3. Selection of the S&P FRP Strengthening System

There is no fixed rule as to whether sheet or laminate should be used. Usually economy dictates the choice of one system or the other, but sometimes it is a design choice. Carbon (laminate or sheet) appears to be more economic for use in flexural or shear strengthening. Certainly, carbon has better fatigue properties than glass, so where the strengthening is used to carry often occurring fluctuating live loads, carbon should be chosen. Glass, because of its lower E-modulus, is more suitable for use in confinement of concrete, although it can, in certain circumstances, be used for flexural enhancement. Because of its low modulus, glass is seldom used for shear enhancement. Aramid is usually used for impact and explosion enhancement.

Laminates can only be applied to plane surfaces, therefore carbon, aramid and glass sheets are used on curved surfaces.

Bi-directional glass fabrics are used for increasing the shear strength of masonry walls. Lighter fabrics are used where the substrate strengths are low, such as in old and historic masonry or brick buildings.

The following table sets out typical uses for the various products:

Composite Type	Fibre direction	Fibre arrangement	Typical application
S&P Carbon Fibre Sheet (CFS)	Uni-directional	Straight	Increase in flexural and shear capacity, confinement
S&P Aramid Fibre Sheet (AFS)	Uni-directional	Straight	Impact or explosion enhancement
S&P Glass Fibre Sheet (GFS)	Bi-directional	Woven	Increase in confinement and ductility
S&P Carbon Fibre Laminate (CFK)	Uni-directional	Straight (partially pre-tensioned)	Increase in flexural capacity

Table 1: Sheet application overview

3.1 Demands on the Substrate

The substrate to which the FRP is to be adhered, must have sufficient strength to transfer the loads from the FRP to the structure. Testing of the tensile strength of the substrate by pull-off tests is imperative. The following table sets out the minimum substrate strengths required for each of the FRP materials to be used efficiently:

Product	**Minimum Tensile Strength (MPa)**
S&P Carbon Fibre Sheet (CFS)	> 1.0
S&P Aramid Fibre Sheet (AFS)	> 1.0
S&P Glass Fibre Sheet (GFS)	> 0.2
S&P Carbon Fibre Laminate (CFK)	> 1.5

Table 2: Demands on the bearing substrate

Fig. 3: Proceq Dyna Pull-off Tester used for determining substrate tensile strength

3.2 Types of Fibres used in S&P FRP Systems

S&P FRP materials comprise either single type fibres or a fibre combination (hybrids). The range of mechanical properties as well as some advantages and disadvantages of the various fibre types are as follows:

Type of Fibre	**Modulus of Elasticity** (GPa)	**Tensile Strength** (MPa)
Carbon	240 - 640	2,500 – 4,000
Aramid	120	3,000 – 4,000
Glass	65 - 70	1,700 – 3,000
Steel	190 - 210	250 - 600

Table 3: Material properties

E-glass: Uncoated E-glass corrodes in alkaline environments, thus there is a risk in using E-glass together with freshly cured concrete, unless the E-glass is completely submerged in epoxy. However, there is no problem when E-glass is applied directly to old concrete, which is the majority of cases. A higher reduction factor is used on the E-glass property by the engineer. Because of the low durability of E-glass.

AR-glass: Alkali resistant glass is suited for use as confinement reinforcement in combination with all epoxy resin matrix. A lower reduction factor is recommended by the engineer, because of the higher durability of the AR-glass.

Aramid: Aramid is a very tough material and thus provides benefits when used as a strengthening material for special applications, such as strengthening of rectangular columns and in the field of impact and explosions. Due to its high cost, aramids can be economically replaced by glass or carbon fibres in most cases.

Carbon: Carbon fibre provides a number of benefits over the other materials. It has a high modulus of elasticity, a very low coefficient of thermal expansion (approximately 50 times lower than steel), excellent fatigue properties, excellent resistance to chemical attack. It will not corrode and exhibits a high resistance to freeze/thaw and de-icing salt attack.

Table S&P repair mortars and matrix systems

When total surface wrapping of concrete or masonry (arches) is intended, aspects of building physics must be considered. 30-50% of the surface of the element should remain water vapour permeable. A total surface coverage with an epoxy matrix is therefore not suitable.

S&P Resicem is a newly developed cementitious epoxy matrix. The combined effect of the two binders that have completely different chemical bases, is that the cement particles, due to water vapour pressure, penetrate into the microstructure of the epoxy resin. Thus, the matrix system, which is vapour-proof at the time of its application, becomes vapour-permeable as the water vapour exposure increases. The cement contained in the matrix provides an additional alkali deposit, which protects the internal reinforcement against corrosion. The water vapour diffusion coefficient of an FRP application (thickness 1 mm) with S&P Resicem will eventually level out at approx. 3,000-5,000. Application is possible to substrates with a moisture content of up to 12%.

In the following table the possible S&P repair mortars and matrix systems are listed:

Primer and Resin for injection under FRP Systems
S&P Resin 50 *(shall not be used as a primer under permeable systems)*

Repair mortars FRP Systems	
Vapour permeable	Not vapour permeable
S&P Repcem *(PCC Repair Mortar)*	**S&P Resin 220** *30 Weight % filled with quartz-sand*
Saturant for S&P Sheet	
Vapour permeable	Not vapour permeable
S&P Resicem *(S&P applied for world-wide patent)*	**S&P Resin 55**

Resin for laminates CFK	
S&P Resin 220	Application on dry substrate (Humidity < 4 %)

Table 4: Repair mortars and matrix systems