Title: **WET LAY HYDROENTANGLED GLASS FIBER COMPOSITES FOR INDUSTRIAL APPLICATIONS**

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ABSTRACT

Hydroentanglement process has emerged in recent years as an alternative to adhesive, chemical or thermal bonding process. Hydroentanglement is a purely mechanical bonding process that uses very fine high-pressure water jets without the need for any additional binder similar to the needle-punching process.

Hydroentangled fibrous assemblies can be produced as one integrated structure of significant thickness as alternatives to needle punched nonwovens and laminates, Hydroentanglement eliminates

- The fiber damage attributed to needle punching
- Delamination problem attributed to laminates.

Hydroentangled structures can also be produced in the form of, apertured and crimped structures. It is also possible to blend or multi-lay different fibers with different properties to impart desired strength, texture and surface qualities to the fibrous assembly for industrial applications.

This work will focus on a preliminary study investigating the suitability of hydroentangled glass and hybrid nonwovens for industrial applications. Various glass fibers and their blends are to be used to form hydroentangled composite fabrics that will be the composite precursors. Their structural properties are to be investigated by using an imaging system, and the material-structure-process property relations will need to be determined.

INTRODUCTION:

1. NONWOVENS

A nonwoven fabric is a fibrous assembly, which is generally defined as a sheet or web structure made by bonding and interlocking fibers by mechanical, thermal, chemical or solvent means. Nonwovens are generally used in applications such as filtration, geotextiles, garment lining, protective clothing, surgical gowns and pads and carpet components. Nonwovens have a wide range of manufacturing processes giving rise to a large variety of properties. This makes them eligible for a number of applications: floor coverings, geotextiles, furnishings, thermal insulation, wipes, protective clothing, medical applications and reinforcements in structural composites.

The definition of nonwovens from EDANA (European Disposables and Nonwovens Association) is similar to that of ISO (International Organization for Standardization) which defines a nonwoven as a manufactured sheet, web or batt of directionally or randomly orientated fibers (not yarns or rovings) bonded by friction and/or cohesion and/or adhesion (Batra et al, 1986).

There are primarily two stages to nonwoven production: web formation and consolidation, which can be followed by finishing. A web can be made of randomly or directionally orientated fibers and is produced by one of the following methods: dry-laying, wet-laying, air-laying, spun-laying and meltblowing. Once a web is formed it can be consolidated using one or more of the following means: chemical bonding, thermal bonding and mechanical bonding or hydroentangling.

2. HYDROENTANGLEMENT TECHNIQUE

- **Background**

Hydroentanglement also referred to as spunlacing or jetlacing or water needling, is a method of mechanically bonding together textile and high performance fibers uses high-pressure jets of water to strike a web so that the fibers knot about one another and provide fabric integrity. Hydroentanglement is the generic term for a nonwoven process that can be used for either web consolidation or fabric surface texturing purposes or both. In other words, it is a mechanism of fiber rearrangement and entanglement within a preformed web by means of fluid forces.

The frictional forces resulting from the entanglement are the basis for the mechanical bonding of the fabric produced. Hydroentanglement technology is now becoming successful with increased production speeds at reduced costs yet still yielding a high strength fabric. It not only offers replacements for conventional nonwovens but also opens up new markets for innovative products.

Hydroentanglement process began to appear in industry in the 1980s. From 1987-95 the annual production rate of hydroentangled nonwovens have increased from 45 to 140 thousand tons. This unique process offers a great opportunity for expansion of the nonwovens market at a rate of 15-20% per annum.

➢ **Advantage** of hydroentanglement:

Hydroentanglement is basically an energy transfer process. Fine water jets used in the hydroentanglement process offer an alternative to mechanical needle punching but without the disadvantages of the physical fiber damage and slow production rates associated with the latter. It also eliminates the need for chemical or thermal binding, reducing environmental pollution. The jets exhaust most of the kinetic energy primarily in rearranging fibers and in rebounding against in the substrates dissipating energy to the fibers. A vacuum within the roll removes used water from the product, preventing flooding.

The advantage of hydroentanglement over needle punching is that water acts as a plasticiser drastically reducing the bending stiffness, flexural and torsional rigidity of the fiber. This allows the fibers to easily bend twist and form loops, under the fluid forces thereby entangling and interlocking them to form a strong nonwoven fabric. Besides, the use of 'water needles', instead of metal needles means less friction and hence less damage to the fiber. Both of these characteristics are important while processing specialty fibers used for composites.

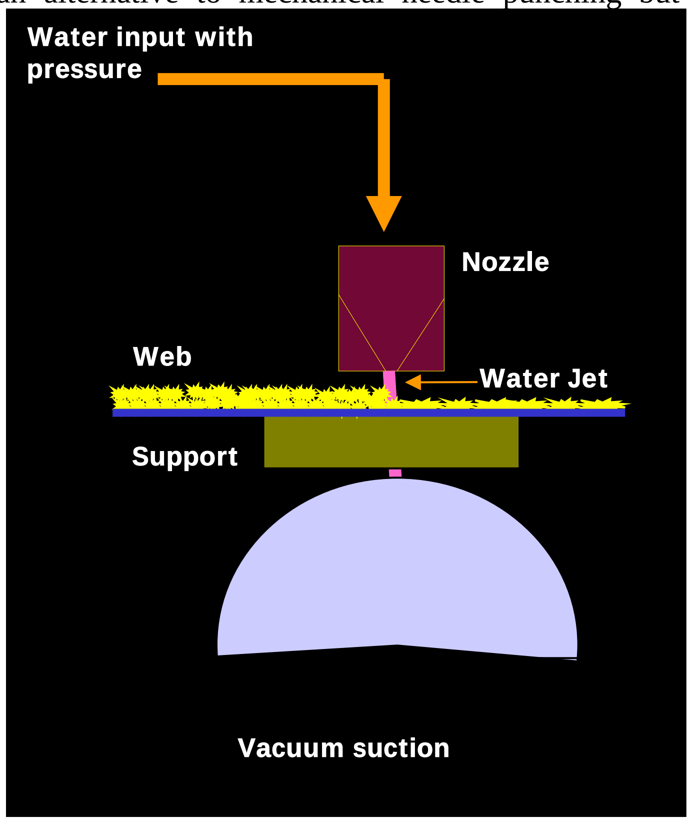


Figure 1 Principle of Hydroentanglement process

➢ **Main Parameters:**

Principal parameters of a hydroentanglement system are as follows:

- **Web Support System**: There can be two main configurations:

1. Travelling conveyor belt type fabric made from a fine woven metallic or polymeric mesh
2. Rotating perforated drum

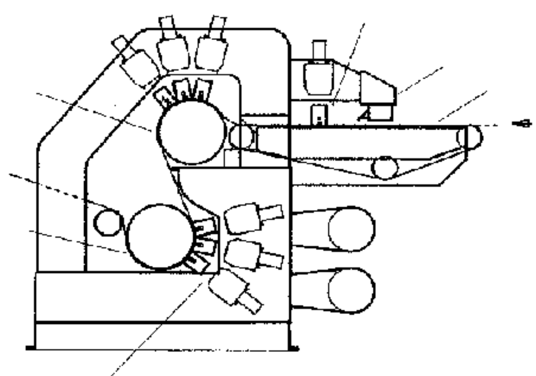
- **Water jets:** Injector hole/nozzle diameter ranges from 100-120μm in diameter arranged in single or multiple rows with a 3-5mm spacing and 1-2 jets per mm. A 200 bar (2900 psi) operating pressure is used commonly in modern hydroentangling machines.

- **Water circulation and filtration**: a filtration system to separate any foreign particles from the recycling water. A large amount of water is required which has a neutral pH, low in metallic ions such as Ca, no bacteria or other organic materials. Therefore filtration system is essential.

- **Water extraction**: vacuum boxes under the supporting substrate to remove the water penetrating the web.

Figure 2 Tandem rotating drum hydroentanglement machine

- **Drying and finishing**: Drying (vacuum or heat drying) is done to remove the moisture



left in the fabric and it gives physical and chemical finishing to impart the fabric desired properties.

High-pressure water enters the jet manifold and exits through the nozzle plate that creates very fine water jets. As the emerging jets impinge upon the web they cause the fibres to reposition and entangle. The frictional forces resulting from the entanglement are the basis for mechanical bonding. Excess water is removed by suction for filtering and recycling.

Entanglement is usually achieved by increasing the jet pressure stepwise from the first injector to the last. It is usually performed on both sides of the web. Figure 2 shows a tandem rotating drum arrangement for double-sided entanglement.

Nowadays, high-production speeds can be achieved as complete hydroentanglement production lines come into use (capable of producing the fibers, then the web and finally a coherent fabric with a good surface finish) but the hydroentanglement units can be added to existing web-forming machines.

- **Applications**

Hydroentanglement process is very suitable way of converting not only the textile fibers, but also new generation and high performance fibers and their blends into nonwovens without damaging them and without the need for any additional binder. The hydroentangled nonwoven fabrics have properties like softness, flexible hand, high drape and bulk, conformability and moldability, high strength without binders and delamination resistance. The characteristics of fabrics can be engineered according to the end use requirement.

Application areas of hydroentangled nonwoven fabrics cover a wide range of product weights, from 20 to 500 g/m^2. A significant part of the hydroentangled fabrics are used for disposable medical products (single-use surgical gowns and drapes; breathable, fluid and bacterial barrier fabrics, medical dressings - 60% of the market) due to the lint-free and clean nature of the fabric. They are also used in household products and wipes, fusible textiles, thermal apparel insulation, heat resistant fabrics, insulation (glass fiber webs), roofing, filtration, hydrophilic and hydrophobic laminates.

- **Industrial Applications**

Hydroentangling machine can process almost any kind of fibre and blends of such fibres to produce composite or hybrid fabrics. High performance fibres like aramids are used in hydroentangled fabrics. Some current industrial applications include aircraft seat fire blocking, auto hood veiling, high temperature and corrosive filter fabrics, fire-fighter jackets. Such fabrics have the advantage of low cost and low weight (or high bulk) because of hydroentangling when compared with woven fabrics. Roofing and insulation, automotive body and interiors, floppy disc liners, circuit boards and other electrical appliances and aerospace appliances use hydroentangled high performance fibers.

3. GLASS FIBER NONWOVENS:

Glass fibers exhibit excellent thermal and impact resistance, high tensile strength, good chemical resistance and outstanding insulating properties. They can be tailored to create different types of glass fibers.

Glass fibers have unique properties such as: low cost; high strength; high temperature, heat and chemical resistance and outstanding insulating properties. Therefore, they are used in high performance applications in the industry. These properties result in nonwovens with good fire resistance, electrical insulation and dimensional stability to temperature and humidity and impact force. They can be tailored to create different types of glass fibers. Some typical industrial applications include asphalt-roofing products, fire barriers and radiant heat barriers. They are also used as carpet backings and substrates for vinyl flooring products. Other uses include electrical wraps and insulation, high efficiency filtration, duct linings, surfacing veils, facings and reinforcement for composites such as printed circuit boards. Glass nonwovens are also used in a number of automotive applications such as gaskets and battery separators.

The different types of glass fibers are:

1) E-Glass:
It is named for its good electrical resistance because of which it is suited for applications where radio-signal transparency is desired as in aircraft radomes and antenna. E-Glass has good strength properties at low cost. It is used in circuit boards of computers to provide stiffness and electrical resistance.

2) S-Glass:

It is named for its good strength. When better strength and low weight are required then such glass fiber is selected. It is often known as R-Glass in Europe and T-Glass in Japan. Its another version is the S-2 Glass. The high strength glass has appreciably high silica oxide, aluminum oxide and magnesium oxide content than the E-Glass.

3) C-Glass:
It is named for its good corrosion resistance. It has high chemical resistance. Usually a 10 micron diameter E-Glass filament typically looses 0.07% of its weight when left in hot water for 24 hours. But C-Glass loses much less of its weight when exposed to an acid or water. Sometimes, glass fibers are coated onto with silane compound so as to make it moisture resistant.

COMPOSITION OF GLASS FIBERS

Materials	E-Glass	S-Glass	C-Glass
	Range %	Range %	Range %
Silicon dioxide	52 to 56	65	64 to 68
Aluminum oxide	12 to 16	25	3 to 5
Boric oxide	5 to 10		4 to 6
Sodium oxide and potassium oxide	0 to 2		7 to 10
Magnesium oxide	0 to 5	10	2 to 4
Calcium oxide	16 to 25		11 t 15
Barium oxide			0 to 1
Titanium dioxide	upto 1.5		
Iron oxide	0 to 0.8		0 to 0.8
Iron	0 to 1		

The glass fibers used normally have diameter in the range of 6.5 micron to 16 micron. The chop lengths range from 3mm to 25mm with moisture content of 10% to 20%. The shelf life is about nine months from the date of manufacture. (Data from Owens-Corning Company)

- **Glass Web Forming Processes:**

Web forming process can be either air lay or wet lay process. Air laying is difficult for glass fibers because of absence of crimp in them. Sizing of glass fibers and blending with other fibers makes air laying possible. Wet laying has been the major process for converting glass fibers into nonwovens. Wet-laying involves uniformly dispersing the right type and quantity of fiber in water, transporting onto a continuous moving fine mesh screen and then forming a mat as a result of filtration. For a stable dispersion the process may require adding surfactants and viscosity modifier into the water. The consistency of the suspension is also critical and a typical mixture contains 0.5% glass. The fiber length/diameter (L/D), stiffness of fiber, kind/amount of crimping, fiber wettability and mechanical agitation of mixture are important parameters for uniform fiber dispersion.

- **Hydroentangling of Glass Fibers**

Both dry laying and wet laying processes produce a glass fiber mat that would not have cohesion between the constituent fibers without additional chemical binders applied to the fabric. Hence the resultant fabric would virtually have no strength. Needle punching is used to impart strength to glass fiber nonwovens used in a number of industrial applications including automotive industry. Needle punching brittle fibers such as glass inevitably causes significant fiber damage. But it is not the case with hydroentanglement.

Table 1. Strength of fine/coarse glass blend hydroentangled fabrics

Blend of fine/coarse glass mat	Strength, Cross direction MPa	Strength, Machine direction MPa
20/80	0.152	0.130
40/60	0.363	0.395
50/50	0.410	0.475
60/40	0.563	0.557
80/20	0.549	0.372

4. EXPERIMENTAL PROCEDURE:

In this experiment, glass fibers will first be blended with Polyester fibers in the ratios of 90:10, 70:30, and 50:50 Glass : Polyester blends. Then the mixture will be wet-laid to produce three different weights of wet lay fabric. The fabric thus produced will be hydroentangled at low, medium and high pressures on both sides. Then the fabric will be compression molded to form a composite. The composite will be tested for tensile strength, angular strain and imaging test will be performed on the composite.

Dr. Acar spent a period of sabbatical in the North Carolina State University and investigated the suitability of textile grade glass fibers for hydroentangling. Blends of different grades of glass fibers and polyester/glass have been hydroentangled with some degree of success. Glass fiber with 16-micron diameter (25 mm long) proved to be very difficult to hydroentangle. However when blended with 6.5 micron diameter (6 mm long) glass fiber some encouraging results were obtained. As the ratio of 6.5-micron glass to 16-micron glass increased, the strength of the fabric produced increased significantly (Table 1). This suggest that with the right blend of fine and coarse fiber glass a good degree of entanglement can be obtained where fine fibers provide entanglement and the coarse fibers give the strength (Figure 4a).

(a) (b)

Figure 3. SEM micrograph of glass and glass/polyester blend hydroentangled fabric

Blends of a textile fiber, such as polyester, with glass fiber also produced good results where textile fiber helped to entangle the blend (Figure 4b). This makes blending of glass with low-melt polymers a way to produce glass reinforced polymer composites.

5. SUMMARY:

The hydroentanglement process is very versatile so that the characteristics of the fabrics thus produced can be engineered by selecting the right combination of fibers, adjusting the hydroentangling process parameters such as pass rate and water pressure, and they therefore offer potential for the production of composite and hybrid fabrics and pre-forms for reinforced plastics for many industrial use.