Fabrication of hybrid thin ply tapes

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Abstract. Thin ply hybrids are composed of at least three different materials: two or more yarns and one binder to fix the final thin ply tape. This study is divided in the steps required to convert the raw materials (carbon, glass, aramid and polyester) into the hybrid thin ply tapes: unwinding of the yarn; spreading of each individual yarn; hybridization, blending and spreading of all the materials, and finally binding and winding the final thin ply hybrid. All these processes are studied individually to determine the effect of each one on different yarns. The more important steps on this hybrid spreading line are the spreading methods and the blending of different materials. Different processes such as ultrasounds, mechanical vibration, convex rollers, air flow, etc, exist to spread the yarns. The choice of this study is to use mechanical vibrations in the individual yarns whereas the second step is performed with vacuum, paying attention to the control of the tension during the entire process. The developed technique allows for production rates from 5 to 20 m/min of hybrid fiber depending on the characteristics of the raw material, showing that the fabrication process of these materials is suitable for industry.

1. Introduction
In the search for composite materials with improved mechanical properties, thin ply based laminates have raised a great interest due to its ability to delay matrix cracking, to improve the free edge delamination or to extend the fatigue lifetime, among other benefits. A further step in this field is to mix different fibers in the thin ply. This can be done to reduce the cost of the material by reducing the use of expensive fibers, or to bring specific properties to the composite material (mechanical or functional properties) adapted to the specific needs of each application. In particular, there is the prospect to be able to enhance the fracture toughness of the material by tailoring the mixture of different fibers. There are many theoretical studies on the damage progression of thin ply hybrids. However, despite of this relevant theoretical knowledge, there is a lack of experimental evidences. Basically, because these materials have not yet been implemented in industry, showing how difficult is to produce these new type of materials.

This communication presents a developed method to obtain this type of materials. In addition to obtaining these materials, it has been possible to obtain them with applicability to the industry, both technically and economically.
2. Spreading hybridization methodology
In an analogous methodology to obtain tow spread fibers of a single material, it is possible to use the same techniques to obtain thin ply hybrid tows. The three forms of hybridization that we have studied to achieve the hybrids fibers are vacuum, mechanical vibrations and the convex rollers.

The method used in this study allows to achieve and study the process to manufacture hybrid tapes of surface density between 40 and 100 g/m² and a width between 10 and 50 mm by combining two equal or different fibers, dimensions of filaments and density count.

2.1. Parts of the machine
The machine is divided mainly into 3 sections. The first corresponding to the unwinding of the raw materials, the second in the opening, hybridization and fixation of the tape and the last in the winding of the final product. Despite the great importance of the three sections, this study focuses on the second part that is the essence of the final product and where there is more uncertainty.

The machine used to obtain the first samples of hybrid industrial fiber materials follows the operating scheme that can be seen below.

The unwinding process is made individual for each one of the fibers that are used. They are performed at a constant tension from the start to the end of the product. For the correct operation of the system it is important to control the unwinding tension. Experimentally it has been verified that with low tension defects from the unwinding process were less than 1% of the defects detected.

During the process of hybridization and opening of the tapes, the tension is controlled at all times, it is one of the most important variables and it affects severally to the final result.

The opening of the tapes consists of two steps, the first one where the different tows are open at the same width and the next step this tows are joined and spread to the desired width. The different methods used to achieve the hybridization are mechanical vibrations, vacuum and convex rollers.

Impregnation is necessary to ensure the dimensions of the tapes once manufactured, in addition to ensuring these dimensions for subsequent processes. It is used a Copolyester because is compatible with epoxy matrices. In this study the amount of binder used in the samples is 6% + - 1% with respect to the total mass of the fibers and the binder.

Finally, the finished hybrid tape is winded with the desired format. The winding tension is very low to not affect the width reached.

3. Experimental results
Experimental tests have been performed using the fabrication line exposed in point 2 to hybridize thin ply tapes. What I wanted to achieve in this study is to hybridize two different carbon fiber tows and on
the other hand, carbon fiber and aramid tows. Both focused on improving the mechanical properties of the final product and reducing the cost. The experiments were carried out to obtain 50 g/m² specimens.

3.1. Different types of fiber
The fibers for this feasibility study of the hybrid thin ply tapes are carbon fibers and aramid fibers. In concrete, the models used are summarized in the following table.

Table 1. Types of fibers used as raw material

| Denomination | Manufacturer | Type of material | Density (g/cm³) | Yield tex (g/1000 m) | Tensile strength (Mpa) | Tensile modulus (GPa) | Strain (%) |
|---------------|--------------|-----------------|----------------|----------------------|-----------------------|----------------------|------------|
| A-42 12k     | AKSACA       | Carbon fiber    | 1,78           | 800                  | 4200                  | 240                  | 1,8        |
| Sigrafil CT24-5.0 | SGL              | Carbon fiber    | 1,81           | 1600                 | 5000                  | 270                  | 1,9        |
| Twaron       | Teijin       | Aramid          | 1,42-1,46      | 336                  | 1650-2200             | 60-80                | 3-4,4      |

The experiments will be done mixing first the two carbons together and then AKSACA carbon and Twaron. Also each of these materials has some mechanical properties as well as a specific format as a raw material. This fact forces to open each combination of fibers to certain dimensions to obtain the desired surface weight of 50 g/m² with the two fibers that make up the final hybrid.

Table 2. Wide calculation A-42 12k and Sigrafil CT24-5.0

| Denomination | Manufacturer | Type of material | Density (g/cm³) | Yield tex (g/1000 m) | Areal weight (g/m²) | Spread width (mm) |
|---------------|--------------|-----------------|----------------|----------------------|---------------------|-------------------|
| A-42 12k     | AKSACA       | Carbon fiber    | 1,78           | 800                  | 16,65               | 48                |
| Sigrafil CT24-5.0 | SGL              | Carbon fiber    | 1,81           | 1600                 | 33,35               | 48                |

Table 3. Wide calculation A-42 12k and Twaron

| Denomination | Manufacturer | Type of material | Density (g/cm³) | Yield tex (g/1000 m) | Areal weight (g/m²) | Spread width (mm) |
|---------------|--------------|-----------------|----------------|----------------------|---------------------|-------------------|
| A-42 12k     | AKSACA       | Carbon fiber    | 1,78           | 800                  | 14,8                | 22,7              |
| Twaron       | Teijin       | Aramid          | 1,42-1,46      | 336                  | 35,2                | 22,7              |

According to the previous tables, the test with two carbons should get a 48 mm wide tape and the next two we should get a hybrid of 22.7 mm wide.

3.2. Baseline data for testing (INPUTS)
The data considered to be relevant to study that have a direct effect on the final result are the following:

- Linear mass density (tex): It depends of fiber type
- Initial width (mm): It depends of fiber type
- Production speed (m/min): It is fixed to 10 m/min for all the test
- Tension between spread and hybridization (cN)

3.3. Data obtained (OUTPUTS)
The data registered to determine the quality of the tape and information to quantify or valuate the tape are the following:

- Thickness (µm)
- Width (mm)
3.4. Test results

The first result that indicates the quality of the tape is the average width reached and the deviation over it. These parameters are directly related to the dimensions of the tape both thickness and the width. The result in the two cases of the hybrids manufactured are the following:

**Figure 1.** Carbon – carbon hybrid width results

**Figure 2.** Carbon – aramid hybrid width results

It can be seen about the variability of the tape is higher in the case of the use of vacuum. On the other hand mechanical vibration with rollers has the best results in the range of the final tape and also in the
reach the medium dimension desired. Finally, although the regularity of the rollers is good enough, most of the tape does not reach the desired width.

In the case of carbon – aramid hybridization with these methods is more complicated. The deviation of the width and, consequently, the thickness is quite variable throughout the production. And although the average case is close enough to the objective value, the profitability of the tape is very bad.

The graph shows how to combine two materials of a different nature is much more complicated than trying to hybridize two materials much closer in terms of length and diameter of fibers. The spaces without material that we find throughout the final product are smaller in fibers equal than in different ones, and a priori the method that brings us closer to the "perfect" hybrid is that use mechanical vibrations.

Parallelism of the fibers is quite constant and it does not provide enough information to compare the results, since in all cases they are very similar.
4. Summary
The results obtained indicate that in order to industrialize the hybrid tape the best system is the mechanical vibration, it is the one with the least empty areas of material that could be defects in the final application of the product, as well as having the best regularity of the methods studied.

As shown in the graph following the profitability of the produced hybrid tapes it is much better in hybrids with a single type of material, as well as with mechanical vibration with respect to the others methods.

5. Concluding remarks
The hybrid thin ply tapes have gained a lot of interest for the industry in recent years. Knowing all the advantages that could be obtained causes the need to manufacture these fibers in an industrial environment.

The first relevant result is that it is possible to manufacture a 2400 tex carbon-carbon hybrid with a width of 48 mm at a speed of 10 m/s and also this system is viable technically and economically.

If mechanical vibration is used as the main method to open and hybridize the fibers, the regularity of the final tape is more stable (variation less than 10%) and the presence of errors is more than 37% less respect to other methods. This implies that it is the most appropriate method for industrializing the process. The maintenance of the equipment is cheap and the cost of manufacture is estimated around 0.18 €/m.

The fibers of different types are more difficult to hybridize, when the fibers do not have the same origin, the efficiency of the system used decreases considerably.

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