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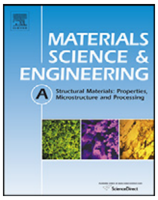

Contribution to direct tensile testing of textile reinforced concrete (TRC) composites

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ABSTRACT

While the development of TRC (Textile Reinforced Concrete) in recent years is undeniable, validated experimental protocols and standards are slow to take hold. By drawing judiciously from previous studies, this work aims to identify and propose contribution to direct tensile test for design purpose which is reliable, efficient and relatively easy to implement. The results obtained on the basis of a large series of experiments involving the laminating technique and the use of field measurements (photogrammetry measurement) have permitted the validation, based on five criteria (considered to be the most relevant), of the test protocol in a design context. The limitations of the protocol were identified, including the poorly reproducible nature of the initial zone and the impact of implementation defects (e.g. dissymmetry of reinforcement in the thickness of the TRC composite and the warping of specimens).

1. Introduction

TRC composites have attracted particular attention for ten years now, with a substantial increase in scientific publications and important projects concerning them (particularly in Germany) leading to a significant increase in the knowledge of this innovative composite. To extend its use, it is important to use standardized characterization tests which are simple to implement and which provide reliable, relevant, comparable and reproducible results. This work draws on tests which have already been undertaken to propose and validate an experimental procedure satisfying these requirements. The scope of the investigation is limited to the field of static load.

As TRCs are primarily used under tensile stress, two types of characterization procedure have been studied: direct tensile characterization [1–5] and tensile characterization by bending [6]. Although there is no published comparison of the two tests, one might well question the appropriateness of the bending procedure in that, beyond the non-“pure” nature of the test, it is particularly difficult to position the reinforcement, this being important due to the impact that accidental eccentricity can have on the quality of the results. There is a plethora of procedures for the TRC direct tensile test [1–3,5,7] (Fig. 1), which may be added to the ferrocement direct tensile test [8,9]. They differ primarily in: the shape and dimensions of specimens, the nature and configuration of end plates and clamps as well as displacement rate and the instrumentation. The ease of implementation is highly dependent on the choices made.

Four shapes – each the result of a compromise between ease of implementation and the requirement to limit stress concentrations induced by the clamps – were identified. The rectangular parallelepiped [1,2,4,7] is easy to implement. The dumbbell [3], for which the specimen section was gradually increased at its ends and a perforated metal plate was placed at mid-thickness to ensure the transmission of force. This configuration seems attractive in that it overcomes the effects of the differentiated shrinkage between the sides of the plate by the use of a vertical mold. However, while the slight additional cost induced by the particular shape of the mold is not a real obstacle, the difficulty of perfectly positioning the perforated plate and the relative unsuitability of this type of implementation for thixotropic mortars can be unacceptable. In [7], a bone-shaped specimen was used. This required expensive molds and particular care in implementation. In [5], a V-notched parallelepiped was used to locate the failure. The test may be useful for evaluating the strength of the TRC, but the imposed location of the first crack (in the V-notched zone) prevents measurement of the overall behavior and limits the scope of the results.

Various methods have been used to transmit tensile load from machine to specimen. Standard clamps were chosen in [1,2]. The relevance of these clamps is questionable, in view of the fragility of the mortar and the impact on the fibers in the immediate vicinity of the clamps, the non uniform character of the stress distribution over the section of the material, the continuous redistribution of stress, and the possible presence of interlaminar shear stress. In [7], the clamps were adapted for bone-shaped specimens. These clamps, conventionally used in the tensile characterization

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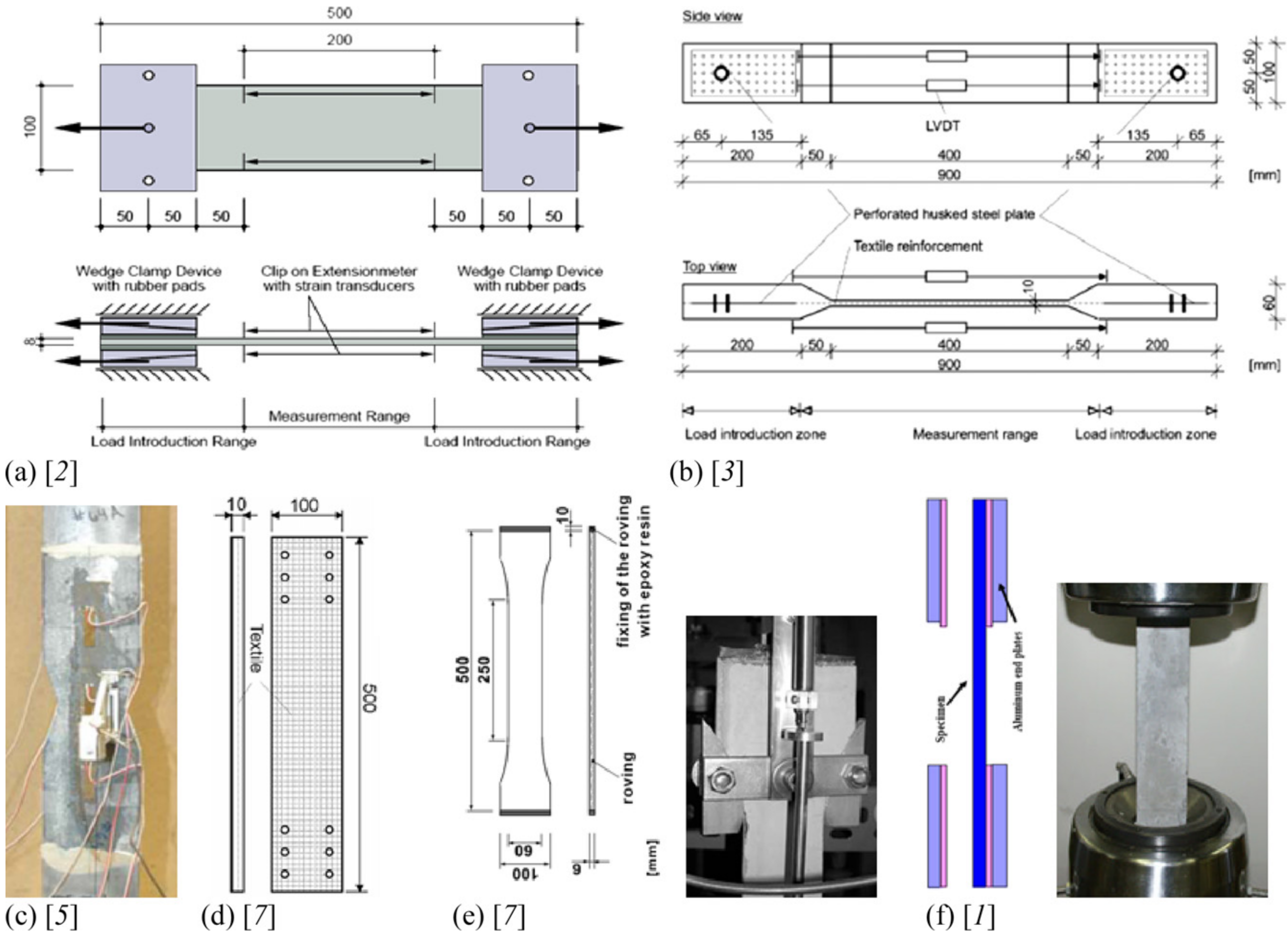

(a) [2]
(b) [3]
(c) [5]
(d) [7]
(e) [7]
(f) [1]

Fig. 1. Different tests for direct tensile characterization.

of mortars, have some drawbacks – the first being the introduction of a parasitic compressive force in the end plates of the specimen, which may artificially increase textile–mortar interaction and, by extension, TRC strength, thus becoming unsafe. Finally, as in [3,7], stress can be transmitted through one or more steel cylinders passing through the specimen at the end plate. Little information is available on the part used to transmit the tensile forces to the cylinder, but its interest is obvious, to judge from the parasitic bending moment induced by the positioning of this element.

Although the measurement analysis method for average stress (which is applied either to the TRC cross-section or to that of the yarns parallel to the loading direction) vs. average strain (considered uniform) seems to have been established, the procedures for measuring deformation diverge. Strain gauges are used in [5], but they can be quite inadequate in the case of multi-cracking behavior. In [1], the displacement of the clamps of the test machine is measured; this is certainly of interest, but it is inadequate for describing the ultimate tensile behavior of TRC because of the integration of the peripheral cracks, which are more sensitive to the pull-out effect (behavior observed by Hegger et al. [3]), in the measurement zone. In [3], however, the movement from end plate to end plate is measured with LVDT (Linear Variable Differential Transformer) displacement transducers. This probably improves the quality of the results, but suffers from the same limitations as the test in [1] – the difficulty of taking the pull-out phenomenon into account when measuring average strain [2], sets the measurement zone away from the end plate by placing two LVDTs in the central part of the specimen; this seems to be more appropriate.

Specimen lengths vary substantially, from 50 to 90 cm [3], while the generally used width is 10 cm. In addition to ease of implementation and the representativeness of the measurement area, the dimensions should be adapted to limit the impact of the Poisson effect in uniaxial stress.

Finally, while all the authors favor a constant displacement rate, it does vary significantly between them: 0.5 mm/min [7], 1 mm/min [3] and 10 mm/min [10]. At this stage it is difficult to assess the validity of these values. Because the displacement rate is dependent on the length measured, it appears that speeds close to 1 mm/min are relatively more in line with static characterization, for 200 mm gauge length. This brief literature review raises two points. The first is that all the designed and developed tests are useful and interesting but they are not equal and are more or less attractive, depending on the criteria used (ease of implementation, quality of results, overall behavior, etc.); they can, therefore, be improved. The second, more surprising, point is that no explicit validation is yet available. So the present study aims to design, develop and validate a direct tensile characterization test. Only the procedure using laminating technique, a priori the worst case, notably in terms of defects, will be discussed, but it can obviously be transferred to other types of implementation.

2. Direct tensile test design

2.1. Implementation and specimen dimensions

Implementation by laminating technique involves a wooden mold (use plaxiglas or steel is also possible) of 600 mm × 400 mm