# A critical assessment of current acceptance criteria for TRM strengthening systems

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**Abstract**

The large amount of research carried out in the past twenty years on the use of TRM as strengthening solution for both concrete and masonry structures has successfully demonstrated that these novel composite systems can provide excellent alternatives to more traditional materials and techniques. Since the first field applications in the early 2000's, TRM systems using different combinations of fibre types embedded in cement- or lime-based mortars have been developed and are currently available on the market. As the performance of TRM systems can vary considerably depending on the physical and mechanical properties of the constituent materials, national and international committees working in the field set out to establish procedures for the accreditation of these systems so as to provide designers with reliable data. In North America, the AC434 document published by the International Code Council-Evaluation Service specifies the experimental procedures to determine the mechanical properties of TRM systems, as well as their performance under fire and environmental exposure, and gives specific guidelines for their implementation in structural design. In Europe, the Italian 'Consiglio Superiore dei Lavori Pubblici' and the European Organization for Technical Assessment published guidelines recommending test methods and procedures for the accreditation of TRM strengthening systems, including their bond performance to selected substrate materials. This paper will discuss recent efforts in developing internationally standardized testing protocols and acceptance criteria for TRM composites. The underlying philosophy is examined, and advantages and drawbacks are discussed in detail with a view of assisting in the development of unified criteria.

## 1. Introduction

In the last decades, the use of composite materials has become one of the most common solutions for the repair and strengthening of existing buildings. In particular, Externally Bonded Reinforcement (EBR) systems have been shown to be a rather effective alternative to more traditional systems such as saddles, chains, connectors and concrete ring beams, without modifying original masses, geometry and stiffness.

However, the use of a polymeric matrix in FRPs has several drawbacks, such as poor performance at elevated temperatures, lack of vapour permeability, difficulties of applications on wet surfaces or at law temperatures and also on substrate materials like clay or masonry. Most of these limitations can be addressed by using inorganic mortar matrices in combination with a structural textile (e.g. basalt, carbon, glass and PBO) to form a Textile Reinforced Mortar (TRM). Mesh reinforcements comprising continuous steel cords (Ultra High Tensile Strength Steel, UHTSS) have also been recently introduced as an alternative type of reinforcement for grout-based systems (Steel Reinforced Grout - SRG).

Given the fast adoption of TRM in field applications, a great effort was made by various national and international committees to develop recommendations for testing and design, as well as to establish detailed procedures for the qualification of TRM systems for strengthening applications.

RILEM technical committee 250-CSM recently published a set of recommendations for the characterization of the bond behaviour of TRM to different substrates based on the implementation of single lap shear bond tests [1], while the tensile properties of the TRM composite can be determined using the direct tension test procedure proposed by TC 232-TDT [2].

In North America, the AC434 document [3] published by the International Code Council-Evaluation Service specifies the experimental procedures to determine the mechanical properties of TRM systems, as well as their performance under fire and environmental exposure, and gives specific guidelines for their implementation in structural design. In Europe, the Italian 'Consiglio Superiore dei Lavori Pubblici'[4] and the European Organization for Technical Assessment [5, 6] published guidelines recommending test methods and procedures for the accreditation of TRM strengthening systems, including their bond performance to selected substrate materials. This paper briefly reviews the main philosophy adopted by the examined documents and compares the requirements for the qualification of TRM systems.

## 2. Qualification procedure and acceptance criteria

The main aim of the three documents examined here is to provide guidelines for the preparation and testing of TRM systems and determine the mechanical properties that are required in strengthening applications. An overview of the test requirements for short term mechanical properties is given in Table 1 and the main differences are discussed in the following sections.

*Table 1 Short term mechanical characterisation tests of FRCM/SRG systems*

| Tests \ Guideline | AC434 | Italian Guidelines | EAD |
|---|---|---|---|
| Direct tensile strength of fabric | | ✓ | ✓ |
| Direct tensile strength of composite | ✓ | ✓ | ✓ |
| Lap tensile strength | ✓ | ✓ | ✓ |
| Composite interlaminar shear strength | ✓ | | ✓ |
| Pull-off bond strength | ✓ | | ✓ |
| Bond shear strength | | ✓ | ✓ |
| Pull-out strength of anchors (if needed) | | ✓ | ✓ |

### *3.1 Tensile stress-strain behaviour of textiles and composite systems*

The geometry of the specimens to be tested in direct tension according to the various guidelines is similar and the main difference lies in the adoption of a different gripping system. While a clevis type is recommended in AC434, the Italian and European documents prescribe the use of a clamping grip. Although both gripping mechanisms can be designed to effectively transfer the load to the specimen, the lack of a transverse confinement pressure in the clevis grip system can lead to premature slip between the textile and the mortar in the clamping region when relatively high values of bond stress are generated (depending on the type of textile under investigation), thus possibly leading to a 'softer' stress-strain response. On the other hand, the use of clamping grips could lead to premature cracking of the specimen following the application of the lateral pressure. Although direct tensile tests on the FRCM/SRG system are required to fulfill all certification procedures, tensile tests on the bare textiles/fabrics for all systems are only explicitly required by the Italian and European guidelines. AC434 only requires test on dry steel fabric to assess their possible degradation when subjected to pre-bending and aggressive environments.

### *3.2 Bond strength on substrate*

While the Italian and European procedures prescribe the use of single-lap shear bond tests on the intended support materials, the American procedure only determines the bond strength of TRM systems to substrate using pull-off tests and does not require to perform shear bond tests. However, additional tests are recommended in AC434 to validate the structural performance of the system in specific applications (e.g. flexural or shear strengthening of walls). According to the Italian and European qualification procedures, the results of the single-lap shear bond tests are to be used in conjunction with direct tension tests on fabrics to define the design values of stress and strain (conventional limits – see Figure 1). These values are taken as the stress induced in the fabric at the maximum load recorded in the shear bond test, and the corresponding fabric strain.

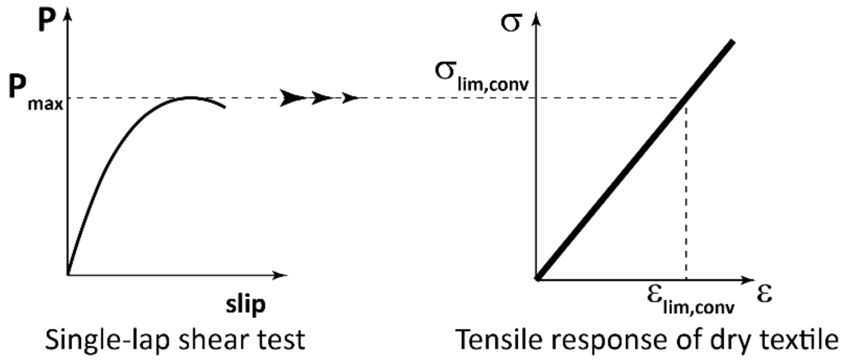


*Figure 1 Evaluation of the conventional limit stress and strain (adapted from EAD)*

Additional tests are specified in the Italian and European documents to assess the pull-out strength of anchorage solutions, typically in the form of rolled up fabrics grouted within holes drilled in the substrate material.

### *3.3 Long-Term Properties*

The effect of exposure to different environments on the tensile strength of the composite system is assessed in all guidelines. The same environments are specified in all three documents, including exposure to water, alkali, saltwater, as well as freeze-thaw, dry heat and fuel, with conditioning periods of 1000 and 3000 hours. Both AC434 and the Italian guidelines impose a minimum strength retention of 85% and 80% after a 1000 and 3000 hours exposure, respectively. The European Assessment Document prescribes the same testing protocols, but does not impose any minimum requirement on strength capacity after exposure. In addition to the environmental conditioning of the composite system subjected to direct tension, accelerated tests are also prescribed in the EAD to assess the long-term bond performance. The EAD also includes provisions for cyclic testing to address strengthening applications subjected to seismic (low number of cycles) and fatigue (high number of cycles) actions.

*Table 2 Main philosophy of the qualification frameworks*

| Guidelines | Scope | Main performance criteria |
|---|---|---|
| AC434 | – To determine design characteristic values<br>– To provide a set of rational assumptions and design equations | Short-term properties: no minimum requirements<br>Long-term properties: minimum strength retention values |
| Italian Guidelines | – To determine design characteristic values<br>- Compliance to the criteria specified in this document is required for a system to obtained appropriate qualification and to be used in structural strengthening applications according to "NTC 2018" [7]. | Short-term properties: no minimum requirements<br>Long-term properties: minimum strength retention values |
| EAD | – To determine design characteristic values<br>- This document offers a voluntary procedure to the suppliers to draw up the declaration of performance and affix the CE marking, for cases where a product is not fully covered by harmonised European standards. | Short-term properties: no minimum requirements<br>Long-term properties: no minimum requirements |

## 3. Performance requirements

Table 2 summarises the main scope of the examined guidelines. All documents are designed specifically to provide a framework that can be used to test, validate and qualify FRCM/SRG strengthening systems. The mechanical properties determined through the implementation of the proposed procedures are to be taken as characteristic values and can be used directly in design. Although the short-term mechanical properties of the systems being qualified do not require to meet minimum performance criteria, minimum strength retention values are imposed by AC434 and the Italian guidelines when assessing their long-term properties. The European Assessment Document, on the other end, does not impose any limitation on long-term performance and provides a more flexible framework for the development of systems that can be used in a wider range of structural applications (e.g. rapid repair and temporary strengthening solutions).

## 4. Concluding remarks

The main concluding remarks are summarised in the following:

- The three documents are based on a different underlying philosophy and different tests are required for the qualification process, thus limiting the adoption of strengthening systems to single market areas
- Although aiming at providing characteristic design values, the use of a different methodology to perform the direct tensile test can potentially lead to the same system being characterised by a different mechanical performance.
- The European Assessment Document does not impose performance limits and provides a more flexible framework for the development of systems that can be used in a wider range of structural applications.
- Despite the lack of standardised testing protocols, the three guidelines include similarities and can provide an excellent basis for the development of international standards.

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[6] EOTA (European Organization for Technical Assessment). SRG (Steel Reinforced Grout) kit made of steel micro-wires, fiberglass mesh and mortar. EAD340275-00-0104 Externally-bonded composite systems with inorganic matrix for strengthening of concrete and masonry structures. (to appear)

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