LOW COST HIGH STRENGTH 3D COMPOSITES ENABLE AUTOMATIC LAY-UP FABRICS

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1. Introduction

Fiber/polymer composites have been widely used in many industries such as aerospace, transportation, construction, wind energy and sports. They are made by lying up fiber sheets layer-by-layer and bonding the sheets with plastics. Tensile strength of the carbon and glass fibers within a sheet can be higher than 3000MPa, much stronger than steel. However, the strength of the plastics between layers bonding the sheets is about 100MPa. The plastic strength is only about 1/30 of the fiber strength. It is pretty hard and expensive to increase the plastic strength by chemical methods such as making toughened resin. Therefore, the low interlamination strength of composite often leads to out of plane failures such as delamination under various loadings, especially under impact and compression fatigue loadings on a composite structure.

In order to minimize the sensitivity of the conventional laminated composites to the out of plane failures, researches have improved delamination resistance through mechanical means, such as through-the-thickness reinforcements by 3D stitching(1, 2), weaving and Z-pins(3, 4). While those approaches have shown promise in improving the impact resistance of composite materials, 3D stitching and weaving need very complicated machines and processes. Those 3D approaches significantly reduce the flexibility and efficiency of the composite whole production cycles from design to manufacturing. So they are still not widely used in composite industry. Layer-by-layer lying up is still major processes in composite industry.

After fiberglass appeared in 1940s, lightweight fibers and plastic composites have been used in many industries. Fiber composites were further boosted by carbon fibers since 1970s. However so far those industries have not yet taken advantage of Velcro technology available in 1955 to increase composite interlamination strength and enable automation in lay-up fabrics.

This paper investigates a new approach of using Velcro (hook and loop fasteners) on both sides of fiber plies to make 3D composites to increase their interlaminate strength and enable automation for lay-up fabrics. When the Velcro fiber ply is laid on each other, the adjacent fiber ply will be locked together by the Velcro fasteners, which act as trans-ply reinforcement fibers. Its inventor names these kind fabrics for composites as Han-3D-fabrics. Carbon fiber, glass fiber and almost any fiber can be used to make Han-3D-fabrics. Impact tests are performed on those fiberglass Han-3D-composite samples. Velcro locked samples have increased about 60% to 90% in impact resistance in comparison with the counterpart samples without Velcro fasteners.

Hand lay-up fabric process is a major barrier for applying fiber-reinforced composites in automobile industry. Han-3D-Fabrics can enable automation due to the easy handling of hook-and-loop fabrics. Velcro fabric on a cutting table can be picked up by a Velcro tool at the end of an automation arm. Then, the automation arm can place the fabrics in a mold and release them to get performs. A car body model is made by the partially automatic lay-up fabric method and RTM process to demonstrate the new solution.

2. Han-3D-Fabric Has Velcro on Its Both Sides

The fabrics having Velcro (hook, loop) fasteners on its both sides to improve the interlaminate strength and enable automation in lay-up fabrics is named as Han-3D-Fabrics. Han-3D-Fabrics are a new international patent-pending approach from 3D Nanocomposites, Inc. and Advanced Fiber Materials Technologies Co., Ltd. Han-3D-Fabrics are able to provide stronger 3D composite products at a lower price in comparison to the current 2D laminate composites in the market.

Han-3D-Farbrics can be made by carbon fibers, Kevlar fibers and fiberglass, shown in Figure 1. Han-3D-Fabrics has been recognized by international composite society and won the 2010 JEC Paris Innovation Award in raw material category (5).

3. **Impact Test**

Fiberglass Han-3D-Fabrics were used to make samples for impact tests. In comparison, the counterpart plain weaved fiberglass fabrics without hooks and loops are also made. All the composite samples are made by vacuum assisted resin infusion process. There are 8 layers fabrics in the laminate samples of 3 mm thickness. The fabric lay-up sequence is (0/+45/–45/90/0/-45/+45/0). The resin in resin infusion process is epoxy.

Put the samples to cover the center hole of an impact test fixture. The center hole is 50 mm in diameter. Impact rod head diameter is 12.7mm. Drop weight of 1 kg from 80 cm height. Move the sample and repeat the impact with the same impact load.

The impact dent marks are shown in Fig. 2. The small dent marks at the top row are on Velcro locked samples, and the very big dent marks at the bottom two rows are on the samples without Velcro. Han-3D-Fabric can significantly increase the impact strength of composites.

In order to obtain smaller dent mark sizes on the samples without Velcro, the drop weight height is reduced. When the drop weight height is reduced to 40 cm, the dent mark sizes on the samples without Velcro is similar to the dent sizes on the Velcro locked samples with a drop weight height of 80 cm. So the Velcro fasteners almost increase the impact strength of the composite 100%. The smaller Velcro fibers between plies may also increase the delamination resistance (6).

Besides increase impact strength, Han-3D-Fabrics are able to make next generation low cost 3D composites with a stronger interlaminate strength, compression strength, fatigue strength, bolt hole strength, bonding/connection strength. More results will be published in other papers.

4. **Han-3D-Farbrics Enable Automation for Lay-Up Fabrics**

Hand lay-up fabric process is a major barrier for applying fiber-reinforced composites in automobile industry. It is very hard to manufacture more than 10000 composite parts by hand lay-up fabrics for an automobile company. Hand lay-up fabric process is too slow and expensive for a mass production. Han-3D-Fabrics can enable automation due to the easy handling of hook-and-loop fabrics. Velcro fabric on a cutting table can be picked up by a Velcro tool at the end of an automation arm. Then, the automation arm can place the fabrics in a mold and release them to get performs. The cost of fabric raw materials is only about 20% of the whole cost of a composite part. The lay-up fabrics and molding processes occupy 60-70% of the whole cost of a composite part. So the new automatic lay-up solution can reduce composite cost at least 50%.

A car body model is made by the partially automatic lay-up fabric method and RTM process to demonstrate the new solution. Han-3D-Fabrics with Velcro fasteners lets the mass production of composite parts for automobile industry at low cost become possible.

5. **Summary**

This paper provides a new approach of using Velcro (hook and loop fasteners) on both sides of fiber plies to make 3D composites to increase their strengths and enable automation for lay-up fabrics. A car body model is made by the partially automatic lay-up fabric and RTM processes.

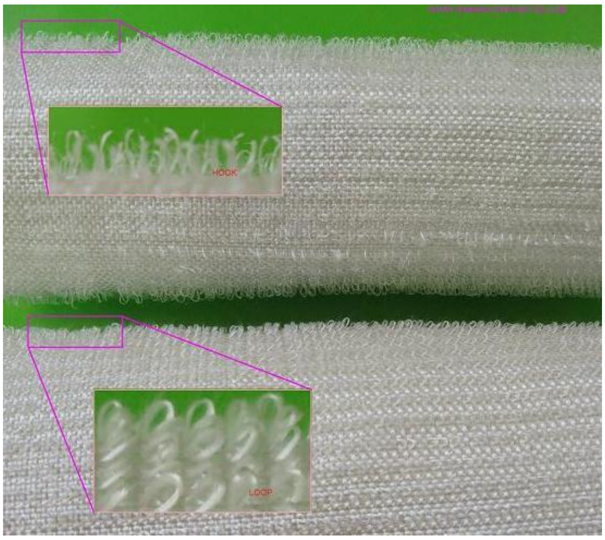

Fig.1. (1) 3D glass fiber fabric.
Width: Min./ Max. 0.4/1.80m
Unit Weight: 300-1200g/m^2
Yarn Diameter: 300-2400TEX

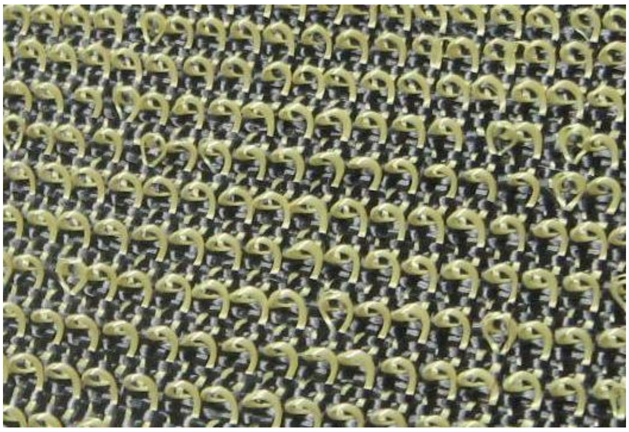

Fig.1. (2) 3D carbon fabric (Base 2D fabric is carbon fiber, hook and loop are aramid fibers).
Width: Min./ Max. 0.4/1.80m
Unit Weight: 100-600g/m^2
Yarn Diameter: 3-12K/800-3000D

Fig.1. (3) 3D aramid fiber fabric.
Width: Min./ Max. 0.4/1.80m
Unit Weight: 150-800g/m^2
Yarn Diameter: 800-3000D

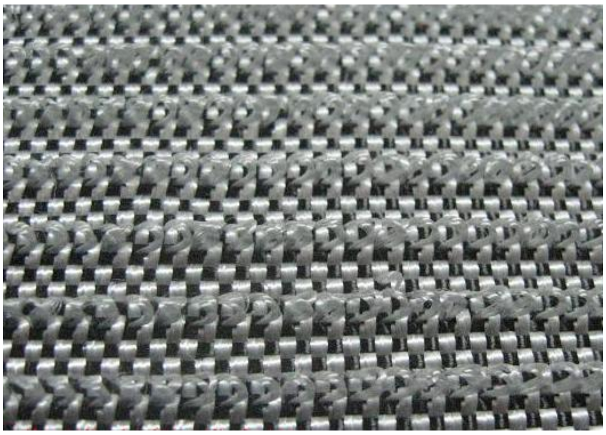

Fig.1. (4) 3D carbon and glass fiber hybrid fabric.
Width: Min./ Max. 0.4/1.80m
Unit Weight: 200-1000g/m^2
Yarn Diameter: Carbon:3-12k
Glass fiber: 300-2400TEX

Fig.1. Han-3D-Farbrics have Velcro on their both sides

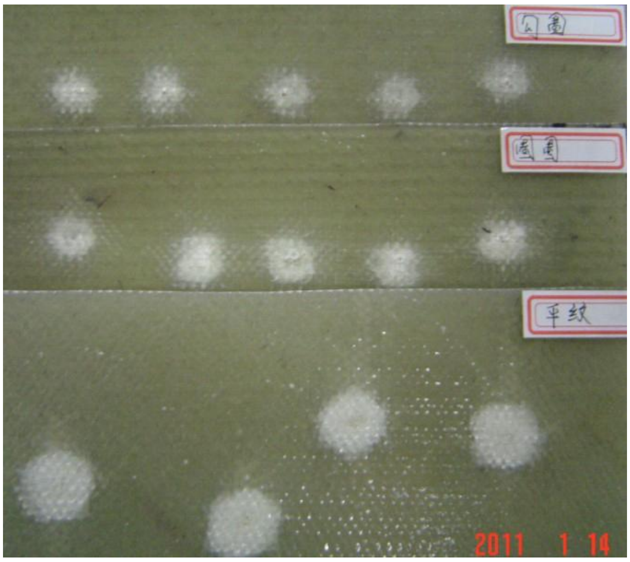

Fig. 2. The dent marks at the top row are on Velcro locked samples, and the dent marks at the bottom two tows are on the samples without Velcro.

Fig. 3. A car body model is made by the partially automatic lay-up fabric method and RTM process.

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