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On the design of shear-strengthened RC members through the use of textile reinforced mortar overlays

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ABSTRACT

Textile reinforced mortar (TRM) is a promising alternative to the FRP retrofitting solution for shear strengthening of reinforced concrete (RC) beams, based on the experimental results presented so far in the literature. Thus, the development of reliable and accurate design models for shear strengthening of concrete members with TRM is required for enabling their wider use in real applications. The available experimental data in the literature are limited and in most cases, a detailed description of the failure modes observed in the TRM jackets and information related to the characteristics of the textile material and the mortar strength are missing, complicating the development of design guidelines. In this paper, a design model to calculate the contribution of the TRM jacket to the total shear resistance was developed using all the well reported available data that were grouped based on the observed failure modes. Specifically, local damage of the jacket including slippage of the fibres through the mortar constitutes a recurring failure mode in concrete beams strengthened in shear with TRM jackets, apart from debonding of the jacket from the concrete substrate including peeling-off of the concrete cover or fracture of TRM jacketing that are also observed in case of fibre reinforced polymer (FRP) jacketing. The key parameters affecting each failure mode were defined and design formulations to calculate the contribution of the TRM jacket to the total shear resistance of RC beams for each failure mode were suggested, whereas a criterion indicating when each failure mode is possible to be observed was also set for using the proper formulation for each TRM system.

1. Introduction and background

The use of textile reinforced mortar (TRM) for strengthening existing reinforced concrete (RC) members has been widely studied during the last decade [e.g. 1–3]. TRM combines advanced fibres in the form of textiles (with open-mesh configuration) with inorganic matrices, such as cement-based mortars. The same material can also be found in the literature with the acronym “FRCM” (fabric reinforced cementitious matrix) [e.g. 4]. TRM is a low-cost, resistant at high temperature [5,6], compatible to concrete and masonry substrates and friendly for manual workers material, which can be applied at low temperatures or on wet surfaces. For all these reasons, the use of TRM is becoming more attractive for the strengthening of existing RC and masonry structures than the widely used fibre-reinforced polymers (FRP).

The bond between TRM and concrete substrates has been studied by several researchers in the last decade [e.g. 7–14]. The TRM system has also been investigated for flexural strengthening [15–19], confinement or seismic retrofitting of RC elements [2,20–23] and strengthening of masonry elements [24–27] and has been found to be a promising solution. Selected case studies of actual applications of TRM in the construction field can be found in Ref. [28].

Shear strengthening of RC beams or bridge girders in old RC structures is one of the most common needs when assessing their strength under the current code requirements (e.g. Eurocodes [29]). This is due to insufficient amount of shear reinforcement, corrosion of existing shear reinforcement, low concrete strength and/or increased design load. Shear strengthening of RC beams with TRM jacketing has been investigated by several researchers in the last decade [1,29–43]. In these studies the main investigated parameters were the performance of TRM versus FRP jackets [1,35,36,40,41], the number of layers (1, 2, 3, 7) [32,33,35–37,40–42], the strengthening configuration (namely side-bonded jacketing, U-jacketing and fully-wrapped jacketing) [34,36], the end-anchorage of TRM U-jackets in T-beams (namely, mechanical anchorage system, fibre anchors and textile-based anchors) [32,35,40], the amount of internal shear reinforcement (no stirrups, stirrups of 0.6d

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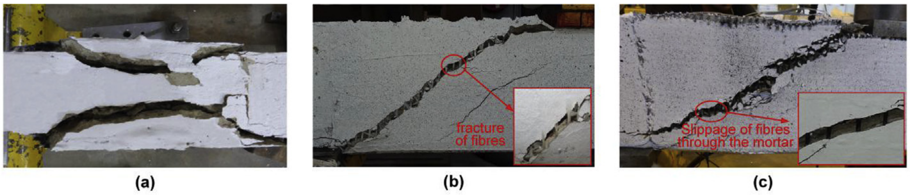

Fig. 1. Failure modes of RC beams strengthened in shear with TRM jacketing.

spacing and stirrups of 0.3d spacing) [41], the textile geometry [40,42], the shear span-to-depth ratio (varied from 1.6 to 3.6) [42] and the effect of high temperature (exposure temperature varied from 20 °C to 250 °C) [5].

In particular [35], concluded that TRM jackets are nearly 50% less effective than their counterparts in case of non-anchored jackets on the basis of two specimens retrofitted with U-jackets, whereas [36,40–42] reported that TRM U-jackets can be practically as effective as FRP U-jackets based on tests conducted on both medium-scale and full-scale T-beams. The shear resistance significantly increased with the number of layers [35–37,40–42] [36]. concluded that U-shaped jackets are much more effective than side-bonded jackets in increasing the shear capacity of beams, contrary to [34] that concluded that side-bonded and U-shaped jackets exhibited similar performance in terms of strength [32]. and [35] investigated the use of mechanical end-anchorage system in T-beams strengthened in shear with glass or carbon TRM U-jackets to delay the early debonding of the jacket from the concrete substrate and they concluded that the effectiveness of the TRM jackets was significantly improved [40]. used textile-based anchors that are versatile, non-corrosive, lightweight and compatible with the materials used for TRM jackets as end-anchorage system of U-jackets improving dramatically the effectiveness of the TRM jackets.

Based on the results presented in the recent study of [41], the contribution of the TRM jacketing to the total shear resistance, V_f, is not affected by the amount of stirrups. Recently [5], compared TRM with FRP jackets in shear strengthening of concrete beams subjected to high temperature concluding that side-bonded and U-shaped TRM jackets are much more effective than their counterpart FRP jackets when specimens are exposed to high temperature (100 °C and 150 °C). Finally [42], investigated the effect of shear span-to-depth ratio and the textile geometry in RC beams strengthened in shear with U-shaped TRM jackets. They concluded that the shear span-to-depth ratio has no effect on the failure mode nor the contribution of the jacket to the total shear resistance of the beams. The failure of all strengthened beams was attributed to debonding of the TRM jacket with peeling-off of the concrete cover.

Textile reinforced mortar (TRM) is a promising alternative to the FRP retrofitting solution for shear strengthening of RC beams, based on the experimental results presented so far in the literature. Thus, the development of reliable and accurate design models for shear strengthening of concrete members with TRM is required for enabling their wider use in real applications. The available experimental data in the literature are limited and in most cases, lack information related to: (a) description of the failure modes observed in the TRM jackets; (b) the TRM system (weight of textile fibre material, width and thickness of fibre roving, mortar strength or ultimate stress of the textile fibre material) or the RC beam (shear resistance of unretrofitted beam or concrete strength). Such incomplete information complicates the development of design guidelines.

The most common failure modes of RC beams strengthened in shear with FRP jackets are: (a) debonding of the FRP jackets with peeling-off of the concrete cover, in case of side-bonded (SB) or U-wrapped (UW) FRP jackets and (b) fracture of FRP jacketing mainly observed in fully wrapped jackets or glass, basalt and aramid SB or UW jackets. The aforementioned failure modes of RC beams receiving FRP jackets were also observed in RC beams strengthened in shear with TRM jackets. However, in case of TRM jacketing, local damage of the jacket including slippage of the fibres through the mortar constitutes a recurring failure mode. TRM is as effective as FRP jacketing in increasing the shear capacity of RC beams when failure is associated with debonding of the jacket [36,40–42], but it becomes less effective when failure is attributed to local damage of the jacket instead of debonding [36,42]. Therefore, the failure mode associated with the local damage of the TRM jacket should be investigated.

In this paper the parameters affecting the local damage of the TRM jacket are defined for the first time and design models for the calculation of the contribution (V_f) of TRM jacketing to the total shear resistance of RC members are developed taking into account the TRM characteristics (textile geometry and mortar strength). Details are provided in the following sections.

1.1. Description of failure modes observed in TRM-strengthened beams

The failure modes observed in RC beams strengthened in shear with TRM jackets are summarised as: (1) debonding of the TRM jackets with peeling-off of the concrete cover, in case of side-bonded or U-wrapped TRM jackets (Fig. 1a), (2) fracture of TRM jacketing mainly observed in fully wrapped jackets or glass and basalt SB or UW jackets (Fig. 1b) and (3) local damage of the jacket including slippage of the fibres through the mortar (Fig. 1c). The first two aforementioned failure modes were also widely observed in RC beams strengthened in shear with FRP jackets, whereas slippage of the fibres through the epoxy resin was prevented in FRP jackets (tested at ambient temperature) thanks to the high strength of epoxy resins usually used in FRP applications. It should be mentioned that the failure mode related to slippage of the fibres through the mortar was observed in TRM specimens strengthened with dry/uncoated textile materials [e.g. 35–37 and 40], whereas it was prevented when coated textile materials were applied [41].

The failure mode significantly affects the effectiveness of TRM jacketing. In particular, TRM is as effective as FRP jacketing in increasing the shear capacity of RC beams when failure is associated with debonding of the jacket [36,40–42], but it becomes less effective when failure is attributed to local damage of the jacket instead of debonding [1,35,36]. Full exploitation of the tensile capacity of the textiles is achieved when failure of specimens is associated with the rupture of the fibres in the TRM jackets.

1.2. Textile material

Textile mesh materials used as reinforcement of the TRM composite material consist of fibre rovings arranged in two or more directions. Fibre rovings are spaced at specific distance to allow for the formation of textile mesh (Fig. 2). The perforations between the fibre rovings enable the impregnation of fibres with the matrix material (mortar) and as a result they contribute to the mechanical interlock between the reinforcement and the matrix. Textile mesh material can be fabricated by weaving of warp and wept fibre rovings (woven textiles) or by simply holding the warp with the wept rovings using either stitching or thermo-sealing (non-woven or stitched textiles). Woven textiles are usually quite stable whereas the stability of non-woven textiles depends on the quality of stitching or thermo-sealing used to fasten the warp with the wept fibre rovings. In any case, coating of both woven and non-woven textiles with epoxy resin can improve even more the stability of textile material and the mechanical interlock between the