THE FIRST MAGAZINE DEDICATED TO THE FILAMENT WINDING MARKET

TOPFIBRA MAGAZINE

N°2 / YEAR I

QUARTERLY
MAY 2019

AVOID THAT THE MOST IMPORTANT PROJECT FOR YOUR COMPANY BECOMES AN INSURMOUNTABLE PROBLEM page 39

EFFECTIVE FILAMENT WINDING®

MOST OF THE FAILURES OF A GRP PIPELINE ARE RELATED TO INSTALLATION PROBLEMS

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Mauricio Facchinetti

editor and

Co-Founder Topfibra d.o.o.

I am delighted to introduce the second edition of our TOPFIBRA magazine, the first of its kind specialized in the filament winding market. It provides a really exciting opportunity to understand the nature of the filament winding technology in an environment of major changes and increasingly tougher competition in the market.

The objective of our TOPFIBRA magazine is to publish up-to-date and original specific articles, to help you move correctly in this market. Each issue of the magazine contains five sections, the first being the News section, will provide brief, contemporary information pertinent to technology implementation and our strategic partnerships undertaken in the Filament Winding market.

The second section, Columns, will provide precise and detailed information regarding our EFFECTIVE FILAMENT WINDING, the first-ever method for profit making in the Filament Winding market, as well as GRP pipe designs and relative fabrication methods, and finally on the main resins used.

The third section will be focus on improvements relative to the Continuous Filament Winding technology and useful tips with important information for your production plant.

The fourth section will give a clear contribution to knowledge in the field of GRP pipes and installation thereof.

The fifth section is reserved for Research and Development activities in the field of composites, as well breaking news regarding spare parts, consumables and assistance.

I wish you pleasant reading!

Feel free to send me your impressions and suggestions via the email address below:
marketing@topfibra.eu

To the next issue!

TOPFIBRA
MAGAZINE

FIRST MAGAZINE DEDICATED TO THE FILAMENT WINDING MARKET

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EFFECTIVE FILAMENT WINDING®

NEWS

COLUMNS

CONTINUOUS AND DISCONTINUOUS FILAMENT WINDING PLANTS

PRODUCT SOURCING AND SUPERVISION SERVICES

DESIGN, PROTOTYPING, AUDIT, CONSUMABLES, SPARE PARTS AND AFTER-SALES ASSISTANCE

EFFECTIVE FILAMENT WINDING®

Which results have heen obtained through the Effective Filament Winding method in Colombia?

Topfibra implemented the first phase of the EFFECTIVE FILAMENT WINDING method in PAVCO, MEXICHEM, COLOMBIA.

The immediate results obtained has impressed the plant management, with:

- cost reduction in the production of CFW pipes;
- profit increase without the need of an investment in a machine upgrade;
- scrap reduction by more than 50 %;
- a clear strategy of the process and full control on the results.

During the subsequent months, a second phase of the EFECTIVE FILAMENT WINDING method implementation will be carried out, together with the installation of the automatic tensioning system device.

Topfibra became a member of Almaco and Coopmaco in Brasil

TOPFIBRA's mission is to promote and strengthen the sustainable development of the GRP pipe market in Brazil.

The filament winding industry still has a big potential for improvement and development of new products, as well as for the reduction of final costs in the composite world.

We have already accomplished results in many countries, which a year ago were considered unobtainable and now we are ready to implement our EFECTIVE FILAMENT WINDING method in America Latina, starting with Brazil.

This forms part of TOPFIBRA's ongoing commitment to support the Brazilian market and to continue using GRP pipes in the big infrastructure projects in the most effective way, exceeding the expectations.

TOPFIBRA is proud to announce the signing of a partnership agreement, with the Brazilian Group JOPLAS, for the Continuous Filament Wound GRP pipe projects in Brazil.

The JOPLAS Group has always invested in R&D, obtaining international certifications, product optimization and international patents and now the Group has decided to implement the EFFECTIVE FILAMENT WINDING method to boost their profits in the filament winding market even more.

Through this partnership, we will combine our efforts, strengths and knowledge to continue the development of GRP products for infrastructure and industrial applications in water, irrigation, wastewater, hydropower and industrial plants.

JOPLAS

TOPFIBRA

Topfibra's project management for the GRP pipe supply for Beni Suef combined cycle power plant project was successfully completed

At the end of February 2019, TOPFIBRA performed the closing activities regarding the project for the supply of the GRP pipes for the cooling system on the Siemens Turbines.

The 4.8 GW power plant is located in Beni Suef, in the southern part of the country, approximately 110 km south of Cairo and TOPFIBRA closely monitored various aspects of the project.

The achievements in Beni Suef are numerous.

In 150 days, they:

- installed 6 main and 6 auxiliary transformers;
- erected 10.150.000 kg of Steel structure,
- poured 115.000 m³ of reinforced concrete;
- installed 6 gas turbines, including all auxiliaries;
- installed and started up all GRP lines for the cooling system.

EFFECTIVE FILAMENT WINDING®

Amazing results obtained by three production plants using the new steel band

We have already sent the new steel band, optimized for the continuous filament winding process, to several plants.

The Plants have achieved:

- an increased stability on the continuous filament winding machine mandrel;
- better performance of the steel band during the production of diameters smaller than ND 600;
- better properties during the welding and annealing operation.

All the above has led to an increase in Production Plant profits.

Leoma diamant presented the new cutting disks for composites

Thanks to our collaboration with Leoma Diamant in the composite industries, we have an immediate response to specific needs regarding coated tooling for Filament Winding production.

Diamond coating tooling is extremely important in the FW process because every minimal mistake on the shape or final surface smoothness can create extensive losses for your company. For example, the diamond used to coat the tooling is one of the main contributors to the prevention of joint leakages.

The diamond grain used is therefore perfect for fiberglass tooling and we guarantee that it will help your production plant to positively increase the performance of pipes and sleeves.

Our technical staff is at your disposal discuss this important issue with you.

Alfebor GRP pipes boost project in Iraq

Alfebor plant and Topfibra technology continue with the production of high-quality GRP pipes following the EFFECTIVE FILAMENT WINDING method.

ALFEBOR GRP pipes are manufactured utilizing the EFFECTIVE FILAMENT WINDING method and the latest technological systems delivered by TOPFIBRA.

For this reason, the products have a lifetime of 50 years, and are economical and advantageous due to the low maintenance costs.

ALFEBOR GRP Pipes are manufactured with lengths ranging from 6 m to 12 m with the possibility of customizing the finished lengths from 0.5 m to 16 m, based on the project requirements.

ALFEBOR GRP Pipes are manufactured with stiffness ratings ranging from SN 2500 N/m², SN 5000 N/m², SN 10000 N/m² with the possibility of manufacturing any stiffness required, as per project requirements.

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The method of EFFECTIVE FILAMENT WINDING reduces raw material waste and increases profit

Author: Fabio Fracasso

As in any industrial process, including the filament winding process, the problem concerning optimization of the consumption of raw materials has a strategic importance, from both an economic and environmental point of view.

The use of the correct quantities of raw material, including the limitation of losses due to waste or overdosing, involves various areas of the industrial process. The losses of raw material can be therefore be classified as follows:

1. Losses due to over-dimensioning of the product;
2. Losses due to overdosing;
3. Losses during the production process;
4. Product waste from off-cuts;
5. Non-compliant products.

Inherent to the Filament Winding technology, the difficulty in managing waste is amplified by a few aspects:

1. The high volume of waste (especially the end rings in the discontinuous filament winding process);
2. The non-recyclability of waste;
3. The difficulty of directing it to landfill;
4. The high costs associated to the above.

Let us look at some figures to better understand the problematics.

Fiberglass waste must be sent to landfill. The cost to do this in Italy is around € 250 / ton.

As far as the production of discontinuous filament wound pipes is concerned, the average value of the raw materials used and therefore wasted is around € 1.30 / kg.

Our research has shown that in a year of production of medium-large sized pipes (diameter 800/1200), a global consumption of about 5000 tons of raw material is in the norm. We measured waste percentages of around 7 %, which translated to around 350 tons.

The cost of landfilling was € 84.000. To this value, we need to add the value of the raw material related to such waste, namely € 455.000! In short, the company paid € 84.000 to send almost half a million Euros of raw/scrap material to landfill! And these values do not include the industrial processing costs (personnel, energy, equipment amortization, etc.).

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To conclude, the numbers related to the management of production waste are extremely elevated. Reducing the percentage of waste sent to landfills or, more generally, optimizing the use of raw materials, represents a resource for every company operating in this sector.

The EFFECTIVE FILAMENT WINDING method has been developed to ensure maximum benefit in terms of return on investment and profit for those who have invest or intend to invest in this technology. This method, which is transferred to the investor through specialized courses, focusses on the activities of the various industrial phases, leads to the generation of the flow of information, contextualized for each area, which leads to the improvement of the overall performance of the production process. The correct application of this method allows the waste to be transformed from a loss to a profit-making resource.

So then, which industrial phases does the EFFECTIVE FILAMENT WINDING method actually optimize?

In filament winding, you need to imagine an OBJECT which must first be ENGINEERED, then produced by HUMAN RESOURCES through a PROCESS in which you will use MACHINES and MOLDS, that need proper MAINTENANCE. You will therefore transform RAW MATERIALS and at the end of the production chain you will verify the QUALITY of this OBJECT. Each of the aforementioned phases will create a portion of what at the end of the process will be your PROFIT.

Let’s see how each of the aforementioned phases actually influences the correct use of raw materials.

ENGINEERING: the design of the product is the fundamental phase, in which a recipe is determined that must guarantee the performance of the component, for a certain period of time, with certain safety coefficients. There are several parameters involved and, if not correctly understood, can lead to over-sizing and therefore waste of raw material.

HUMAN RESOURCES: properly trained staff, which are involved in the business process, is a guarantee of efficiency. Personnel competence must be adequately updated to the ever-improving standards.

PROCESS: it represents a set of concepts, ranging from chemistry (concerning the formulation of resins), to mathematics (regarding winding trajectories), to the engineering of materials (regarding laminate composition).

“The EFFECTIVE FILAMENT WINDING method has been developed to ensure maximum benefit in terms of return on investment and profit for those who have invest or intend to invest in this technology.”

MACHINES: the quality of the components, correct automation management, automatic supervision

- Heavy duty bearings for high pressure and low speed rotation. Due to the 45 % lifetime increase, you will not need to stop your production for repairing or replacing

- New bearing position to increase the steel band lifetime and reduce the risk of overlap

- Fast change support block to drastically reduce the time for the diameter change operation

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models, are all aspects that can influence profits through efficiency and reliability.

MOLDS: the molds must be designed and manufactured with full technological competence. It may seem strange, but a badly conceived mold can lead to 20 % more of production waste, due to bad trajectories or difficulties in demolding operations.

> **Properly trained staff, which are involved in the business process, is a guarantee of efficiency.**

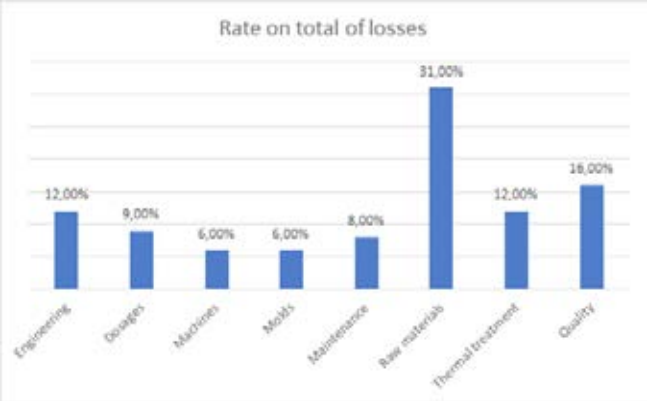
MAINTENANCE: the correct planning of routine maintenance and careful supply management of spare parts can guarantee better reaction times in case of failure, with a reduction of up to 15 % in the costs related to losses related to plant shutdown.

RAW MATERIALS: the filament winding technology is influenced more than any other technology by the correct choice of raw materials. An incorrect choice of raw materials, perhaps due to an apparent saving in the cost of purchase, can cause 60 % more losses from higher production costs, compared to a situation where conscious management of raw materials is carried out.

> **Quality control is the most important step and the tools to ensure this must be reliable and designed around your product and technology.**

QUALITY: before placing your product on the market, you must ensure that the quality thereof is in line to safeguard your reputation. This is no joke. Quality control is the most important step and the tools to ensure this must be reliable and designed around your product and technology. Do not underestimate this aspect, it could be the last thing you do.

As can easily be inferred at this point, each phase has an influence on the use of the raw material. The analysis carried out by examining the last 5 years of production showed that each of the phases described has an impact on the total waste and were traced back



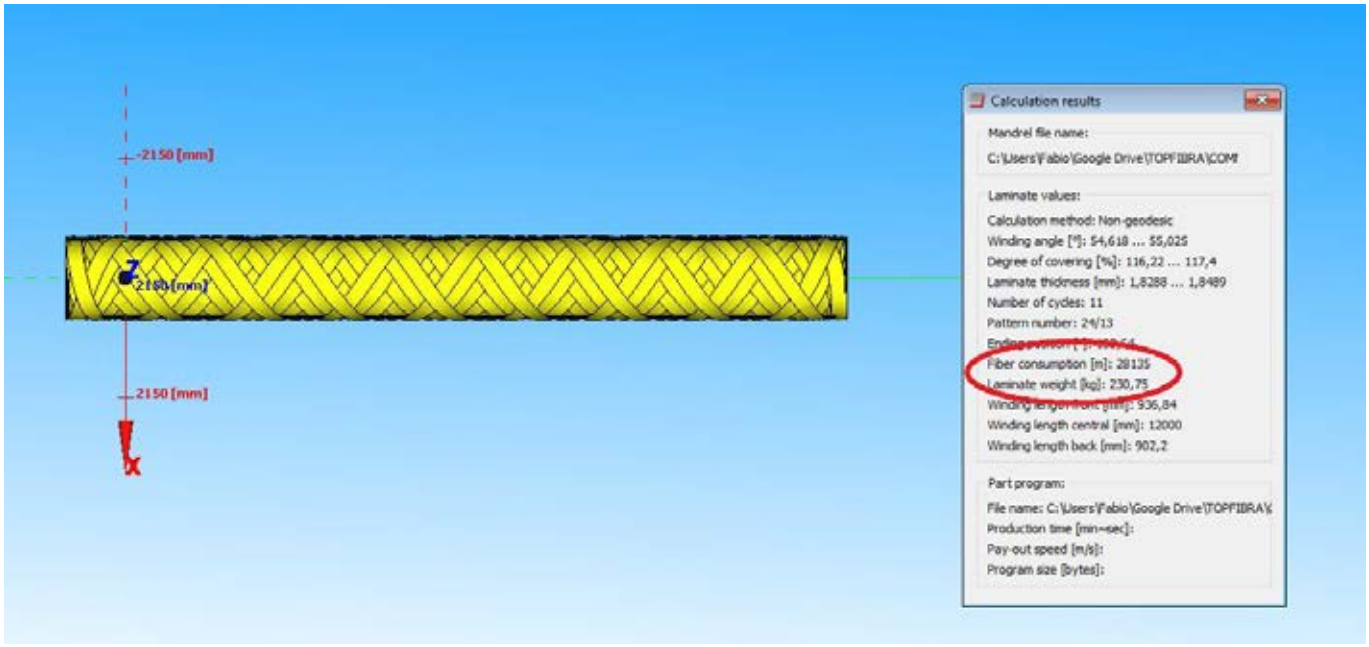
to inefficiencies on the management of raw materials. After the careful analysis of each phase and the study of the influence of each of these on raw material losses, and therefore on the related lack of profit, tuning of the required interventions is needed in each of these areas, aimed at optimizing the use of raw materials.

The method applied must have two characteristics:

- It must include a control and an intervention phase;
- The results must be measurable.

As an example, we illustrate an intervention carried out in the process and automation phases, that promoted a considerable saving of raw material in the production of fiberglass pipes.

As can be seen from the following images, the winding pattern strongly influences the amount of raw material used, ensuring in any case an equal mechanical performance. In this way, it is possible to obtain savings in raw materials of up to 10 %, by only intervening on the winding mathematics.



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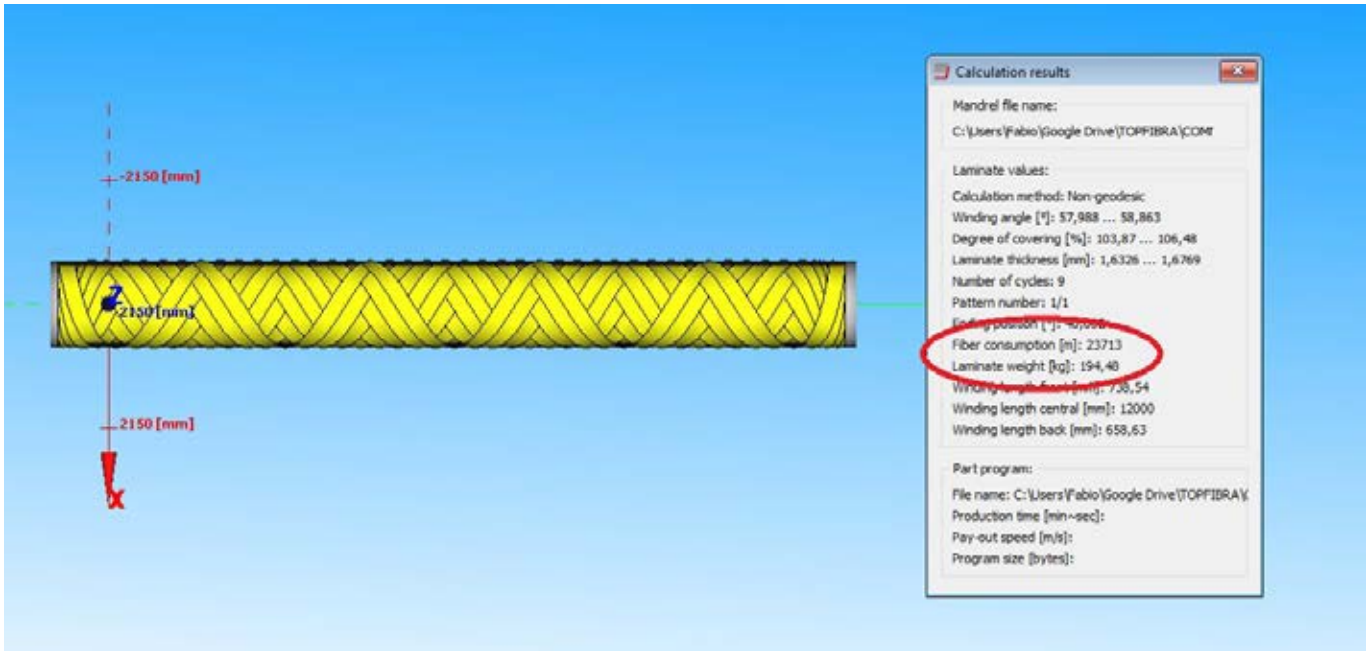

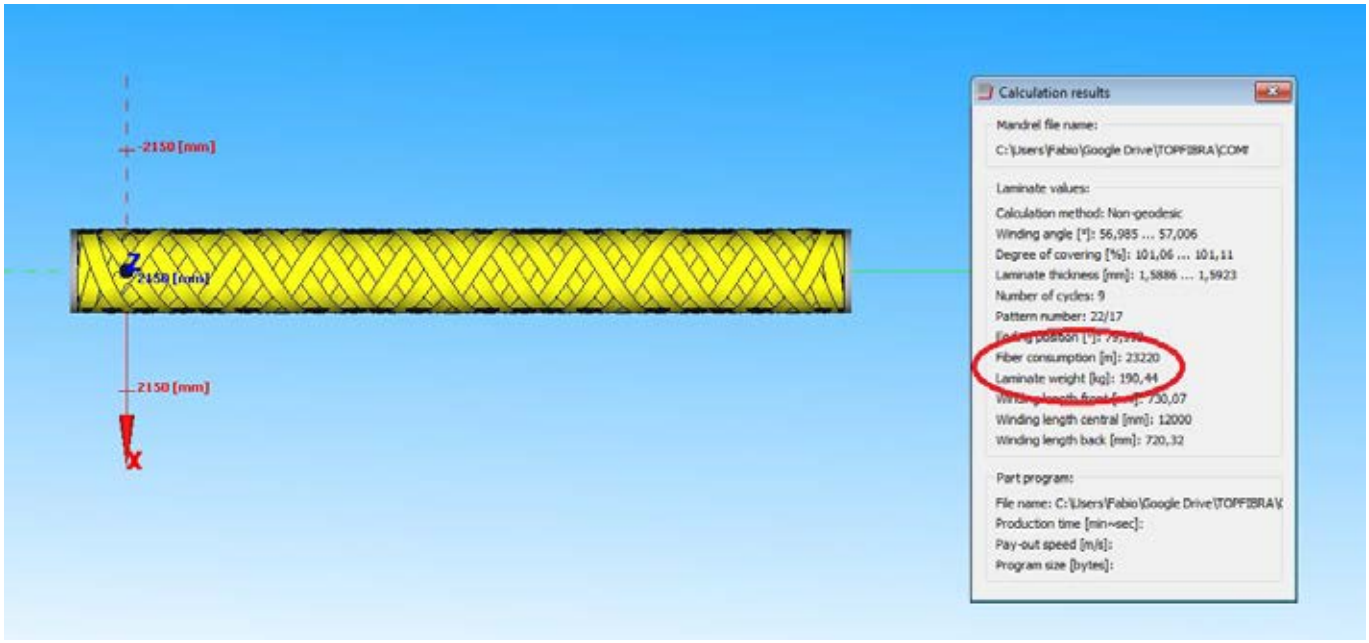

The intervention consists in the optimization of the winding machine, with the development of appropriate numeric controls, and the development of calculation models able to determine the best winding strategy

> **Process control systems have also been implemented, that have led to a production process with elevated automation levels, with increased stability and reliability.**

related to savings in raw materials.

Process control systems have also been implemented, that have led to a production process with elevated automation levels, with increased stability and reliability. In particular:

- In-line systems for controlled heating of the resins have been introduced;
- Flow meters with feedback on the pumping system were placed on the metering lines;
- Application systems have been developed on the molds to limit process losses.

Finally, personnel training was fundamental, through in-depth training sessions aimed at understanding chemical and process mechanisms and their optimization.

The industrial activities were monitored for one year and finally the results were analyzed and parameterized, in order to perform an analysis, independent of the product size and class, allowing comparisons with parameters from previous years.

The result showed that the incidence of waste of raw material had passed from the initial value of 7 % to a value of just over 4 %. This has made the company more competitive on the market by increasing overall efficiency and therefore profits.#

> **The result showed that the incidence of waste of raw material had passed from the initial value of 7 % to a value of just over 4 %. This has made the company more competitive on the market by increasing overall efficiency and therefore profits.**

GRP pipes – do you really know everything about them?

Author: Mauricio Facchinetti

Selling GRP pipes is much like dating.
Here's what most companies do: they go out into the marketplace, forcing offers onto prospects and asking complete strangers to marry them!
If you think about it in this way, it is quite difficult to convince technical offices to change the tenders, or investors to choose your GRP pipes. You need to have a clear approach and build the trust in the product, but, how can one do this properly?

In the following article you will find some information regarding GRP pipes, some details of which you probably already know, whilst other details will be new to you. Read it carefully and think about it from the prospective of the end users, so you will understand their concerns and fears, making it easier for you to hit the target.

There are several reasons why GRP pipes in many countries have been replacing conventional pipes, so one should keep this relatively new product in mind when evaluating a new or revamp pipe project.

In parallel, Engineers involved specifying GRP pipes should have a clear understanding of its nature and properties.

"There are several reasons why GRP pipes in many countries have been replacing conventional pipes, so one should keep this relatively new product in mind when evaluating a new or revamp pipe project."

You probably already know the main advantages of the GRP pipes, namely:

- Elevated corrosion resistance, because of the inert nature of the materials it is composed of, in comparison with cast iron and carbon steel. It is not unusual to design a GRP pipe for a working life of 50-60 years. Nowadays, some producers are estimating a lifetime of over 100 years. GRP pipes can be designed to resist corrosion from the inside and outside. In fact, with the aid of an internal-external barrier, and the use of correct resin barriers, the pipe can withstand varied corrosion environments;
- Lightweight construction is another major benefit. Typically, a GRP pipe has a weight of 35 % of that of a comparable carbon steel pipe, and 10 % of a comparable concrete pipe. The cost of handling, shipping, long-haul transport and site installation are significantly lower;
- Ordinary GRP pipes don't conduct electricity, and consequently have much better electrical properties than its steel counterpart. However, if electrical conductivity is required, it is possible to add conductive reinforced fiber or fillers during the fabrication process;
- Due to its composite structure, the GRP pipe can be designed to exactly match the project requirements, therefore leading to cost saving;

"Lightweight construction is another major benefit. Typically, a GRP pipe has a weight of 35 % of that of a comparable carbon steel pipe, and 10 % of a comparable concrete pipe. The cost of handling, shipping, long-haul transport and site installation are significantly lower."

- Surge pressure absorption is another plus of GRP pipe: they are designed to absorb 40 % of the surge pressure, without the need to increase the pressure class;
- GRP pipes possess a natural damping property. The fatigue endurance and strength to weight ratio are key attributes associated with replacement cost and the ability to design lightweight;
- Thanks to its smooth inner surface, friction loss is at a minimum, and it keeps this characteristic throughout its entire service life;

"Thanks to its smooth inner surface, friction loss is at a minimum, and it keeps this characteristic throughout its entire service life."

- low maintenance is another feature associated with these pipes, because they don't undergo the corrosive attack that the metallic counterparts have.

Many advantages, right?

In spite of these advantages, the decision makers must also consider some particular characteristics of the GRP pipes.

- To calculate the investments costs correctly, the investor must also consider the installation, erection and maintenance costs, to be able to compare these with other materials; if only the initial cost is evaluated, the project's figures will not be realistic;
- The market of composites is not as big as that of many traditional materials, so you can't consider a GRP as a commodity. It is a customized product that must be prepared for every single project, thus the delivery times may be longer than traditional materials;
- The design of a GRP pipe, as I said before, is performance based; in other words, the investor must take care in identifying the project requirements and true operating conditions, and only then share the information with the pipe supplier;
- The composite pipe manufacture should

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require that the investor adheres to specific instructions in order to ensure the long-term performance of the pipeline.

It is very important that the Engineers also understand the limitations of a GRP pipe, which also depends on the technology used to manufacture it. I have noticed, during recent years, that some projects have been influenced by strong marketing and miraculous promises from some pipe manufactures, leading to an incorrect use of the product.

For example, the performance of a Continuous Filament Winding pipe is very high on certain applications and lower in some other applications, the same applying to the Discontinuous Filament Wound pipe or the Centrifugally Cast GRP pipe.

Which one is the right one for your application and needs?

As I said before, it depends on your specific project, from the design to the installation method.

“For example, the performance of a Continuous Filament Winding pipe is very high on certain applications and lower in some other applications, the same applying to the Discontinuous Filament Wound pipe or the Centrifugally Cast GRP pipe.”

As indicated in one of my previous articles, we can generally say that the marine, industrial and oil & gas markets demand small quantities of pipe of medium to high pressures and with particular technical characteristics, so generally the pipes need to be produced with the discontinuous filament winding system. This concept is also applicable to the civil infrastructure market but is related to very small quantities and medium to high pressures.

If extensive lengths of pipelines are needed for civil infrastructure projects (over 1000 km), a CFW production line is recommended, also because the cost of produced pipe is 15-30 % lower compared to that produced with a discontinuous or centrifugally cast line.

If small quantities and low pressures are mostly called for by a particular market (for example sewer pipes for small works), a centrifugally cast line can be chosen, even though this system does not offer the flexibility of a continuous or discontinuous system.

All clear until now?

“The resin mostly used in the filament winding process are polyester, vinyl ester and epoxy resins.”

Let’s talk a little bit more about the Raw Materials, because you need to understand their properties if you would like to understand GRP pipes better.

The resins mostly used in the filament winding process are polyester, vinyl ester and epoxy resins.

What’s the role of the resin in a pipe? It serves as the “glue” that binds the fibers together in the pipe after the curing (when the resin sets). The pipe liner resin also provides the most definitive corrosion resistance to the transported fluids. Its chemical properties and physical properties play a key role in the pipe design.

The polyester resins used in the manufacturing of the composite materials may be classified as Orthophthalic, Isophthalic or Terephthalic resins.

The Orthophthalic resins are general-purpose resins, for water conveyance and sewerage applications. They are used for manufacturing laminates, which are not subjected to strong chemical attacks or weathering. From a thermal point of view, these resins are employed at ambient or medium-to-low temperatures. Mention must be made that the Orthophthalic resins should not be used for constructing the internal liner of a fiberglass pipe. Isophthalic resins find their most suitable end-use in the manufacture of pipes conveying waste liquids, drinking water and seawater, above or below ground. In fact, they are more resistant to corrosive substances present in the ground, to most salts and to mildly oxidizing acids at medium concentrations. This type of resin is always used for the internal liner of the pipe.

“Mention must be made that the Orthophthalic resins should not be used for constructing the internal liner of a fiberglass pipe. Isophthalic resins find their most suitable end-use in the manufacture of pipes conveying waste liquids, drinking water and seawater, above or below ground.”

Vinylester resins combine a greater resistance to chemicals with a high mechanical strength, also at high temperatures. Of course, they are more expensive than Polyester resins.

Finally, Epoxy resins are normally used for smaller diameters and for higher pressures, compared to other resins.

Besides the quality of the resin, decisive factors for obtaining an excellent final result are the types of glass employed, and the use of the same in the most appropriate manner for fully exploiting their structural properties.

Glass fibers are obtained with silica glass-based melting mixtures of inorganic materials, at temperatures varying between 1300°C and 1600°C. Under these conditions, the cross-linked structure of the silica is destroyed, its continuity is interrupted and its structure is modified by the introduction of other oxides.

“Epoxy resins are normally used for smaller diameters and for higher pressures, compared to other resins.”

The form of the fiber reinforcements varies considerably, depending on the pipe manufacturing process and the design load requirements. The major examples include directional fibers (roving), chopped fibers and fabric reinforcement forms (mat, woven roving, etc.). The actual fiber content in a composite depends on the end use design. The fiber orientation, the layup sequence of the laminate and the number of reinforcements determine the actual pipe stiffness, strength and mechanical properties.

The reinforcements used in the manufacturing of the industrial products, such as vessels, silos and pipes, are made starting from three different types of glass compositions:

- “C” glass which displays very good properties of chemical inertness to corrosive environment;
- “E” glass which is not so resistant to corrosion but displays a very high mechanical strength;
- “ECR” glass is similar to E-glass but without boron and fluorine. Due to the absence of these components, the chemical resistance (including water-resistance, acid-resistance and alkali-resistance) is greatly improved. When compared to the E-glass fibers, the ECR-glass shows higher temperature resistance, better dielectric strength, lower electrical leakage, and higher surface resistance.

In many cases, design and manufacturing of GRP pipes incorporate additional components. Many of these, including catalyst and hardeners, are processing aids for the resins and are necessary for the completion of the chemistry and curing of the laminate. Filler may be used to enhance the appearance, economy or performance of the pipe. Another role of the fillers is to increase the stiffness of the pipe structure.

If your intention is to maximize your return on investment in the composites market, utilising a filament winding technology, it is important for you to know that you will need to get the maximum capacities out of your raw materials.

Unfortunately, less than half of the existing manufacturing plants are optimizing their design, using the same pipe design regardless of the type of materials involved in the production.

“If your intention is to maximize your return on investment in the composites market, utilising a filament winding technology, it is important for you to know that you will need to get the maximum capacities out of your raw materials.”

This happens because many investors who, in good faith, followed the incorrect advice offered by the technology and machine suppliers, now find that they are the ones who have to face the wrath of the competitive market.

We have spent more than 16 years travelling, installing CFW plants (more than 35), helping companies to penetrate the market with the GRP pipes. We have developed and successfully applied our EFFECTIVE FILAMENT WINDING method, the first ever which guarantees profit making.

Our secret? Deep knowledge on the Filament winding process, hard work and effective steps to be implemented through an analytical method.

“Unfortunately, less than half of the existing manufacturing plants are optimizing their design, using the same pipe design regardless of the type of materials involved in the production.”

If you have a project and are looking for a company that can guarantee the reliability of the pipeline that your end customer deserves, without unpleasant surprises occurring during the installation even if the project is located in remote or complicated locations, thus ensuring you with maximum profits, then you seriously need to consider contacting me and my team.

Contact us by writing to us at support@topfibra.eu and together with my staff in TOPFIBRA, we will evaluate together with you to see if and how we can help.#

WE UNDERSTAND YOU NEED TO HAVE YOUR PROJECT EXECUTED CORRECTLY THE FIRST TIME ROUND, WITHIN YOUR BUDGET AND RIGHT ON SCHEDULE

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WE ARE READY TO HAVE A CONFERENCE CALL WITH YOU, COMPLETELY FREE OF CHARGE, to clear your initial doubts before you do the next move, upgrading or investing in your plant. Avoid the possibillity of putting the complete investment in high risk of failure.

Do you want to improve your continuous filament winding GRP production efficiency and immediately maximize your profits?

Author: Mauricio Facchinetti

Did you ever calibrate the resin pumps of a dosing system for GRP pipe production? Or maybe you saw your technician going up and down, weighting the resin, changing parameters, adjusting the pumps and trying his luck?

It is always a lottery. If you want to get really precise, you have to be sure that all the calibration steps have been carried out properly, hoping that the viscosity of the resin will be the same during the entire production phase.

If your intention is to maximize your return on investment in the composites market, utilising the filament winding technology, then this article is indispensable for you.

It is important for you to know that at present, only a few continuous filament winding machines are able to produce with performances which are equal or superior to the original average objectives.

Furthermore, the most disconcerting fact is that management continues to look for new solutions to reduce the production costs, to be more competitive on the market or increase the profits. Unfortunately, this continued search occurs because the management invested in a Continuous Filament Winding (CFW) Plant that does not allow them to be competitive enough, due to elevated scrap levels during production and the impossibility to reduce it, or the inaccurate dosing of raw material, and, even worse, due to the fact that they are producing with recipes or processes that are not optimized. With such initial conditions, is it clear that they cannot reach their cost targets?

“If your intention is to maximize your return on investment in the composites market, utilising the filament winding technology, then this article is indispensable for you.”

So, how does one solve these issues in a sure and rapid way? Let me reveal a secret to you: to correct the weak points on your existing manufacturing plant is much easier than you can imagine.

> **What is the role of the resin in a pipe? It serves as the "glue" that binds the fibers together after the curing.**

If your company is trying to optimise GRP pipe production and you want to ensure that you benefit from a rapid return on investment through profit maximisation, then you cannot refrain from reading on about one of the most important steps you need to take to ensure that every dollar invested will generate profits.

As you know, in GRP pipe production the most expensive raw material is the resin.

What is the role of the resin in a pipe? It serves as the "glue" that binds the fibers together after the curing (when the resin sets). The pipe liner resin also provides the most definitive corrosion resistance to the transported fluids. It's chemical and physical properties play a key role in the pipe design.

> **The recipe of a GRP pipe combines different materials such as resin, fibres, fillers, tissues, etc and the behaviour of such materials are not exactly the same in every manufacturing plant.**

But we need to put the exact quantity of resin because an excess of resin implies an increase in waste/ scrap and lower pipe specifications. Yes, you have understood correctly, if you put more resin than the exact needs for the pipe, you are spending money and producing an inferior quality pipe.

If you keep that concept in your mind all the time, I am sure that you can expect at least 2 things from your technology:

1- Obtain a good pipe recipe, where the quantity of the resin is the correct one for the laminate;

2- Obtain a machine that is capable to dose the exact quantity during the production.

Let's start addressing the pipe recipe.

The recipe of a GRP pipe combines different materials such as resin, fibres, fillers, tissues, etc and the behaviour of such materials are not exactly the same in every manufacturing plant. For that reason, during a production plant start-up, adjustments are needed to correctly calibrate the pipe design program. But such calibration can be done only if you are sure that the CFW machine is dosing correctly.

> **Unfortunately, and as I indicated before, most of the GRP plants are not performing well and have manufacturing cost that are 5-7 % higher than optimal due their outdated CFW dosing system.**

Now let's address the dosing system of a CFW machine.

Unfortunately, and as I indicated before, most of the GRP plants are not performing well and have manufacturing cost that are 5-7 % higher than optimal due to their outdated CFW dosing system.

If you want to understand why, read till the end of this article and you will find the answer.

NEW STEEL BAND FOR CFW LINES

Avoid low productivity in your plant due to steel band overlaps, breakages and fast wearing using our new steel band optimized for continuous filament winding process

- Hydrogen quench for a high-grade, clean surface, reduced wear & tear and longer life span, even for the production of diameters smaller than 600 mm, and to reduce your plant downtimes caused by steel band breakages

- Unique edge processing to reduce the risk of overlapping during production and increase your overall plant productivity

- Increased stability on the continuous filament winding machine mandrel

Feel free to contact us for more information by writing to
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Several years ago, when the continuous winders started to be installed in the composite market, the electronic systems were not well enough developed to assure a good dosing precision. The solution, at that time, was to choose good resin pumps that would perform their job well.

Before starting the production, the operator would start the calibration of the pumps knowing that the dosing would change slightly due to the resin viscosity, production speed, resin temperature, etc. Years ago, this solution was good enough because the market was not so competitive.

What about the new systems? The first bit of good news is:
NO MORE RESIN PUMP CALIBRATIONS ARE REQUIRED!
And the high precision dosing is constant for all pipe diameters.

“Before starting the production, the operator would start the calibration of the pumps knowing that the dosing would change slightly due to the resin viscosity, production speed, resin temperature, etc.”

The resin pumps have changed and they are not piston pumps anymore. The new gear or lobe pumps give a constant flow and they are PLC controlled by a mass flowmeter.

What does it mean?

It means that you don’t need to worry about resin temperature and viscosity variations, pump performance depending on the line pressure, production speed changes, etc. All is electronically controlled and the result is pure dosing precision.

Having a precise and reliable resin dosing system allows you to tune the pipe design program and avoid scrap and bad quality pipes.

“What about the new systems? The first bit of good news is: no more resin pumps calibrations are required! And the high precision dosing is constant for all pipe diameters.”

What about the catalyst?
The polymerization reaction is activated by the so-called initiator or catalyst. The initiator decomposes, producing chemical species called radical, which start the polymerization reaction with the polyester resin and styrene.

If the catalyst in the laminate is not dosed correctly, the polymerization will either be too fast or too slow, with terrible consequences in the end product and for the CFW machine.

If you talk with any CFW operator, he will confirm that the nightmare of any CFW machine captain is to have a problem with the catalyst dosing. A while ago, it was very common to hear the sentence: “The curing point is moving, be careful!”

The catalyst pumps were quite delicate because the quantities to be dosed are only 1-3 % of the resin quantities. The production speed was very important, to remain within the correct range, and the speed changes were done very carefully to give the pump enough time to balance the line pressure. And they also had to be calibrated!!

In few words: a real nightmare.

But now it is time for the second bit of good news:
NO MORE CATALYST PUMP CALIBRATIONS ARE REQUIRED! The catalyst pumps have been changed and they are not piston pumps anymore. The new

gear or pumps give a constant flow and they are PLC controlled by a mass flowmeter.

It means that you don't need to worry about manufacturing speed or speed changes any more, hoping to get the correct amount of catalyst. All is electronically controlled, and the result is pure dosing precision.

> **"No more catalyst pump calibrations are required! The catalyst pumps have been changed and they are not piston pumps anymore."**

If you want to avoid:

- that your products are not competitive, and your profit is continuously diminishing;
- that the average production scrap is constant or continuously increasing;
- that the lower productivity of your plant forces you to increase your selling prices or decrease your profits;
- that you have downtimes due to polymerization problems;
- that the pipe specifications of the finished products are lower than expected, with higher costs,

and you wish to obtain:

- stable GRP production, no more dosing problems;
- automatic and precise calibration;
- absence of resin excess in the laminate;
- high plant efficiency and higher profits,

then I am ready to have a conference call with you, completely free of charge, to clear your initial doubts on all the aforementioned issues and tasks, before you make the next move and to avoid placing the complete investment in a high failure risk situation.

Feel free to contact us for more information writing to support@topfibra.eu#

DO YOU WANT TO MAXIMIZE YOUR PROFIT IN THE FILAMENT WINDING INDUSTRY AND ENSURE THAT YOU BENEFIT FROM A RAPID RETURN ON YOUR INVESTMENT?

EFFECTIVE FILAMENT WINDING®

WE ARE READY TO HAVE A CONFERENCE CALL WITH YOU, COMPLETELY FREE OF CHARGE, to clear your initial doubts before you do the next move, upgrading or investing in a new plant. Avoid the possibillity of putting the complete investment in high risk of failure.

Feel free to contact us for more information writing to **support@topfibra.eu**

The key is to focus on the optimal filament winding process and production plant carefully calibrated for your business needs

Avoid that the most important project for your company becomes an insurmountable problem

Author: Mauricio Facchinetti

Have you experienced the feeling of when you are about to start a fascinating project where you place all your expectations and those of the company, which all form the basis of the success of your future strategies? But sometimes the reality isn't so beautiful and everything seems to become a problem, a tragedy, the solutions do not work and your future suddenly becomes bleak. If you are thinking that these situations depend on bad luck, let me reveal a secret:
In our world there are no misfortunes, but latent dangers that must be found and resolved before it is too late.

But sometimes the reality isn't so beautiful and everything seems to become a problem, a tragedy, the solutions do not work and your future suddenly becomes bleak. If you are thinking that these situations depend on bad luck, let me reveal a secret: In our world there are no misfortunes, but latent dangers that must be found and resolved before it is too late and, in this article, I decided to address them.

> **"In our world there are no misfortunes, but latent dangers that must be found and resolved before it is too late and, in this article, I decided to address them."**

Often the projects of a GRP pipeline (glass reinforced pipe pipeline) are underestimated, for the continuous reassurance that the final customers receive from the pipe producers and because some engineering designers or pipeline installers do not have specific experience to use the products correctly.

But what are the consequences when these projects are tackled without the proper methodology and staff?

To better explain what's happening, I have decided to tell you a story. It's about a high-pressure GRP line and if you have the patience to read all the way down, you'll find a lot of information that will help you to avoid big problems in the future.

Everything started one year and a half ago. In the middle of my working day I received a call where an important and structured company asked me for advice in order to produce large diameter and high-pressure glass-fiber pipes.

Having already successfully participated in more than 30 similar projects, I was very aware that basic information is essential. So, in order to deal with this request, I decided to organize a free conference call to better understand the project and help my potential client to make the first steps correctly.

Such starting information is for example the place where the project will be done, the type of soil, the annual rainfall, the natural drainage of the site, the pipeline route, the pressures involved, etc. Only after receiving this information is it possible to move on to a second phase and discuss other more technical details necessary to give the integral evaluation.

> **"The first analysis is extremely important because it allows me to frame the possible problems and help my potential client to have an immediate and overall vision of his project."**

The first analysis is extremely important because it allows me to frame the possible problems and help my potential client to have an immediate and overall vision of his project.

After a few days we organized a free conference call for half an hour and during this first telephone meeting came out the first chilling news: "The contract with the final customer has already been signed for the production of these pipes but the project has not yet been completed. The pressures in play exceed 25 bar (imagine that the pressure of a wheel of your car is 2 bar) and the dimensions of the pipes exceed two meters in diameter."

> **"Here we are once again, I thought, complex projects, faced by people who are certainly valid but without the specific experience to ensure an optimal result. And the end customer, who invests a lot of money by carefully calculating the expenses, receives reassurances from everyone until the first problem arises."**

After a moment of silence, I directly asked: "Is it clear that the project is not there yet? But at least the pipeline route is definitive? Does the designer have experience in high pressure GRP lines?"

The answer was even more worrying than the first statement when they explained that the designer had only sketched the layout and had little experience in pressure pipelines and even less in pressure pipelines in GRP.

Here we are once again, I thought, complex projects, faced by people who are certainly valid but without the specific experience to ensure an optimal result. And the end customer, who invests a lot of money by carefully calculating the expenses, receives reassurances from everyone until the first problem arises.

Changes in the pipeline route

Piping projects must include many aspects, such as the geological study, to understand not only the pipe installation conditions but also final operation of the line. When you are faced with a geological problem that would require large infrastructure works to be solved, you for sure will prefer to make a variant in the original layout to avoid big costs. The same can happen if there are strong interruptions to the natural drainage of rainwater or if, at some point, the necessary permits to complete the work are not obtained.

The changes in the route involve changes in quantity, changes in curves or reductions, or even in the type of piping but for sure the final cost will be much lower than big infrastructures with no guarantee on the final result.

> **"I know that right now you are thinking that it is difficult to always work with a definitive project and that these changes happen very often and I only can agree with you but I can assure you that the economic impact of these changes can be greatly reduced."**

I know that right now you are thinking that it is difficult to always work with a definitive project and that these changes happen very often and I only can agree with you but I can assure you that the economic impact of these changes can be greatly reduced.

How?

If from the beginning of the project you foresee a figure like ours that can interface with the various key project managers and coordinate the phases, getting the following advantages:

• Avoid the production of pipes that are not immediately necessary, evading the request for changes due to revisions of projects that involve higher costs, delays and unnecessary tensions with the pipe manufacturer, therefore you will not have to worry every time your project manager will call you, expecting the next "bad news"

• Help your Engineering department make the right decisions, clearly explaining the great advantages of fiberglass pipes, and the necessary precautions to avoid problems during the first tests then, you will be sure that all decision taken will be double checked and the cost will stay inside the initial budget.

• Help your logistics department in loading and transport plans by coordinating site activities with the progress of technical drawings, avoiding you problems with the transport companies or the pipe manufacturer

Problems with backfill material during installation

GRP pipes are flexible pipes and their installation has a strong impact on the final "performance". Studying the type of soil, the type of excavation material, the availability of suitable materials near the installation site, is of utmost importance but it is not enough.

If you want to save money and time, getting the best final project result then you have to find an optimal solution that, depending on the natural terrain, the type of piping and its route, allows a correct installation using as much as possible the materials that are nearby.

During the last 16 years, dedicating myself only to GRP pipes, I have seen many companies try to make such decisions by themselves or advised by consultants who are certainly capable but are not specialists, underestimating this problem, with devastating consequences in terms of line operation or extra expenses to find the "required" materials, traveling

crazy distances to bring them to the construction site. All clear so far? Well, let's go back to the conference call.

During the conversation with my potential customer, I underlined the risks of having to proceed without a definitive project, with a designer without the necessary specialization and without necessary information. I carefully analyzed the main features and the first steps to be taken because "if priorities are defined it is much easier to make the right decisions". But they felt safe, well supported by their consultants and their installation company, so finally, despite the warnings, they decided to move on by themselves. Their statement was:

"If you help us get the best quality pipes in the pipeline, we'll take care of the rest."

Have you ever been sure and convinced of an idea and after a few years you realise that your belief has changed so much that it is in opposition?

If we analyze a statistic of the problems suffered during the testing phase of these lines, the reasons due to the manufacture of the pipes affects less than 10 % but if we ask the end customers their opinion, their answer will most likely be: "The main problems could be due to factory production". Obviously, the product must be made and tested according to international standards and there must be a specialized third party that does the acceptance check but, having done a good job, you will have made about 10 % of the necessary to achieve the desired success.

Convinced of their position, they thanked me for the first half-hour conference call and they told me they would urgently need our services for testing during the production phase. On the same day, after a short chat, I received my order and payment.

The pipes were made, tested according to international regulations, the manufacturer was really good and with a good logistics they were sent to the final location of the project.

Two months after the arrival on site, we received the first call:
"The pipeline route has been changed. We have to request new fittings (special pipes) and other pipe quantities but the pipe manufacturer has just told us that he cannot produce them economically with such short notice and the price has tripled! We can't proceed with the pipeline, we are bleeding ourselves."

The pipes of high pressure and large diameter are always customized for the application and having to produce a few meters to compensate the project variations involves the following for the manufacturer:

• High costs, because the Plant has to set up the machine for a few meters of production.

• Slow reaction to the request because, being purpose made for each project, the producer cannot interrupt the ongoing production without the risk of being late.

After having explained the above-mentioned problems, they decided to restore the route but had to do important infrastructure works facing highunforeseen costs.

> **"We have got installation problems. The installer blamed the pipes, the manufacturer blamed the engineering and the engineers blamed the manufactures and the engineers."**

15 days later, I received a second phone call:
"We have got installation problems. The installer blamed the pipes, the manufacturer blamed the engineering and the engineers blamed the

manufactures and the engineers."

Conclusion: other unexpected costs.

They asked me to intervene immediately, to analyze the project, assess the damage and supervise it to proceed with the immediate repair and complete the installation.

"But why did I want to tell you about this episode? And why should you pay extra-attention too?" Because you have to be very careful.

These projects can go smoothly like oil when we immediately tackle and solve all possible critical issues. But if they are not followed from the day 1 by those who can prevent the potential problems, the costs to repair them will be much higher than the initial savings. Repairing, restoring, correcting is always possible but the costs are much higher and you experience stressful situations that can be avoided.

> **"If you want to avoid that your project becomes your nightmare that does not make you sleep at night, I'm the only one who, with the method of Effective Filament Winding, can prevent and solve the hidden dangers, avoiding that your money will drain or that your staff suffers serious accidents."**

How does the story end?

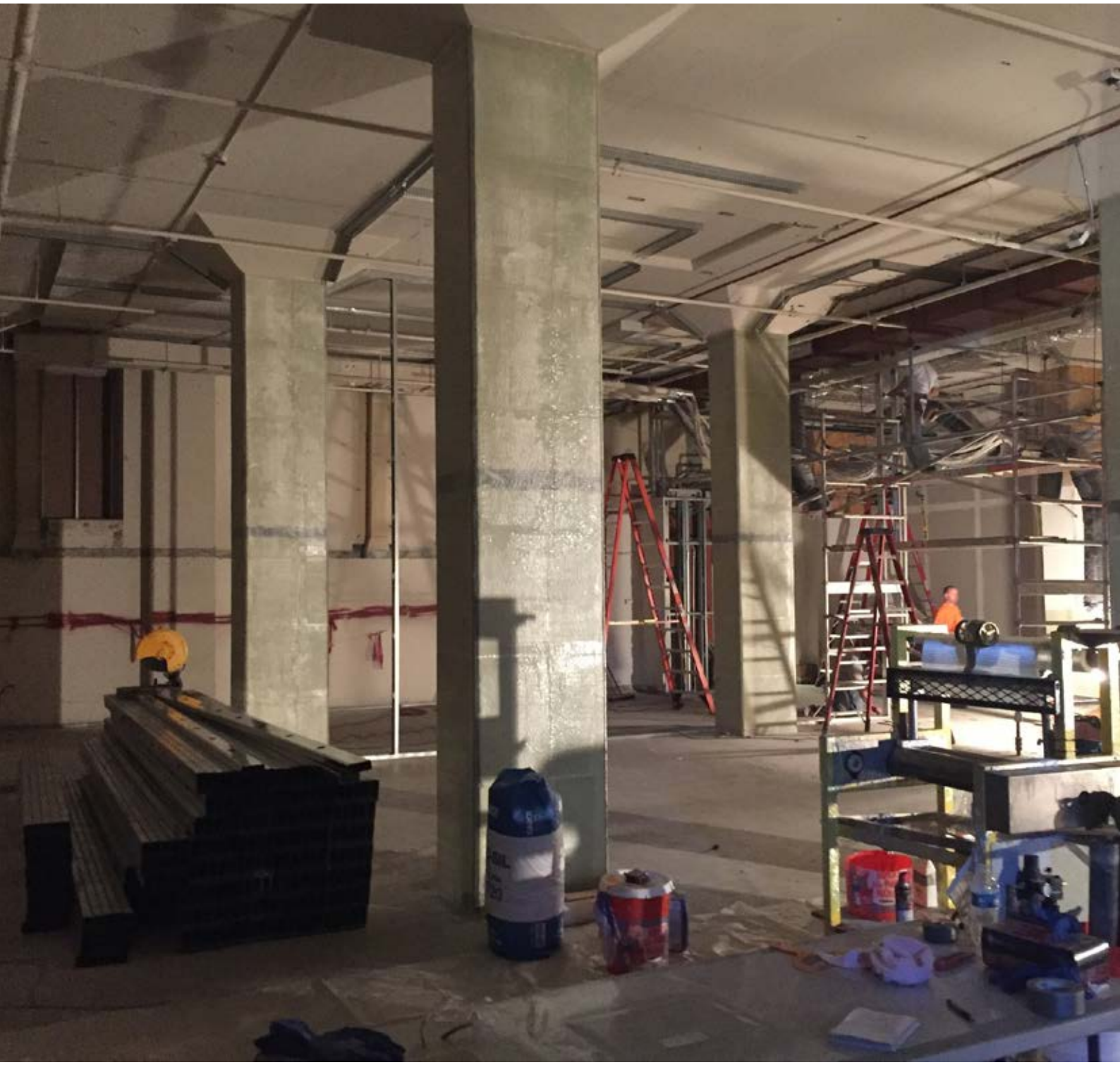
They entrusted us with the repair and testing of the line, we found and provided solutions for tracing problems, support works, repaired the pipes, and put the lines into operation but without doubt, utilising a much greater effort than if they would have involved us on all the phases from the first day.

During the final meeting, happy to have come out of a critical situation, they told me they made a big mistake, spending 10 times more believing that they could have saved money during the early stages. It is a situation that we have experienced several times, and it could happen to you, even if you think you have done everything necessary to avoid it.

If you also have a project and looking for a company that can guarantee the reliability that your end customer deserves, without unpleasant surprises during the installation even if the project is in difficult locations then you probably need me and my team.

We study your case and offer you the best solution for your project and budget, taking responsibility for every decision and action taken.

If you want to avoid that your project becomes your nightmare that does not make you sleep at night I'm the only one who, with the method of Effective Filament Winding, can prevent and solve the hidden dangers, avoiding that your money will drain or that your staff suffers serious accidents.#



Innovative technologies for FRP confinement of concrete elements

Author: Mauricio Facchinetti

Wrapping of concrete columns using Fiber Reinforced Polymer (FRP) confinement can significantly improve their structural behavior. In this article we show the analysis of the experimental and remarkable results especially about the rectangular sections, encouraging to performing other tests on large-scale elements.

The main properties of Fiber Reinforced Polymer (FRP) materials (high specific strength and stiffness, low thickness and weight, high resistance to corrosion), allow them to be conveniently applied in the civil engineering field.

In particular FRP-confinement has been recognized as an efficient method for structural rehabilitation and strengthening of reinforced concrete columns.

Several experimental studies and pilot applications have demonstrated that a confining action on concrete is obtained by wrapping vertical elements with FRP jackets, improving strength and ductility of the whole element.

In this article you will read two innovative techniques for FRP confinement of concrete, both based on the automatic wrapping of reinforcing tows.

> **“Several experimental studies and pilot applications have demonstrated that a confining action on concrete is obtained by wrapping vertical elements with FRP jackets, improving strength and ductility of the whole element.”**

EXPERIMENTAL PROGRAM

Specimens involved in the experimental program are different in terms of cross section geometry (circular, square and rectangular), the presence of full/hollow core and resin impregnation technique.

> **Specimens involved in the experimental program are different in terms of cross section geometry (circular, square and rectangular), the presence of full/hollow core and resin impregnation technique.**

Concrete specimens, resins and reinforcing fibres

A total of 42 specimens have been tested, which included 30 FRP wrapped specimens and 12 plain concrete specimens. The used concrete mix had the ratios of water/cement, sand/cement, gravel/cement of 0.5, 2.5, 1.7, while the coarse aggregate consisted of crushed stone with a maximum size of 9 mm. All specimens have been cured for 60 days at a temperature of 20°C and a relative humidity that exceeded 60 %. A minimum of 3 samples for each specimen have been prepared.

Tenax carbon fibers (STS 5631, 1600 TEX, F24000) have been employed for all experiments, and they have been used for the reinforcement of vinyl ester resins. The choice of the resin systems and the additives mixing have been done by considering the impregnation and winding methods.

Automated tows winding machine

An innovative automatic wrapping machine has been designed and built in order to realized the carbon tows winding around concrete cylinders and prisms. The main features of the prototype machine can be summarised as follows:

- a circular guide allows the relative movement of the bobbin with respect to the sample. The guide can be open in order to install the machine around the concrete element;
- a vertical linear guide with a belt transmission assures the relative movement along the vertical axis;
- the bobbin unwinder, positioned on a trolley moving on the linear guide, and equipped with yarn guiding and tensioning device.

The winding geometry has been purely hoop, and obtained by the right combination of the vertical and circular movement of the tower supporting the bobbin. The band width of the single tow wound on the surface has been 5 mm. At the maximum revolution speed of the machine, ω =3.37 rpm, the vertical step has been h=5 mm per turn and the winding angle about 89.8°.

Impregnation processes: wet winding and infusion of dry wound fibers

In the wet-winding FRP confined samples, resin impregnation has been realized during the wrapping step; while in the samples obtained by VARTM the resin has been infused after the dry tows have been positioned by the same winding machine. In both the cases resins cured at room temperature and catalysis has been set-up in order to guarantee the proper pot-life during the process.

For the wet winding process, two pure resin layers have been placed, the former applied on the sample surface in order to smooth the surface and prepare it for the wrapping, the latter has been applied above the last FRP layer acting as a protective liner. The

> **Therefore an high viscosity resin has been employed for the wet winding process, in order to achieve the proper impregnation.**

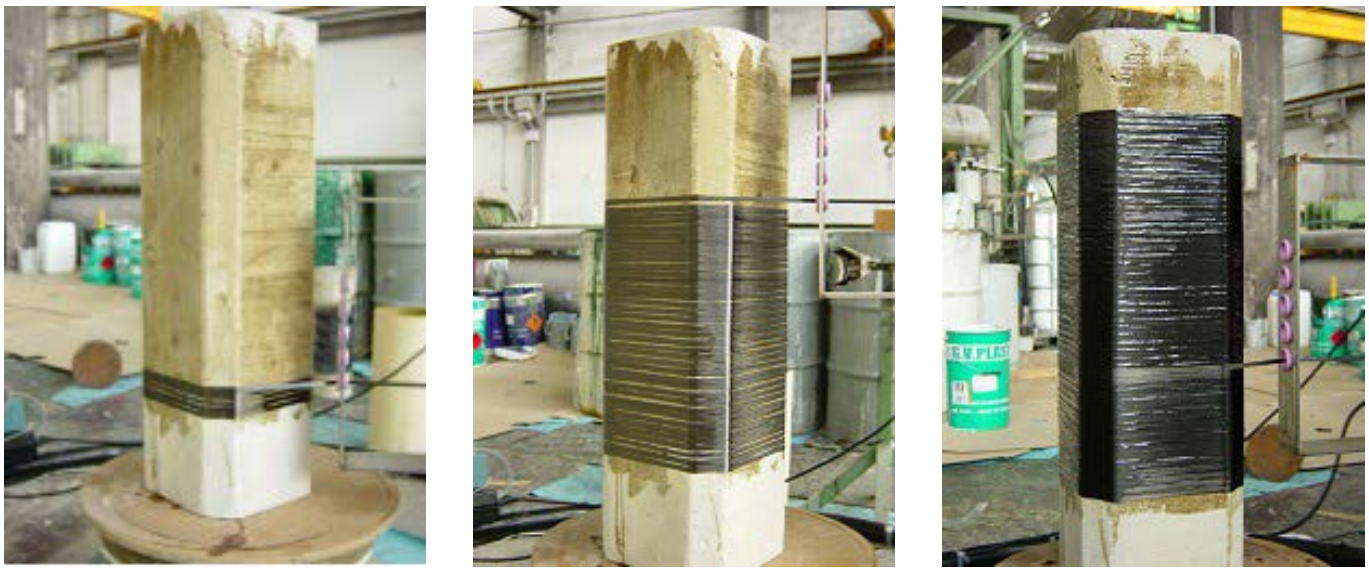


FIGURE 1: *Wet –winding confined sample*

impregnation has been realized during the winding process by using brushes and finishing rollers. Therefore an high viscosity resin has been employed for the wet winding process, in order to achieve the proper impregnation.

In the case of infusion technique, a typical Vacuum Assisted Resin Transfer Moulding (VARTM) scheme has been adopted and a very low viscosity resin used. Before resin impregnation, every specimen has been dried for 2 h at 65° C in order to remove moisture from concrete and from wrapped fibers, than the peel ply and an high-permeability distribution medium have been applied and a vacuum bag has been used to seal the assembly as shown in Figure 2. Vacuum has been pulled inducing fiber compaction under atmospheric pressure and drawing liquid resin into the reinforcement through the injection line.

At the end of the impregnation process, good fibre impregnation and adhesion to concrete have been evidenced for every cylindrical specimens obtained

A B C

FIGURE 2: *VARTM- vacuum bagging (A-B); confined concrete cylinder (C)*

by the two techniques, due to the geometry and not to the chemical affinity. Only minor non-impregnation defects have been observed in correspondence of concrete voids or inclusions. In the case of prismatic samples, a good resin impregnation but a very bad composite adhesion to concrete have been observed. Besides, vacuum micro-leakages have been noticed, due to high concrete porosity and defects, and this has led to not desired resin paths.

> **In order to avoid that the axial load be applied directly on the fibres, the end rings of the composite shell have been cut away by means of a diamond wheel, producing a narrow gap of about 3 millimetres between the end surfaces of the concrete core and the end of the composite shell.**

Compression tests

Before the compression test an additional step has been necessary. In order to avoid that the axial load be applied directly on the fibres, the end rings of the composite shell have been cut away by means of a diamond wheel, producing a narrow gap of about 3 millimetres between the end surfaces of the concrete core and the end of the composite shell. Then, specimen has been subjected to compression load and axial and radial displacements have been monitored by properly located displacement transducers.

RESULTS AND DISCUSSION

Collapse of FRP wrapped specimens has been due to fibres rupture; failure occurred in a sudden and explosive way and ha been only preceded by typical creeping sounds. Cylindrical and prismatic specimens after failure are shown in Figure 3; fibre rupture in prismatic columns occurred close to the corner regions, as expected from theoretical considerations,

> **Cylindrical and prismatic specimens after failure are shown in Figure 3; fibre rupture in prismatic columns occurred close to the corner regions, as expected from theoretical considerations, then delamination spread towards the entire section.**

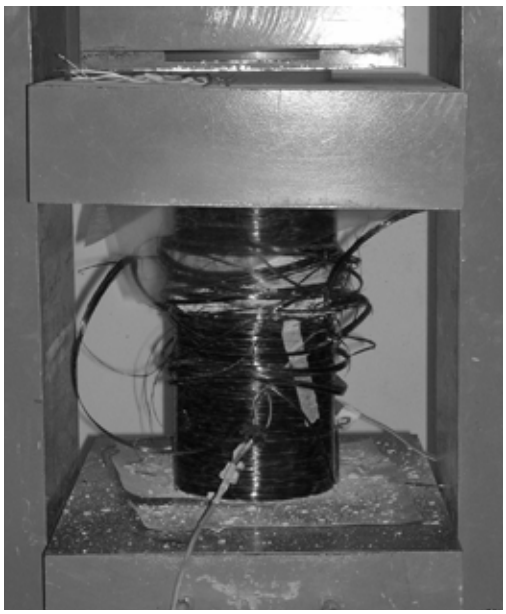


FIGURE 3: *Typical specimens failure*

then delamination spread towards the entire section. Table 1 summarizes the specimens involved in the experimental program and the average experimental results. The specimen designation can be interpreted as follows: the first letter represents the cross section geometry ("C" for Circular, "S" for Square, "R" for Rectangular), followed by the presence

LABEL	Dimensions [mm]	Hollow core dimensions [mm]	Technique	No of plies	Compressive strength (MPa)	Axial strain (%)	f'cc / f'c	εcc /εc
NCF1-2	150x300	0	-	-	25.52	0.50 %	-	-
CF1	150x300	0	Wet	1	45.34	2.06 %	1.78	4.15
CF2	150x300	0	VARTM	1	47.10	1.61 %	1.85	3.24
NCH3-4	150x300	50	-	-	13.11	0.47 %	-	-
CH3	150x300	50	Wet	1	48.81	2.52 %	3.72	5.36
CH4	150x300	50	Wet	2	62.46	4.39 %	4.77	9.35
NCH5-6	250x500	50	-	-	16.44	0.41 %	-	-
CH5	250x500	50	Wet	1	27.06	0.98 %	1.65	2.38
CH6	250x500	50	Wet	2	33.37	2.20 %	2.03	5.36
NSF7	150x150x300	0	-	-	26.46	0.62 %	-	-
SF7	150x150x300	0	Wet	1	35.41	1.64 %	1.34	2.67
NRH8-9	150x300x600	200x50	-	-	14.67	0.40 %	-	-
RH8	150x300x600	200x50	Wet	2	22.45	1.92 %	1.53	4.83
RH9	150x300x600	200x50	VARTM	2	18.61	1.85 %	1.27	4.66

TABLE 1: *Experimental results*

of the hollow-core ("H" for Hollow or "F" for Full) and the resin impregnation technique ("Wet" for Wet winding, "VARTM" for Infusion). The increase in terms of compressive strength (f'cc/f'c) and deformation (εcc/εc) is shown in the same table. The label "N" stands for Not confined specimen.

For all the FRP wrapped specimens an improvement of the mechanical properties has been registered with respect to plain concrete, in different amount according to the number of FRP layers, cross-section geometry and resin impregnation technique.

Cross section shape influence

Circular sections

For circular full-core sections the stress-strain curves of FRP confined concrete are bilinear with a transition zone, as expected according to theoretical considerations. The slope of the first part of the curve (i.e. the one of the initial elastic zone) is not substantially altered by the presence of FRP, as the confined and the unconfined specimens behave in the same manner. The strengthening effect of the FRP jacket begins only after the attainment of the unconfined concrete strength: at this stage there is a large lateral expansion of the damaged concrete, so that the transverse strains are able to activate the confining pressure of FRP.

In the case of circular shape the section is fully confined, therefore the slope of the second part of the curve is positive, showing the capacity of confining pressure to limit the effects of the deterioration of the concrete core, allowing the attainment of higher stresses.

The same behaviour is exhibited by circular sections with smaller dimensions of the hollow core. When the dimensions of the hollow core increase, the initial slope remains unchanged also after the reaching of the maximum stress of unconfined concrete. The

second branch is almost a plateau with null slope, due to damage occurred inside the regions that are not affected by strengthening action of FRP. Spalled concrete has been observed inside the hollow after test. Significant increases of both strength and deformation capacities have been measured (see Table 1).

Square and rectangular sections

Related to square sections, it is evident that in this case confinement is less effective than for circular sections, due to the unconfined regions far from the corners.

The same behaviour is evident in the case of prisms with hollow rectangular section strengthened with different techniques, as explained better later. The presence of the typical last branch of the curve testifies the activation of confinement, with remarkable increase of both strength and ductility.

Effect of the number of FRP layers

The effect of the FRP amount has been studied on circular sections (series CH3-CH4 and CH5-CH6). From the obtained results, reported in Table 1, it can be concluded that the increase of the composite thickness results not only in an increase of compressive strength, but also in a remarkable increase of deformation capacity.

> **"It can be concluded that the increase of the composite thickness results not only in an increase of compressive strength, but also in a remarkable increase of deformation capacity."**

Manufacturing process influence

FRP confined samples with circular full-core section, obtained with different resin impregnation technique exhibit a similar behaviour. As explained before, in circular sections confinement effectiveness is mainly due to geometric factors. Therefore, there are not significant differences between the samples impregnated by wet lay-up and those impregnated by VARTM process.

In the case of prisms with hollow rectangular section, resin impregnation technique effect is more significant. In fact, although FRP presence is cause of compression strength and axial strain increases in both samples series, samples confined by wet winding process show better performances than those confined by dry winding VARTM. The reason of this surprising result is most probably due to different composite thickness as result of the intrinsic differences between the two processes and of different resin amount. Samples obtained by wet lay up have higher FRP thickness thanks to resin accumulation and to lower compaction especially in the zones far from the corners. In this case, the better contact between composite and concrete caused by the resin accumulation, results in a smaller unconfined region of the cross section, thus causing a better confinement of the concrete element.

CONCLUSIONS

In this study two different application techniques for FRP confinement of concrete columns have been analysed and compared: wet lay-up and VARTM (Vacuum Assisted Resin Transfer Moulding). In both processes an innovative automatic wrapping machine has been used for winding the carbon tows. Remarkable increases of strength and ductility have been registered both for circular and rectangular sections.

The comparison of the test results with other experimental studies [6, 7] carried out by the authors on similar specimen reinforced with CFRP sheet (having the same basis weight and equivalent mechanical properties of the FRP reinforcement adopt herein) by means of hand lay up technique, shows equivalent performance, as expected, encouraging to investigate these innovative techniques on large-scale elements. #

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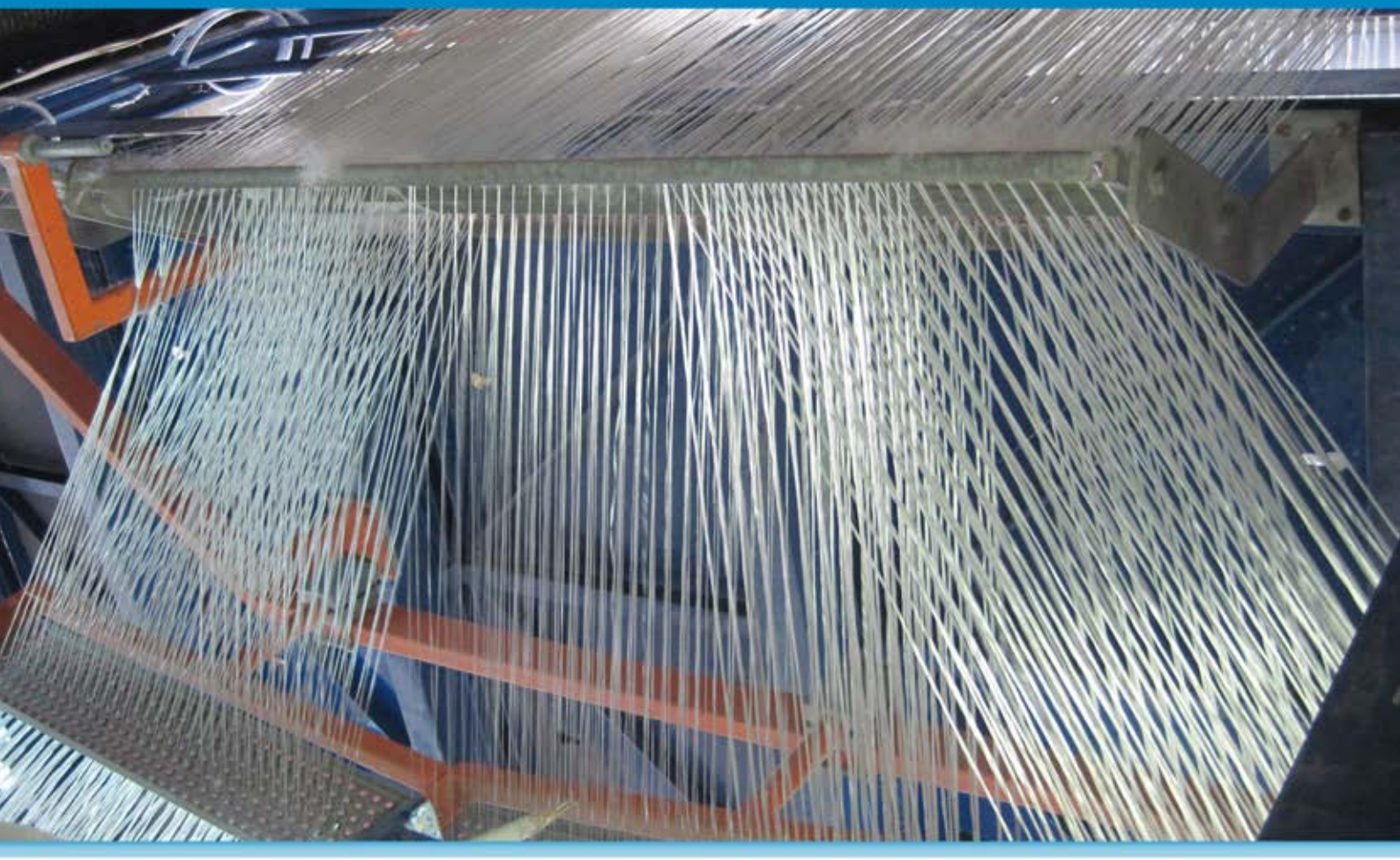

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