FURKA OCH VEREINA, SMALSPÅRIGA JÄRNVÄGS-TUNNLAR I SCHWEIZ, 20/30 ÅR EFTER DRIFTSÄTTNING

Furka and Vereina, narrow-gauge railway tunnels in Switzerland, 20/30 years after commissioning

Permanent rock support with non-metallic GFRP rock bolts.

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Sammanfattning

I Schweiz finns ett utbrett järnvägsnät av smalspåriga järnvägslinjer. I slutet av förra århundradet lades ytterligare två nya långa tunnlar genom Alperna till detta nätverk. Furka tunneln 15,4 km öppnades 1982 och Vereina tunneln 19,1 km öppnades 1999. Den här artikeln fokuserar på bergförstärkningskonceptet med enkelskals förstärkning med sprutbetong och GFRP bergbultar. Föredraget inleds med en presentation av dessa två tunnelprojekt och med en översikt över status för bergförstärkning utifrån kontroller som utförts. Som avslutning behandlas mer ingående hur GFRP bulten är uppbyggd och resultat av tester som utförts.

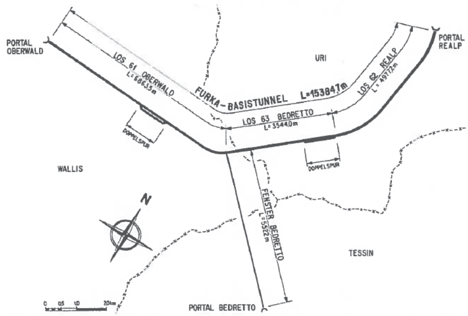
De flesta alpina bergtunnlar i dag är utformade med dubbel lining, d.v.s. sprutbetong och bult samt lining med platsgjuten betong. Det första lagret bergförstärkning har normalt sett bara en temporär funktion och långtidsstabiliteten garanteras med en andra lining, främst en platsgjuten betong, ofta med ett vattentätt membran mellan de två förstärkningarna.

Bergförstärkningen för båda ovan nämnda tunnlarna var designade som enkelskals förstärkning, där bergförstärkningen måste säkerställa långsiktig stabilitet. I designen ingår bergbultar och sprutbetong, såsom de flesta tunnlar i Skandinavien normalt utförs, delvis förstärkt med metallnät (ingen fiberbetong var tillgänglig i dessa dagar!). Särskild försiktighet måste vidtas för att de bergbultar som skulle användas uppfyllde krav på livstid. I båda tunnlarna användes GFRP bergbultar, huvudsakligen för att materialet inte är korrosionskänsligt.

Project presentation Furka tunnel:

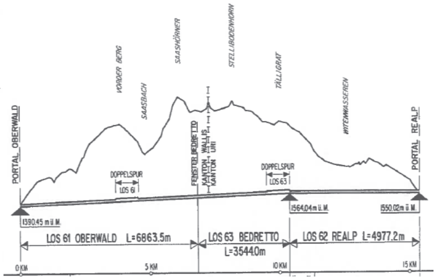
The Furka tunnel is a 15.4 km long narrow gauge tunnel through the Alps connecting the two cantons Uri and Wallis in Switzerland (*figure 1*). The concept includes one single track tunnel and two sections with a larger profile, where the trains can cross each other. The tunnel work was started in 1973 and was driven with drill and blast from the two portals and an intermediate access from the canton Ticino.

The maximum overburden is 1’520 m and the geology is, as mostly within the central Alps very heterogeneous and challenging (*figure 2*). The tunnel was driven with drill & blast and the minors had to overcome numerous challenges until the main brake through in April 1981. The tunnel finally opened in 1982, just one year after the last excavation works! The regular speed in the tunnel is 90 km/h and daily almost 100 trains use the tunnel.



Figur 1: Furka tunnel med de två påslagen i Uri och Wallis samt mellanpåslag från Ticino

Figure 1: Furka tunnel with the two portals in Uri and Wallis and the access tunnel from Ticino

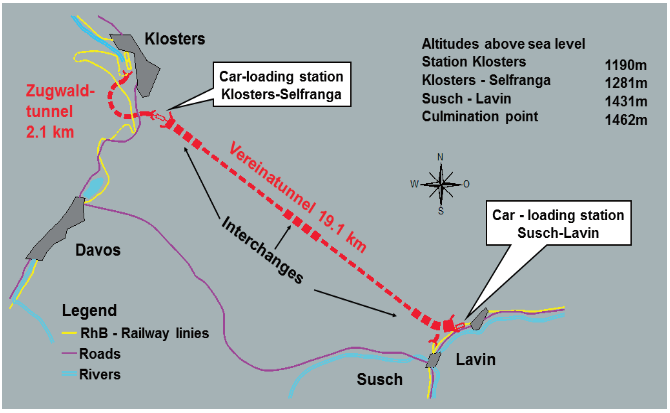


Figur 2: Längdsektion över Furka tunnel med en bergtäckning upp till 1520 meter:

Figure 2: Longitudinal section Furka tunnel with overburden of up to 1’520 m

Vereina Tunnel

The Vereina tunnel is an essential part of the railway network in the Canton of Graubünden in eastern Switzerland. With 19.1 km in length it is the longest narrow gauge railway tunnel in Switzerland. It’s a single track tunnel with three double track areas where trains can cross. Due to the topography there was no intermediate access possible and the whole tunnel was excavated from the two portals (*figure 3*).



Figur 3: Översikt över Vereniatunneln
Figure 3: Overview Vereina Tunnel

The southern part was excavated using drill and blast technology (*figure 5*). From the northern side a TBM was installed for the vast majority of the work (*figure 4*). The overburden ranged up to 1500 m and the encountered geology was very heterogeneous. From frightening rock burst to extensive water inflow and extensive squeezing all potential challenges for a tunnel excavation had to be overcome. The construction began in 1991 and tunnel was opened in November 1999.

Figur 4: Tunnelproduktion med TBM i den norra delen.
Figure 4: TBM excavation in the northern part

Figur 5: Tunnelproduktion med borra/spräng.
Figure 5: Drill and blast excavated tunnel

Rock support

Most alpine rock tunnels, especially nowadays are designed with double shell lining concepts. The rock support has only a temporary function and the long term stability is guaranteed with a second lining, mostly a cast in place concrete shell, often protected with an impermeable membrane in between the two layers. The rock support for both above mentioned tunnels was designed as a single shell lining, where the rock support itself has to ensure the long term stability (*figure 6*). The concept included rock bolts and shotcrete, partly reinforced with wire mesh (no fibers those days!). Special care had to be taken to the rock bolts, as they need to fulfill their function for the whole design life time. In both tunnels GFRP rock bolts were used, mainly because the material is known as not sensitive for corrosion.

Figur 6: Furkatunnel, bergförstärkning med sprutbetong och GFRP bult.
Figure 6: Furka tunnel, single shell lining

Furka tunnel

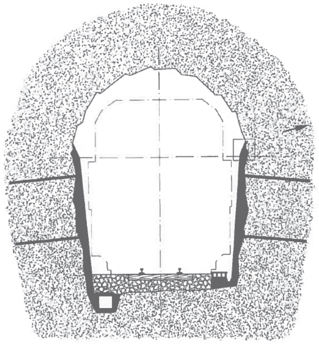
The Furka tunnel was subject of intense political discussions, especially due to larger cost overruns in early design phases. Therefore the pressure to keep construction costs low was continuously growing and the designers had to optimize the whole design more than once. As double shell linings with a cast in place concrete lining entail high costs the single shell concept was studied quite early and a lot of advantages could be identified:

- The shotcrete of the rock support can be integrated in the permanent support and optimized according to the geotechnical needs (whereas a concrete lining requires a minimal thickness, independently of the geology).

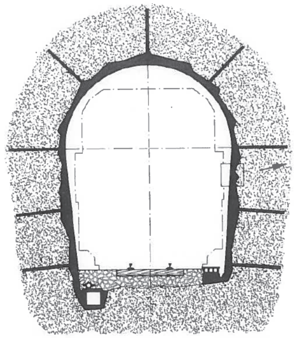
  => In total less concrete is required.

  => The cross section, especially the excavation volume can be optimized.
- No formwork required, especially beneficial in the numerous parts with changing cross sections.
- Due to space constraints the foundation of the concrete lining was easier with respect of the drainage system in the invert.

A rough comparison after completion of the works shows, that a double shell concept would have needed roughly 40’000 m3 of additional concrete and would have prolonged the construction time about 8 to 10 months. In total 16 rock support types and sub types were designed. They ranged from type 1 with 0.8 m3 shotcrete per m tunnel up to type 4 with 5.6 m3 shotcrete and 6 rock bolts per m tunnel (*figure 7 & 8*).



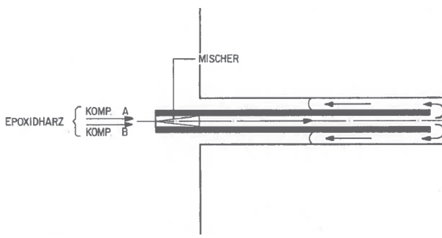
Figur 7: Berförstärkningsklass typ 1
Figure 7: Rock support type 1



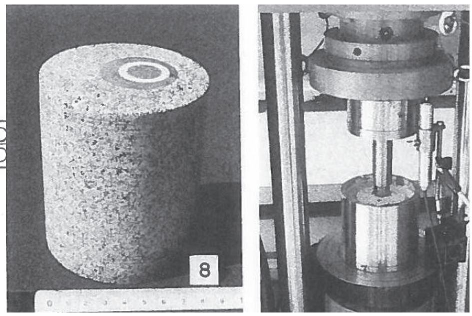
Figur 8: Bergförstärkningsklass typ 4
Figure 8: Rock support type 4

During rock excavation the tunnel was supported with rock bolts and shotcrete directly at the front after every round. In a later stage and for the long term stability this initial rock support was completed with additional shotcrete and, in areas where necessary, also with complementary rock bolts. This rock support had of course to be designed as permanent. For the shotcrete this could be made quite easily with high quality restraints on the site and a strict quality control.

When it comes to rock bolts there were many more questions to be answered. Pretty soon it was clear, that normal steel bolts would not fulfill the long term requirements due to potential corrosion and loss of effect over time. As an alternative GFRP rock bolts were considered interesting. But for this material other questions such as the long term behavior (relaxation), corrosion of the bolt and corrosion of the resin amongst other had to be verified. An intense research program was set up and the results showed, that a combination of GFRP rock bolts and two component epoxy resin would fulfill the requirements for a long term rock bolt (*figure 10*).



Figur 9: GFRP bult med 2 komponents resin ingjutning
Figure 9: GFRP rock bolt with two component resin



Figur 10: Utdragstest i laboratorie.
Figure 10:Pull out tests in laboratory

The two components were mixed directly in the rock bolt itself and pumped through the bolt to the end of the drill hole (*figure 9*). From there it was pressed back at the outside of the bolt backwards. Due to the possibility to mix the two components with different proportions the set time could be adjusted. In areas with rock temperatures up to 25°C the rock bolts had full bearing capacity after 30 minutes and even in portal areas with lower temperatures down to 5°C in winter sufficient reaction times could be achieved. Additionally tests showed, that the resin completely insensitive to the chemical properties of the groundwater. Pullout tests showed that the system rock, resin and GFRP bolts fulfilled the design requirements.

In the end GFRP rock bolts with a length form 2.0 up to 4.5 m and an outer diameter of 20 and 27 mm were used in combination with not less than 15 cm shotcrete.

Vereina Tunnel

When the Vereina tunnel was designed the experience of the Furka Tunnel was taken into account. From the beginning the single shell lining was part of the design, as the concept made it possible to significantly reduce the costs. GFRP rock bolts were considered as favorable due to the positive resistance to corrosion and the easy handling.

Compared to the Furka tunnel the shotcrete application system was changed from a dry to the whet shotcrete. This was a very important innovation those days, as the dust in the tunnel and though the work environment could be improved significantly. Furthermore the performance was increased up to 10 and 15 m3 / hour and the rebound could be significantly reduced (*figure 11*).

Figur 11, Applicering av sprutbetong från TBM

Figure 11 Application of whet shotcrete from the TBM

Figur 12, GFRP bultar i Vernia tunnel

Figure 12, GFRP rock bolts in the Vereina tunnel

Also the concept of the rock bolts was slightly changed. At the face rock bolt bars with epoxy cartridges were applied instead of the hollow bolts used in the Furka tunnel (*figure 12*). The handling was easier and the costs were lower. But first of all they could be some kind of prestressed. In the very deep of the bore hole fast reactive epoxy cartridges were used, further back slower reacting cartridges. After 10 minutes the fast reacting epoxy had hardened already and the bolt was prestressed manually. This increased the effectiveness of the rock bolts at the face. Together with the whet shotcrete this was sufficient for the rock support after excavation.

For the long term stability the first round of rock bolts were partially considered, but usually only 30%. Additional shotcrete and hollow GFRP rock bolts were added to be able to cope with the requirements and guarantee a long term stability. The decision where to add how much shotcrete and how many rock bolts was taken on site in the tunnel accordingly between designer, site supervision and contractor. Altogether almost 100’000 GFRP rock bolts were used in the Vereina tunnel.

Experience from today’s point of view

Both tunnels were opened some decades ago and have been used excessively since then. Regular inspections show, that the chosen concepts work up to now - although the design life span is still far in the future.

Furka Tunnel

The Furka Tunnel was opened in 1982 and after more than 30 years of operation a larger upgrade program is undertaken at the moment. The reason is mainly new safety requirements and some damages on the ballast track. During the necessary inspections also the rock support was assessed in detail. Additional calculations showed that the rock support still fulfill all requirements and there are no large scale measures to be undertaken. This was also approved by an independent checker and the specialists of the client.

Vereina Tunnel

After the opening in 1999 the Vereina Tunnel has been operated almost 20 years. Regular inspections from the client’s side show that the tunnel and especially the rock support are still in very good conditions. As far as we know there is no larger refurbishment campaign planned in the near future.

Figur 13, Furka tunnel i drift
Figure 1, Furka tunnel in operation

Figur 14, Verenia tunnel i drift
Figure 2, Vereinatunnel in operation

Conclusion

The combination of GFRP rock bolts and shotcrete for a single shell permanent lining worked out very well for the two examples presented in this paper. After almost 20 respectively more than 30 years of operation the applied system still fulfils the requirements. There are no signs that this will change during the next inspection period and although the design life time is still far away in the future the concept has proven to be successful for these two case studies.

In consequence a permanent rock support design with shotcrete and GFRP rock bolts can be an interesting option for future projects.

References

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[3] Die Vereinalinie, SIA Heft 44/1994

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GFRP technology and GFRP rock-bolt endurance

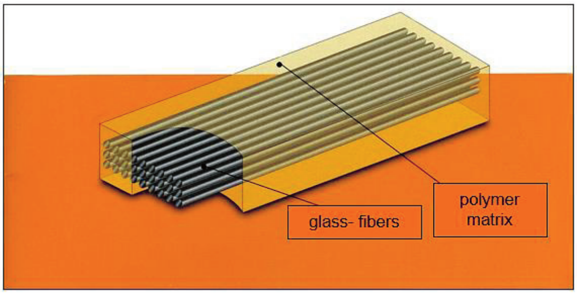
It is more than 30 years since the Furka tunnel was open and during this time the technology of GFRP rock-bolt production has been improved. Also construction of GFRP rock-bolts is improved and today’s elements are somewhat different from those used at that time.What has changed is primarily the machinery and precision of laying fiber layers and types of resins forming the matrix for glass fibers disposed therein.

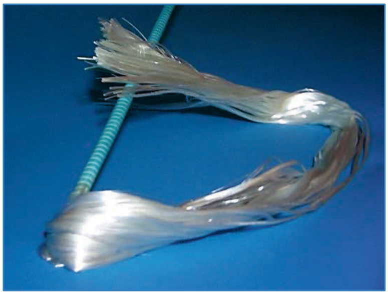
During construction period of the tunnels Furka & Vereina was the standard in GFRP technology the straight glass fibers in the profile elements and use of the basic polyester resin as a binder.

On the basis of the research conducted at that time, such combination actually could not offer the desired service life and right decision was to increase endurance of GFRP elements using epoxy resin (injection resin, lately cartridge system) instead of conventional cement grout. It is well known fact that GFRP (Glass-fiber-reinforced polymer) are not subject to ordinary corrosion, but this statement should be clarified as the durability is one of the key benefit of composites. Corrosion of "metal" materials is really different from the degradation of "plastics" (generally synthetic materials).

In case of metals the corrosion is natural process of gradual destruction of material by chemical or electrochemical reaction with their environment, which converts a refined metal to a more chemically stable form such an oxide, hydroxide or sulfide. In the most common understanding of word corrosion is the electrochemical oxidation of metal in reaction with an oxidants such as oxygen or sulfur. Rusting is the formation of iron oxides on the surface of metal elements.

When we talk about composite elements (generally fiber-reinforced-polymers) the situation is very different. Composite material consists of two (or more) distinct physical phases, one of which – the fibrous phase (reinforcement), is dispersed in a continuous matrix phase (polymer).

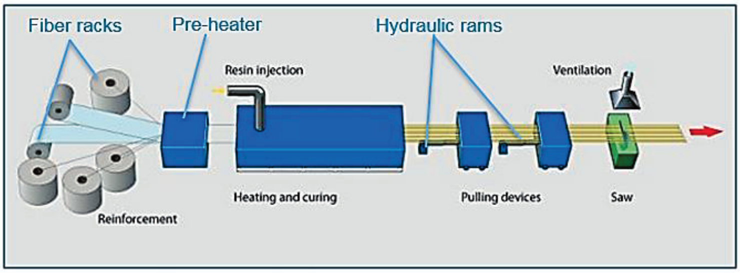




Figur 15: Schematisk bild över GFRP struktur och glasfiber för tillverkning av Glasfiberbult.

Figure 1:Schematic illustration of the GFRP structure and glass-fibers for production of R-B

Apart from different structure of materials is the manufacture of composites completely different from the iron and steel industry. Modern pultrusion method of the continuous production of GFRP allows optional routing of glass fibers (direct and indirect fibers in profile), the choice of the ratio of fiber / matrix in cross section and also the choice of various resins. Certain combinations of fibers (their direction and density) and the resin results in a different resulting parameters of GFRP.



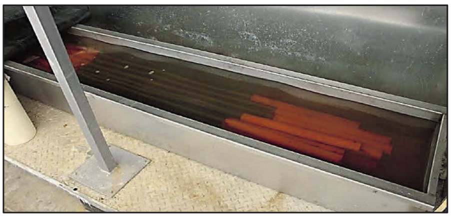
Figur 16: Schematisk bild över tillverkning av Glasfiberbult
Figure 16, Schematic illustration of the GFRP production method

Are GFRP materials really so durable? Their lifespan is obviously long, but it depends on the specific product and especially on the used resin. If we talk about the corrosion of plastics then it should be divided into two categories – chemical corrosion of glass and chemical corrosion of polymer. From our technical perspective we can characterized glass fibers (glass) by a high degree of corrosion-resistance. Because of their high water-resistance glass is often used as primary packaging material in the pharma industry since most medicines are preserved in a watery solution. Besides its water-resistance, glass is also very robust when being exposed to chemically aggressive liquids or gases. While other materials like metal or plastics quickly reach their limits, special glass-types can easily hold up.

Chemical corrosion of polymer is generally possible. The most common and related problem is "swelling", where small molecules infiltrate the structure, reducing strength and stiffness and causing a volume change. Many polymers are intentionally swelled with plasticizers, which can be leached out of the structure, causing brittleness or other undesirable changes. Therefore for the production of permanent composites the special resin types with closed molecular structure must be used. Such resins prevents the penetration of liquids and gases into composite body and prevent contamination - weakening the structure of the resin over time. Finding the optimal combination of fibers and resin, and its long-term testing in an aggressive environment is a basic requirement for achieving the desired objective - permanent rock-bolts.

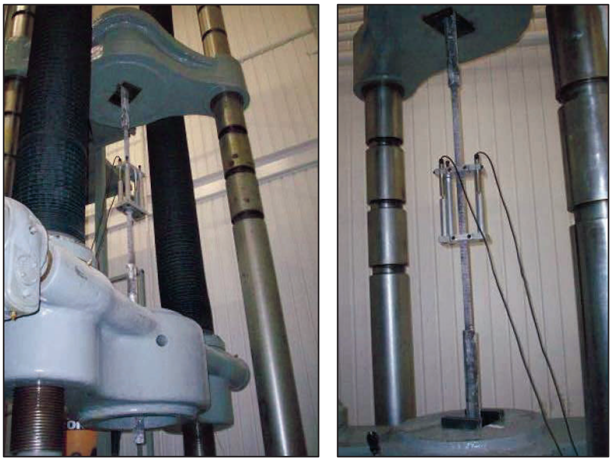
Long-term testing of GFRP rock-bolts durability

In order to simulate long-term durability of GFRP rock-bolts the most difficult conditions have been defined. For accelerated test method of durability the GFRP rock-bolts specimens have been placed in high-alkaline solution containing 118.5 g $Ca(OH)_2$, 4.2 g KOH and 0.9 g NaOH per liter (pH=13) and exposed to increased temperature (environmental chamber / temp 20°C, 40°C and 50°C – various speed of aging). The level of alkaline solution and pH level were checked periodically and a new solution was added, when necessary. After a certain period the portion of samples (exposure time 1000, 3000 and 5000 hours) were removed from high-alkaline solution and subjected to tensile test. The test specimens were instrumented with two LVDTs to capture the specimen elongation during testing. The tests were carried out using the Baldwin testing machine. The load was increased until tensile failure occurred. The applied load and bar elongation were electronically recorded during the test using a computerized data acquisition system.



Figur 17: Preparering av GFRP bergbultar i 50 °C (provbultar i vatten representerar verkligt förhållande i fält)

Figure 17: Conditioning of GFRP Rock Bolts at 50 °C (samples in water representing the field conditions)



Figur 18: Dragprovstest setup efter preparering
Figure 18: Tensile test set-up after conditioning

Based on the carried out tests were determined the loss in tensile strength and E-modulus and strength in time values have been extrapolated. From the graph is evident that a major loss of strength takes place in the initial 50 years, then the curve is relatively flat depletion. In any case, for a specially manufactured GFRP is the loss of strength relatively small (up to 10%) and varies within a safe tolerance design values – the most common strength value limitation for permanent rock*-bolts is 65% of original ultimate strength.

<table>
<tr><th rowspan="2"></th><th colspan="2">At 20°C</th><th colspan="2">At 40°C</th><th colspan="2">At 50°C</th></tr>
<tr><th>Average Tensile Capacity (N/mm²)</th><th>Tensile Capacity Retention R_{et} (%)</th><th>Average Tensile Capacity (N/mm²)</th><th>Tensile Capacity Retention R_{et} (%)</th><th>Average Tensile Capacity (N/mm²)</th><th>Tensile Capacity Retention R_{et} (%)</th></tr>
<tr><td>Non-conditioned specimens (reference)</td><td>1069</td><td rowspan="2">100</td><td>1069</td><td rowspan="2">97</td><td>1069</td><td rowspan="2">98</td></tr>
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<tr><th rowspan="2"></th><th colspan="2">At 20°C</th><th colspan="2">At 40°C</th><th colspan="2">At 50°C</th></tr>
<tr><th>Average Elastic Modulus (GPa)</th><th>Elastic Modulus Retention R_{et} (%)</th><th>Average Elastic Modulus (GPa)</th><th>Elastic Modulus Retention R_{et} (%)</th><th>Average Elastic Modulus (GPa)</th><th>Elastic Modulus Retention R_{et} (%)</th></tr>
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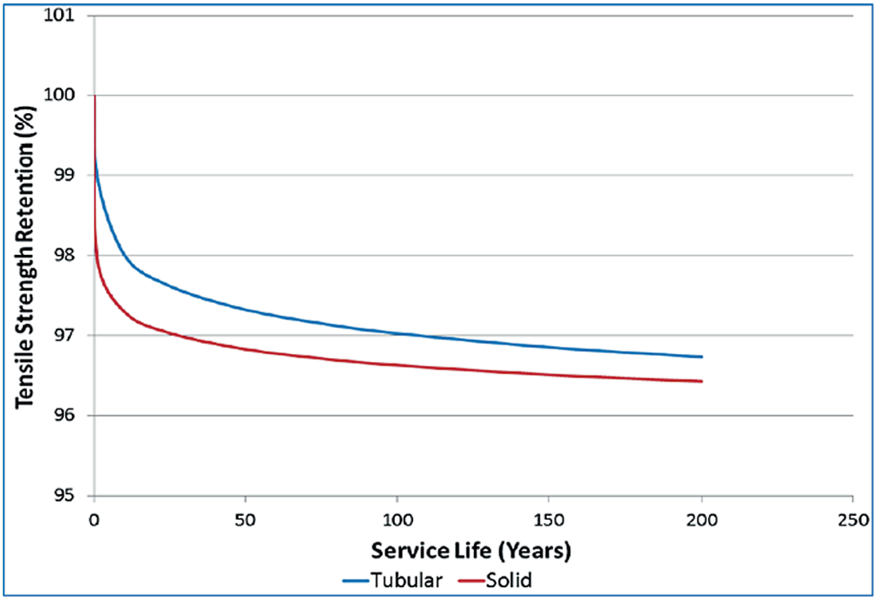

Figur 19: Resultat av utfört test, relation mellan draghållfasthet och förväntad livslängd.
Figure 19: Results of tests, relation between the tensile strength and the predicted service life

Conclusions

GFRP in its special form (optimized combination of fibers and resins) offers high levels of strength but also extreme durability. When using them it is always necessary to realize that the composites are in principle different from of metals by their behavior and specs and the unchangeable fact must be taken into account.

GFRP-rock bolts are an interesting alternative for corrosion protected steel elements in stable rock without significant deformation or in high-aggressive environment where the standard methods of corrosion protection of steel components could fail over the longer period of time.

However, GFRP rock-bolts are not applicable always and under all conditions – especially in squeezing ground the other types of rock-bolts (like yielding rock-bolts for example) suited better. Accelerated durability test was shown that GFRP can achieve high durability exceeding 100 years. This conclusion does not apply in general for all GFRP products, but only for specially designed components using high-quality close-cells resins.