.

## Data processing methodology and results

The goal of the work is the measurement of the thickness variation as a function of the applied pressure. The indirect thickness measurement method allows a thickness measurement using only the displacement registered by the testing machine and the load measured by the load cell. This method implies a regular measurement of the machine displacement vs load without sample because the pivot is not attached to the column, so it can slide between samples especially in wet conditions. By the comparison of calibration curves, displacement at the same load, it can be concluded that the setup remains stable throughout the experiment. In dry compression the curves do not vary more than 1 μm, while in wet conditions this variation does not exceed 3 μm. In this process, the average curve of five free compression tests (without sample) is converted into two second-degree polynomial (one for the loading and unloading branches of the curve), providing the loading and unloading reference (calibration) equations. This conversion introduces an average uncertainty of 0.5 μm in the measured values. The curve extremities that do not coincide with the trend line are not considered, for that reason the uncertainty is greater at the curves ends (around 3 μm), see Figure 1a).

The dry and wet compaction show no significant differences. The curves overlap in the majority of the points and the thickness at maximum pressure remains unchanged in both cases (2.23 μm (± 0.04 μm), Figure 1b). Considering the thickness at maximum pressure as a scatter indicator, it can be affirmed that the manual staking results in a maximum scatter of 115 μm in wet conditions and 62 μm in dry conditions. The relaxation with fabrics shows a non-physical decrease in thickness of 18.1 μm (± 0.05 μm). In relation to the compression in dry and wet conditions the compaction behaviour does not show significant differences, Figure 1b).




(a) (b)

Figure 1: *Typical dry and wet compaction measurements: (a) Difference between the actual compaction curve without a sample and its polynomial regression used in the data processing; the extremities were excluded in the data processing; (b) Compression curves obtained in dry compression, wet compression and wet compression with relaxation stage at 1 bar: a) relaxation test in detail, the thickness decrease during relaxation stage is progressive and reaches its maximum at the end of the stage.*

## Conclusions

The correction for the setup and the machine compliance in dry and wet compaction tests allows measurement of the fabric stack thickness with precision in the microns range, which is much smaller than the scatter of the fabric stack thickness induced by the manual arrangement (about 15 … 20 μm per fabric layer).

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