Construction and Building Materials 102 (2016) 884–892

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Trass-lime reinforced mortars in strengthening and reconstruction of historical masonry walls

Jerzy Jasieńko, Dominik Logoń, Witold Misztal *

Institute of Building Engineering, Wrocław University of Technology, Plac Grunwaldzki 11, 50-372 Wrocław, Poland

HIGHLIGHTS

- Paper describes possibilities for limiting first cracking, strengthening and deflection in relatively weak trass-lime mortars used in the reconstruction of historical buildings.
- The influence of mortar reinforcement on strengthening, repair and reconstruction of historical stone walls depends mainly on good anchoring ('matrix-reinforcement' adhesion).
- Most effective when assessing first cracking was reinforcement which had the best anchoring, largest strength and highest Young modulus value.
- The best results in terms of strengthening were achieved with hybrid reinforcement using highly-flexible carbon netting and low-flexible polypropylene fibres.
- It appears that continuation of the research programme should address application of fibres, which are non-linear, and spatially distributed.

ARTICLE INFO

Article history:
Received 13 March 2015
Received in revised form 7 August 2015
Accepted 10 August 2015
Available online 21 November 2015

Keywords:
Trass-lime mortars
Assessing wall strengthening and deflection
Stone walls
Strengthening
Reinforcing wall joints

ABSTRACT

The paper describes the behaviour of tensile joints in irregular external faces of stone walls and the results of laboratory testing of selected technologies for strengthening mortar, which can be applied in strengthening, repair and renovation of historical stone masonry walls, with special references to structures with irregular faces. A research programme of the Building Institute at Wrocław Technical University on the effectiveness of strengthening irregular, three-leaf stone masonry walls using modern technologies is also presented.

Special attention is devoted to technologies introducing stainless steel tie-rods Ø2 mm in diameter into joints in the external wall face in conjunction with filling joints with trass-based mortar (TUBAG TWM). Results of laboratory testing of plates ($40 \times 160 \times 138$ mm) of mortar reinforced with various types of synthetic fibres. Tests were carried out based on a four-point bending, which was treated as representative from the point of view the static behaviour of the reinforced tensile joints in the wall. The possibilities of curtailing the first cracking, strengthening and deflection of the trass-lime mortars are also described, in situations where the stress value exceeds that at which first cracks appear (FSD – first crack, strengthening, deflection). Composites were strengthened with dispersed polymer fibres, steel tie-rods, polypropylene and carbon netting. The analysis indicates that there is a need to identify a hybrid form of reinforcement as an effective solution for strengthening mortars in historical buildings, including joints in historical stone walls.

1. Introduction

Historical stone wall structures are significant elements of cultural landscapes and constitute also irrefutable testimony of past times. Preservation of this type of heritage is the responsibility of current and future generations of specialists from many fields and depends also on their interdisciplinary cooperation on many levels. Due to the historical value of the structures in need of repair and strengthening, conservation doctrine demands that techniques applied are reversible and do not influence the aesthetics of the historical substance of the structure. Solutions include introducing small diameter steel tie-rods and fibre composites into wall joints in conjunction with replacement of mortar [26,27].

Efforts to limit the brittleness of composites based on lime binding agents have been undertaken over many centuries through

* Corresponding author.
E-mail address: witold.misztal@pwr.edu.pl (W. Misztal).

http://dx.doi.org/10.1016/j.conbuildmat.2015.08.098
0950-0618/© 2015 Published by Elsevier Ltd.

application of, for example, reeds, stubble or horse hair. Research on different types of mortar dedicated to reconstruction of historical buildings has been presented in many publications. Brittleness of composites is reduced through application of additives and mixtures aimed at increasing durability. Reinforcement has been achieved through application of dispersed fibres, various types of tapes, mats and steel tie-rods [1–4]. Typically, small and dispersed forms of reinforcement are applied to control contractions and micro-cracking. But applications using composites are often not successful as there is a lack of effective anchoring in weak lime mortars [5–7].

The effectiveness of applying short fibres to strengthen composites has been demonstrated in the use of cement matrices [8], which due to contraction and higher durability are characterised by better adhesion of the 'fibre–matrix' than lime mortars. It has been determined that better results can be obtained when using matrices of higher durability. It has been shown that the degradation process in such composites can limit multiplication of cracking, mainly through use of short fibres and curtailing the propagation of cracking through application of reinforcement which is elongated and dispersed [9–11]. It has been determined that hybrid, dispersed reinforcement using cement composites translates into improved hardness, shock strength and durability in response to tensile stresses, which are the result of synergies arising from the action of fibres and grid [12–14].

Research to date has shown that elongated reinforcement is more effective when it comes to limiting macro-scale cracking in weak lime mortars. The effectiveness of FRCM (Fibre Reinforced Cementitous Matrix) materials for strengthening historical structures [15–18], also in areas subject to seismic activity, has been confirmed by many researchers and verified in field studies [19–24].

This paper presents the possibilities of curtailing the first cracking, strengthening and deflection of trass-lime mortars in situations where the stress value exceeds that at which first cracks appear (FSD – first crack, strengthening, deflection). The influence of reinforcing (steel tie-rods, polypropylene or carbon netting and dispersed fibres) on the mechanical properties of trass-lime mortars is also presented. One of the main conclusions is that solutions are needed, which can exploit synergies of several strengthening methods. It has been shown that deflection can be curtailed through the use of highly durable reinforcement with a lower Young modulus. The possibility of curtailing deflection in situations where stresses are greater than those leading to the first crack is especially significant for strengthening and repairing wall structures located in areas of seismic activity. The consequence is increased durability of composites, their deflection capability and safety in use.

In historical stone walls, mortar is characterised by lower durability parameters than other wall elements, which is why for most loading schemas, the process of destruction of the structure begins in joints. In the first phase, cracking results from tensile stresses (σ) and shear stresses (τ). For this reason, when describing the effectiveness of stone wall strengthening by means of technologies discussed here, an extremely important issue relates to the interaction of steel tie-rods, netting and synthetic fibres with mineral matrix and investigating the destruction schema for the joints after strengthening.

2. Testing semi-technical scale

The Building Institute at the Wroclaw Technical University operates a research programme aimed at assessing the effectiveness of strengthening three-leaf stone walls by means of technologies applied in several configurations.

Fig. 1. Cord locking device inside the wall joint before application of steel cords and mortar.

Fig. 2. Stainless steel cord inside cracked (opened) three leaf masonry wall joint under bending load, during failure.

In a situation where an intervention is needed in a historical stone wall with an irregular external face, the application involves introducing small diameter stainless steel tie-rods (1–2 mm) into the joints between wall elements, Figs. 1 and 2. The steel rods are fixed using mechanical connectors. The strengthening system is made up of the following materials: linear stainless steel tie-rods, characterised by small cross-sections, threaded anchors glued with epoxy composites and elements for tightening the tie-rods in the joints. After removing the mortar to the required depth the furrow created is cleaned.

Next, the anchoring elements in the form of threaded anchors are fixed with glue. The anchoring rods are applied at a density of approx. 4 rods/m^2.

The stainless steel tie-rods are introduced into the joints and joined to the anchoring elements, where the caps applied do not constrain the endings and do not exceed 20 cm. By screwing down the threaded anchoring element, the tie-rod generates an active tensile force, which contributes to increasing strengthening. The strengthening process culminates in filling out the furrows with mortar of higher durability and deflection capability (e.g., dedicated trass-lime mortars).

Material testing was also undertaken to determine the possibility of application and to estimate the effectiveness of technologies analogous to that presented above (based on applying reinforced mortar made from trass and limestone), using fibre composites –