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Fiber glass and "green" special composite materials as structural reinforcement and systems; use and applications from Milan Metro, Brenner Tunnel up to high speed train Milan – Genoa

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ABSTRACT: Glass Fibre-Reinforced Polymer (GFRP) is nowadays a common practice in tunnelling; they are used in several applications as provisional structures, in a safe and cost effective way. Classical example is the so called "soft eye" where a TBM has to pass. GFRP bars have a much higher tensile strength than steel rebars, they are easily machined and can be broken down into small pieces by the cutter head and can then be transported by the conveyor system together with the spoil. We'll describe other different applications of this kind of material as structural elements in the conventional tunnelling, manual constructed reinforcement cages in big launching shafts, ending in special products in the railway industry, where the anti-galvanic corrosion properties are unique. Maplad is working also on special basalt fiber polymer elements, which show increased mechanical and physical properties, most probably the product of the next future.

1 GLASS FIBER REINFORCED POLYMER PROFILES

1.1 *The material*

Fiber reinforced plastic (FRP), also known as fiber reinforced polymer, is a composite material made up of a polymer matrix blended with certain reinforcing materials, such as fibers. The fibers are generally basalt, carbon, glass or aramid; in certain cases, asbestos, wood or paper may be used as the fibers. Composite material is greater than the sum of its parts. The matrix, which is the core material devoid of fiber reinforcement, is hard but comparatively weaker, and must be toughened through the addition of powerful reinforcing fibers or filaments. It is the fiber which is critical in differentiating the parent polymer from the FRP.

The matrix is composed of unsaturated resin as the polymer (normally used are polyester or vinylester and sometime, for particular applications, different resins are used, but hardly for profiles intended for the construction market).

Catalysts and additives are added in the batch with the resin.

1.2 *Pultrusion process*

In the traditional pultrusion process the fibres are pulled from a creel through a resin bath and then on through a heated die. The die completes the impregnation of the fiber, controls the resin content and cures the material into its final shape as it passes through the die. This cured profile is then automatically cut to length. Fabrics may also be introduced into the die to provide fiber direction other than at 0°.

To make the rebars, it is used a different process: the fibers are pulled from creel through a resin bath, cross a ring used to define the diameter of the rebar and they are wound by a

Table 1. Comparison between GFRP and other traditional materials.

Property	GFRP	Steel	Aluminum	PVC	Unit
Density	1.8	7.8	2.8	1.4	g/cc
Tensile strength	300–600	370–500	200–400	40–60	MPa
Flexural resistance	400–450	330–500	200–400	70–100	MPa
Elastic modulus	25–30	210	70	2.8–3.3	GPa
Bending modulus	15–20	210	70	2.8–*3.3	GPa
Tensile elongation	1.5–2.0	13–35	5–35	10–80	%
Impact resistance	200	400	200	85–95	MPa/m^2
Thermal conductivity	0,25–0,35	100–230	100–230	0,15–0,25	W/m°C
Dielectric capacity	5–15	-	-	40–50	KV/mm
Volumetric resistance	10^{10}–10^{14}	0,2–0,8	0,028	$>10^{16}$	ωcm

transversal thread that reduces the section so as to create the improved adhesion of the profile. Catalysis does not take place inside the molds but through ovens.

Pultrusion is a continuous process, generating a profile of constant cross-section.

1.3 *Comparison with other materials used in construction and advantages of GFRP*

The following table, Table 1., shows the average values of the main mechanical and physical characteristics of the profiles in GFRP in comparison with other materials mostly used in constructions.

We can deduced that the GFR profiles are light materials with elevated mechanical features able to replace the steel profiles, but at the same time electrically insulating, with low thermal conductivity resistant to chemical agent; similar characteristics to plastic materials.

The GFRP profiles are also characterized by UV resistance, discoloration resistance and, being a light material, easy to install and assemble.

2 GFRP IN THE TUNNELING'S INDUSTRY

2.1 *Slope and face stabilization – Adeco Technique*

The ADECO-RS (Analysis of Controlled Deformations in Rocks and Soils) is a design philosophy that places at the center of the design of an underground work the deformations that occur in the middle in which the excavation proceeds, analyzing them in depth and identifying their more effective systems to control them.

It was born about 30 years ago from a theoretical/experimental research during which modern constructive technologies were developed - including the reinforcement of the core-face with fiberglass reinforcement - and they were severely tested in the field.

The method focuses attention on the study of the Deformative Response considering:

– the medium through which construction takes place,
– the action taken in order to accomplish the excavation and
– the reaction (or Deformation Response) produced following the above-mentioned action.

The medium is the terrain which, in depth, is subject to triaxial stress states.

The action is produced by the advancement of the excavation front at a determined speed V and causes a stress perturbation in the surrounding soil both in the transverse and longitudinal direction altering the pre-existing tension states.

The speed rate V depends as well to the excavation system used (mechanized or conventional): high speed rates reduce the propagation of the perturbation, influencing the Deformation Response which conditioned by the choice of the excavation system.

The ADECO-RS works on the base of three different components of the Deformative Response:

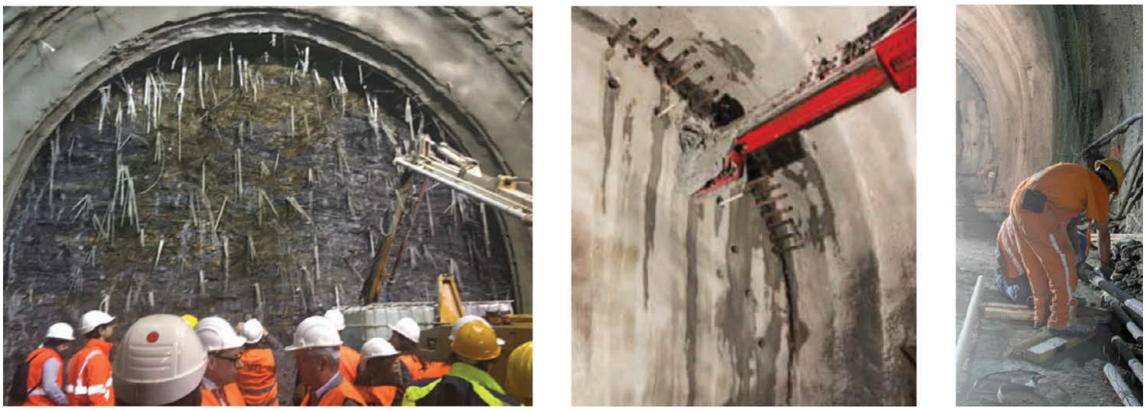

Figure 1. TOTO S.p.A., job site La Spezia. SIG at visit, drilling and manual long bar junction procedure.

- the extrusion, its primary component, which largely gets within the core and manifests itself, in correspondence with the surface delimited by the excavation face, in a longitudinal direction to the axis of the tunnel;
- preconvergence, identified as a secondary component of the Deformative Response;
- convergence, identified as the third component of the Deformative Response.

According to the ADECO-RS the convergence, therefore, is only the last stage of a very complex deformation phenomenon that originates upstream of the excavation face in the form of extrusion and preconvergence of the advance core and then evolve downstream of the same in the form of convergence of the cavity.

The novelty of the ADECO-RS is to always advance to full section and stabilize the excavation by first intervening on the ground upstream of the front using the core as a "control tool" upstream and the immediate closure of the pre-covering with the inverted arch as a downstream control instrument.

The ADECO-RS, having understood the true genesis and evolution of the Deformative Response, concentrates all efforts on the control of the extrusion which, being the "initial stage" and the source of the deformation process, if properly maintained in the elastic field, evolves towards preconvergence and convergence phenomena also in the elastic field, thus allowing to minimize the thrusts on short and long-term coatings.

The same method identifies three categories of fundamental tensile-deformational behavior:

- category A or stable core-face behavior;
- category B or short-term stable core-front behavior;
- category C or unstable core-face behavior.

It is therefore evident that in order to stabilize a tunnel during excavation in the short and long term (Figure 1), type B and type C behaviors must be reported to category A, intervening on the stiffness of the advance core by means of conservative pre-assembly of the cable and, subsequently, regulating, downstream of the excavation face, the extruding manner of the core-face, by closing and stiffening the first phase covering, close to the front, with the inverted arch.

The analysis and the control of the Deformative Response play a fundamental role as indispensable steps to design and correctly realize a work in the underground:

- the analysis must be performed using suitable analytical or numerical calculation tools based on the forecasts made and the designer must also make the necessary operational choices, in terms of systems, phases, digging cadences, consolidation and stabilization tools;
- control takes place at the "construction moment", when, by proceeding with the excavation, the design choices are made and verified by the measurement of the Deformative Response of the means to the actions implemented.

  It follows that to correctly design and build a work in the underground is essential:
- in the planning phase:
  - preliminary study of the tenso-deformative behavior (Deformative Response) of the ground, in the absence of stabilization works;

- define the type of pre-containment or containment actions necessary to regulate and control the Deformative Response of the excavation vehicle;
- choose the type of stabilization work;
- to compose, according to the expected behavior of the ground, the typical sections defining, in addition to stabilization interventions more appropriate to the context in which it is expected to operate, phases, cadences and times of implementation of the same;
- sizing and checking, the selected interventions to achieve the desired behavior of the excavation and the necessary safety coefficient of the work, also providing the tensile-deformative behavior of the same thus stabilized;

- under construction:
  - verify, during construction, that the tunnel's behavior during the excavation is the same as that foreseen by analytical way during the design phase. Then proceed with the development of the project by balancing the weight of the interventions between the core-front and the perimeter.

2.2 *Diaphragms walls and piles – Soft-eye Technique*

For several decades, TBM's have been used for the construction of tunnels. Depending on the local situation, the TBM may be placed at the start or at the end of its drive; for example maybe in a precut in the open terrain or maybe by lowering it into an excavation shaft down to the tunnel level. This latter technique is used mostly in congested city areas. A few years ago, starting and receiving a TBM in an excavation shaft required extensive measures such as breaking through the walls of the shaft, which are secured out of steel reinforced concrete. This preparation work needed time and has been expensive. In recent years however the use of Soft-Eyes in these areas are becoming more and more popular. A Soft-Eye may for example be a diaphragm wall or bore piles reinforced with Glass Fiber Reinforced Polymer bars (GFRP) instead of reinforcement out of steel. Also an anchored tunnel face with GFRP anchors will not obstruct the TBM head driving through. The use of GFRP products in tunnelling is getting more and more common in Southeast Asia and is widely applied in Europe and Japan nowadays.

Soft-Eyes consist usually of bore piles or diaphragm walls, which are locally reinforced with GFRP bars. The sections below and above the tunnel are reinforced conventionally. Depending on the designer and contractors preferences, full rectangular sections are built out of GFRP bars and the fiber reinforcement follows more closely the tunnel section resulting in a circular arrangement of the GFRP links or may be a circular sections.

Both possibilities have their advantages. While a rectangular arrangement saves time during the design and assembly of the cages, following more closely the tunnel section thus reducing the material costs for the GFRP bars. Often applied as a compromise, where the vertical bars cover a rectangular section, while the shear links follow the circular layout. Experience shows that this approach decreases the material costs for the GFRP material by less than 5% still maintaining the detailed design and managing the assembly of the cage to be efficient. Building the corresponding reinforcement cages out of GFRP bars on site requires the same working procedures as for an equal steel cage.

The necessary bars are tailor made and delivered to site where the assembly takes place. The bars are fixed together with binding wire, cable binders or similar products. U-bolts are used for clamping bars together when high loads have to be transferred over a connection.

This is a connection between the vertical GFRP bars and the corresponding steel bars, which have to carry the dead load of the reinforcement cage during the lifting process and lowering of the cage into the trench. Welding as is commonly done with steel reinforcement but not possible with GFRP bars.

2.3 *Railways and subways*

The polymeric nature of the materials used for the production of glass fiber reinforcement polymer profiles as well as the insulating characteristics, the chemical resistance, atmospheric agents and the mass pigmentability allow installation and use with practically zero maintenance, thus producing high technical/economic advantages compared to the traditional use of aluminum, steel, wood or PVC.

The elements lend themselves easily to normal assembly and coating operations by means of connections by bolts, screws and rivets or simply by gluing and painting.

The traditional solutions in steel or wood type materials, although apparently cheaper, require assembly operations with heavy vehicles due to their high weight as well as to painting and/or surface treatments that make them partially resistant to the aggressions of the typical environments in which they are used.

3 APPLICATIONS

3.1 *Isarco, Rebars*

The Brenner Base Tunnel is the central element of the new railway line that connects Munich to Verona and will represent the longest underground railway link in the world with its 64 km. The construction lot called "Sottoattraversamento Isarco" is the extreme southern part of the Base Tunnel before access to the Fortezza station (BZ).

The construction of the works is technically very complex: the tunnels of the main tubes and interconnections will pass below the Isarco River, the A22 motorway, the SS12 state road and the Verona - Brennero historic railway line.

Before starting the tunnel construction work, a series of preliminary surface activities must be carried out, including the displacement of the SS12 national road, the construction of two bridges, over the Isarco river and the Rio Bianco, and the construction of the loading area/ unload on the A22 which will be necessary for the transport and supply of construction materials. As part of the implementation phases of the intervention, the definitive deviation of the historic Verona-Brennero railway line for a stretch of about 1 km is also required. The construction of 4 deep wells of about 30 ml includes the temporary reinforcement in GRFP, the assembly of which is made with straight bars and curvilinear elements (Figure 2).

3.2 *M4, Reinforcement for soft-eye*

MM Line 4: Usage of GFRP Rebar Cages for Tunnel Boring Machine "Soft-eye" openings Metro Line 4 will be serving the densely populated areas in city centre of Milan. In order to minimize disruption caused by construction activities, it has been designed to be compatible with other modes of transport and maintain sufficient groundwater level. Metro Line 4 will have twin tunnels with single tracks in each direction. Extensive use of tunnel boring machines (TBM) will be required. Metro Line 4 will have a total of 21 stations, including interchange stations on Lines 1, 2 and 3. The 21 stations, including the terminal, are San Cristoforo FS, Segneri, Gelsomini, Frattini, Tolstoi, Washington-Bolivar, Foppa, Parco Solari, S. Ambrogio, De Amicis, Vetra, S. Sofia, Sforza-Policlinico, San Babila, Tricolore, Dateo, Susa, Argonne, Forlanini FS, Q.re Forlanini and Linate Airport.

The stations are built in open construction pits: An open central shaft and blind-hole side tunnel technique will be implemented to facilitate passage of the TBM and minimize excavation.

Figure 2. Isarco shaft consolidated with GRFP i-BARS in the bypass tunnel area.

TBMs can not cut through steel-reinforced concrete drilled shaft walls as the steel bars get caught in the shovels of their shield. In addition, the steel bars can not be cut into pieces small enough to allow their transport by the TBM's conveyor belt system. As a result, the conventional construction method with steel-reinforced drilled shaft walls needs the manual removal of the steel reinforcement in the path of the TBM. Not only is this time-consuming and expensive in itself, it also required the stoppage and retraction of the TBM in front of each shaft wall. Finally, to ensure that neither the soil nor potential groundwater outside the shaft wall would collapse into the opened hole, complex and expensive soil stabilization measures are required outside the wall. All these time-consuming and costly measures are not required when the areas of the launch shaft head walls to be penetrated by the TBM are reinforced with glass fibre-reinforced polymer (GFRP). Even though these bars have a much higher tensile strength than steel rebars, they are easily machined and can be broken down into small bar segments by the cutter head of the TBM. These segments can then be transported by the machine's conveyor system together with the excavated soil. The TBM does not have to be stopped, and soil stabilization measures are not required, as the soil is always stabilized by the TBM. The resulting savings in the overall construction time and cost are substantial.

Construction of the first two shafts for the project, at Argonne and Frattini Stations, was opened for bids in January 2015. In both cases, GFRP reinforcement was specified in the bid documents. In early July 2015, MAPLAD was awarded the contract to deliver the soft-eyes GFRP rebar cages (Figure 3).

3.3 *Cociv, i-PIPE profile for face stabilization*

The new high-speed railway line called Terzo Valico develops for a total of 53 km, 36 km of which in the tunnel, and covers 14 municipalities in the provinces of Genoa and Alessandria and the regions of Liguria and Piemonte.

In detail, the line, starting from the railway junction of Genoa (Bivio Fegino), develops almost entirely in tunnels (Galleria di Valico and Galleria Serravalle) up to the Piana di Novi, with the exception of a short section in the open air at Libarna. The Valico Tunnel, about 27 km long, has four intermediate adit tunnels, both for construction and safety reasons.

By the most advanced safety standards, the sections in the tunnel will be largely made of two single track tunnels side by side and joined together by transversal connections so that each can serve as a safety tunnel for the other. From the exit of the Serravalle tunnel the line develops mainly outdoors until you enter the Pozzolo Gallery, at the exit of which the line develops outdoors until it joins the existing line Pozzolo Formigaro - Tortona (to Milan); in the uncovered section between Novi Ligure and Pozzolo Formigaro, the construction of the artificial tunnel link from and to Turin on the current Genoa-Turin line is planned.

Figure 3. Metro Milano breakthrough in “GFRP mode”.

Figure 4. Left: Consorzio Tunnel Giovi (Pizzarotti S.p.A. & Collini S.p.A.), GFRP at the front face. Right: Oberosler S.p.A.. radial and face long bars for front excavation and subsequent cavern enlargement.

For the sections to be made in traditional excavation, the consolidation of the fronts is done by stabilizing the core-face with fiberglass reinforcement and the design and construction phases are managed through the ADECO-RS method.

MAPLAD is presently working in practically all the contracts (Figure 4).

4 RESEARCH APPLIED ON NEW MATERIALS – IBAR® BS BY MPLD

4.1 *Basalt fibers*

Basalt fiber is a material made from extremely fine fibers of basalt, which is composed of the minerals plagioclase, pyroxene and olivine.

It is similar to carbon fiber and fiberglass, having better physic mechanical properties than fiberglass, but being significantly cheaper than carbon fiber.

Basalt fibers are 100% natural and inert. Tested and proven to be non-carcinogenic and non-toxic and easy to handle. In contrary, fiberglass is made from a mixture of many materials, some of which are not environmentally friendly.

Since basalt is the product of volcanic activity, the fiberization process is more environmentally safe than that of glass fiber. Basalt continuous filament is a green product. Abundant in nature so can never deplete the supply of basalt rock.

The "greenhouse" gases that might otherwise be released during fibre processing were vented millions of years ago during the magma eruption so won't affect the current pollution scenario.

Further, basalt is 100 percent inert, that is, it has no toxic reaction with air or water and is non-combustible and explosion proof.

4.1.1 *Advantages*

Superior Thermal Protection: Maplad's Basalt has a thermal range of -260 ˚C to +982 ˚C (1800 ˚F) and melting point of 1450 ˚C. Fibers are ideal for fire protection and insulative applications.

Durable: Tough and long-lasting, fibers deliver acid, alkali, moisture and solvent resistance surpassing most mineral and synthetic fibers. They are immune to nuclear radiation, UV light, biologic and fungal contamination.

They're stronger and more stable than alternative mineral and glass fibers, with tenacity that exceeds steel fibers many times over.

Additionally, basalt fibers are naturally resistant to ultraviolet (UV) and high-energy electromagnetic radiation, maintain their properties in cold temperatures, and provides better acid resistance.

In Table 2 and 3 some technical data are reported.

4.1.2 *Mechanical and physical characteristics of basalt fiber reinforced polymer rebar*

Basalt rebar has a lower Young's modulus compared with steel, but is 15–30% higher than fiberglass rebar. It is strong in tension and has very little stretch.

Table 2. Comparison between basalt fiber and glass or carbon fiber.

Capability	Basalt fiber	E-Glass fiber	S-Glass fiber	Carbon fiber	Unit
Tensile strength	3000–4840	3100–3800	4020–4650	3500–6000	MPa
Elastic modulus	79.3–93.1	72.5–75.5	83–86	230–600	GPa
Elongation at break	3.1	4.7	5.3	1.5–2.0	%
Diameter of filament	6–21	6–21	6–21	5–15	μm
Tex	60–4200	40–4200	40–4200	60–2400	
Temperature of Application °C	(-260)-(+500)	(-50)-(+380)	(-50)-(+300)	(-50)-(+700)	

Table 3. Breaking strength of basalt fiber for different diameter.

Capability						Unit
Filament diameter	5	6	8	9	11	μm
Breaking strength to weight ratio of elementary fibers	215	210	208	214	212	kg/mm^2

Table 4. Comparison between basalt rebar and fiber glass rebar.

Properties	Glass Rebar	Basalt Rebar	Unit
Elastic modulus	>30000	>50000	N/mm^2
Elongation at break	>2	>2.5	%
Fiber content	>60	>70	%
Shear strength	>16	>20	Ksi

If rebar is subjected to beyond the spec limits then it will break rather than stretch. The rebar placement design needs to allow for this.

The structural engineering needs to consider “tensile modulus”. In a properly structurally engineered design, the rebar will not be subjected to anything like the force needed to break it.

The thermal expansion coefficient is very close to that of concrete (whereas steel is very different). This helps a lot to avoid concrete cracking.

Table 4 is a short properties comparison sum up.

4.2 *Green pultrusion*

A strongly growing demand for reinforced concrete reinforcements in GFRP has been reconDited on the market in the last decade,

Especially for underground works realized by mechanized excavation, the traditional reinforcement is a limitation because it cannot be easily demolished.

In this specific field of application, experimentation on the applicable materials aims above all at the development of innovative and sustainable pultrusion processes.

Hence the “Green Pultrusion” project fielded by the Universities of Catania and Palermo and by some Italian companies headed by Maplad, a leading company in the sector of pultruded elements production.

The phases of the project include the design and construction of a prototype pultrusion plant dedicated to the production of environmentally friendly products, using raw materials of natural origin, totally reusable with a recycling process with low environmental impact.

The steps of the project include the study of the characteristics of natural fibers in relation to their use in the developed pultrusion process, the optimization of a recyclable and

Figure 5. Left: basalt rebars. Right: basalt fibers clothed in a reel.

environmentally friendly resin system and the creation of a recycle loop with a low environmental impact.

The project also includes advanced process control and automation.

Industrial research will therefore focus on the characterization of the fibers, on the stretching and alignment processes of the same as well as on the development of the resin formulation and its recycling process.

In this phase the study of the mechanical characteristics of the fibers is essential because the resistance properties of the natural fibers do not easily allow direct use in the normal pultrusion processes.

The same pultrusion process will be developed specifically to manage both the wettability and premixing phase of the fibers as well as the extraction, ironing and cooling of the pultruded material to guarantee a correct and valid compatibilization of the composite.

The entire process is designed in every single phase according to the chemical-physical properties of the selected natural fibers and to the characteristics of the required polymer fiber/matrix composite.

The project will realize eco-friendly composites with low environmental impact and easily recyclable.

This last aspect is an absolute novelty that, in perspective, can lead to significant advantages in terms of containment of disposal costs as well as representing a new opportunity for the development of recycled products.

In the usual pultrusion processes the reinforcement is impregnated with a resin and pulled through a heated mold in which the resin polymerizes. Almost all pultruded products containing glass fibers and thermosetting resins are non-renewable materials.

The only replacement of glass fibers with natural fibers can not fully realize the scope in order to obtain a truly “green” composite because of the thermoset ones have the greatest environmental impact.

This is especially true with compared to the energy parameter (MJ/ton) required associated to production (Cumulative Energy Demand).

LCA (Life Cycle Analysis) studies of Sachsenlinen show that, for the production of a panel of 1.2 m^2, glass fibers get an energy consumption of 76.08 MJ and the thermosetting resin 84.42 MJ. Therefore, although the replacement of glass with vegetable fibers involves a reduction to 12.58 MJ for the contribution of the reinforcement, the contribution share of the matrix maintaining the traditional resin would always be at a value of 81.04 MJ using fossil-based resins. The cause of the full influence of the matrix is to be found in energy-consuming operations connected to the extraction of fossil products.

The project faces the challenge of introducing an eco-innovative business concept in the pultrusion industry, from the use of sustainable raw materials to the use of a new ecological recycling strategy.

It aims to reduce energy consumption through the use of low impact materials and through the implementation of advanced control systems on the plant.

Greenpultrusion also provides for the installation, along the process line, of a series of self-correcting sensors such as to make the process itself innovative not only in terms of biocompatible and eco-sustainable products, but also in terms of intelligent management.

In Figure 5 can be seen basalt rebars under test and basalt fiber product clothed in a reel.

5 CONCLUSION

The use of fiberglass profiles in the construction market, and especially in large underground infrastructures, is now a consolidated fact.

This has happened thanks to the enormous industrial developments following a phase of applied research, carried out in concert between the Academic World and specialized companies.

So we got an entailed technological development and an increase in production also through the now irrefutable awareness that the use of these materials derives a productive and performance benefit.

Moreover, the decrease in the times related to some constructive processes of underground works and the elimination of problems due to the use of reinforcing steel, are some factors that have allowed the development of these technologies.

The presence of products with mechanical characteristics comparable to traditional steel profiles would allow a greater diffusion of the composites, without obviously significantly increasing the cost of construction of the works with the advantage of considerably reducing maintenance costs.

The profiles derived from the use of basalt fibers would allow to increase the mechanical characteristics compared to those made with glass fibers, without however reaching the costs of those made with carbon fibers.

Furthermore, basalt fibers are made from raw materials that are readily available and are not being depleted.

Another factor of considerable importance is the fact that the basalt fibers are a green material, both for intrinsic properties and because the process of extraction of the raw material and processing do not produce pollution.

The latter, however, must be used with a matrix having the same characteristics of low environmental impact. The use of a bio resin, that is coming from naturally occurring materials, allows the creation of a profile that can be defined as Green.

REFERENCES

Afeltra, R. 2017. *Development of a new technology for production of SKEletons in composite materials for realization of pre-cast tunnel segments* Composite Solutions 11, 16

Carrino, L. & Caprino, G. 1995. *Tecnologia della pultrusione – Aspetti tecnici e considerazioni di mercato*, Editrice Promaplast, Varese, Italy

Cicala, G., Kumar, S., Blanco, I., Manuele, G. & Recca, A. 2018. *Novel pultrusion process for bended rebars for civil engineering application*, Catania, Italy

Kovári, K. 1994. *On the Existence of NATM, Erroneous Concepts behind NATM*, Tunnel, No. 1

Lunardi, P. 2001. *The ADECO-RS approach in the design and construction of the underground works of Rome to Naples High Speed Railway Line: a comparison between final design specifications, construction design and "as built"*. AITES-ITA World Tunnel Congress su "Progress in tunnelling after 2000", Milano, 10–13 giugno, Vol. 3, 329–340

Martel, J., Roujon M. & Michel D. 1999. *TGV Méditerranèe – Tunnel Tartaiguille: méthode pleine section*. Proceedings of the International Conference on "Underground works: ambitions and realities" Parigi, 25–28 October

Rabcewicz, L. 1964. *The New Austrian Tunnelling Method*, Part 1, Water Power, November 1964, 453–457, Parte 2, Water Power, dicembre 1964, 511–515

Rabcewicz, L. 1965. *The New Austrian Tunnelling Method*, Part 3, Water Power, January 1965, 19–24.

Starr, Trevor F. 2000. *Pultrusion for Engineers*, CRC Press