Shear lap bond tests of geosynthetic-masonry assemblies under varying temperature: preliminary insights

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Abstract: Unreinforced masonry (URM) is intrinsically vulnerable towards natural hazards, including earthquakes, and are exposed to increasingly severe climatic conditions affecting their structural performance - posing a threat to Eastern Canada's aging building stock. Geosynthetic-reinforced masonry offers a non-invasive reinforcing solution whose effectiveness relies on the bond interaction among reinforcement, mortar and masonry substrate. Understanding the bond behavior mechanism at different temperatures is essential for a design that fits the Canadian climate, featuring extreme temperature swings. This study presents a series of single-lap shear bond (SLSB) tests described by RILEM technical committee 250-CSM on clay bricks assemblies reinforced with polypropylene (PP) geogrids. A total of 36 tests were performed in an environmental chamber across target temperatures from -30˚C to +40˚C. The preliminary results provide insight into the influence of temperature on the mechanical behaviour of clay brick assemblies, which support the development of climate-resilient retrofit strategies for existing URM in Eastern Canada and beyond.

Keywords: Structural repair and retrofit, geosynthetics, single lap shear test, unreinforced masonry and thermal conditioning

1 Introduction

Loadbearing unreinforced masonry (URM) are structural systems that constitutes a significant portion of building stock in Eastern Canada (Nollet et al., 2016) and remains one of the major causes of earthquake-induced socio-economic losses worldwide (Coburn & Spence, 1992). Most of Canada's pre-1970 existing URM buildings inventory are structurally vulnerable to the increasing impacts of climate change, the effects of aging and lack of maintenance (Council of Canadian Academies, 2019). Concurrently, The country is facing a severe housing crisis, characterized by significant housing shortage, contributing to rising homelessness and creating financial

strains for many Canadians (CMHC, 2022). In this context, it is evident that there is an urgent need to preserve and upgrade existing URM building as a part of a broader housing policy strategy. However, the National Building Code of Canada (NBCC) requires existing buildings to meet modern structural/energy efficiency standards in case of major renovations, posing technical and economical challenges. In Canada, structural retrofit and repair has mostly focused on traditional means of reinforcing such as steel, concrete (Korany et al., 2001), timber (Liu et al., 2025) and textile materials (Hamid et al., 2005). Among these, fibre reinforced polymer (FRP) and textile reinforced mortar (TRM), which are both considered externally applied reinforcement (EAR) (D'Antino, 2025). TRM and FRP systems have demonstrated promising results towards repairing and retrofitting concrete components, prompting a paradigm shift towards URM (Hamid et al., 2005). Both EAR are comprised of two distinct classes of composite materials, whereas FRP consist of high strength fibres embedded within an epoxy matrix and TRM typically contains high strength open-mesh fibre embedded within inorganic matrixes, e.g. mortar. The extensive surge of studies has resulted in the availability of several types of FRP and TRM products in the European market, which have been proven very useful for repairing and retrofitting existing URM structures following the 2009 L'Aquila earthquake in Italy with magnitude 6.3 (Da Porto et al., 2013). However, the research gap persists for the North American market, as different parameters such as severe cold weather may dictate and influence their structural behaviour. Therefore, geosynthetics which are still primarily utilized to enhance and stabilize earth structures and geotechnical applications (Andrejack & Wartman, 2010) are being introduced as an emerging strengthening technique for URM. Inspired by TRM systems, the following study examines the temperature-dependent shear bond behaviour of URM assemblies strengthened with polypropylene (PP) geogrid which is manufactured exclusively for North American weather. The testing campaign include conducting single lap shear bond (SLSB) test in accordance with RILEM 250-CSM (2018) at different temperatures ranging from -30 ˚C to 40 ˚C. The retrofitting technique is conceived as a low-cost, climate resilient and non-invasive for URM building in Eastern Canada. The novelty lies in the usage of geogrids tailored for geotechnical applications as an alternative repairing strategy for Canadian climatic conditions, with an overarching goal of targeting life-safety (LS) performance levels, as prescribed by ASCE 41-23(2014) and chapter 5 of the NBCC.

2 Brief overview of shear bond mechanics

Numerous efforts have been made to accurately characterize the mechanical behaviour of textiles and textile-strengthened masonry elements with publications dating back to 1998 (Kolsch, 1998). In contrast to FRPs, stress-strain curves derived from tensile testing on textiles are insufficient, whereas the use of a cementitious matrix

has its unique influence on the interface between the matrix and textile, as well as on the interface between the matrix and masonry substrate. For the abovementioned reason, it is necessary to emphasize on the fundamental principles governing the shear bond behaviour in URM-reinforced with textiles, which highlights the importance of the conducting SLSB. A typical SLSB test would comprise of an initial phase during which both textile and the matrix are in the linear elastic stage, microcracks begin to propagate in the matrix – depending on the mortar-to-textile bond – and the grid starts slipping, dissipating energy by friction. Once the stresses exceed the maximum tensile stresses of the matrix, no further cracking occurs and the load is solely resisted by the grid. Indeed, the combination of textile, matrix and masonry substrate will further complicate the accurate characterization of textile-strengthened masonry. According to the recommendations of RILEM 250-CSM(2018), six possible individual or mixed failure modes are identified in the literature: (A) cohesive debonding within the substrate, (B) detachment at the matrix/support interface, (C) detachment at the textile/matrix interface, (D) textile slippage within the matrix, (E1) Textile rupture outside the mortar matrix and (E2) textile failure within the matrix.

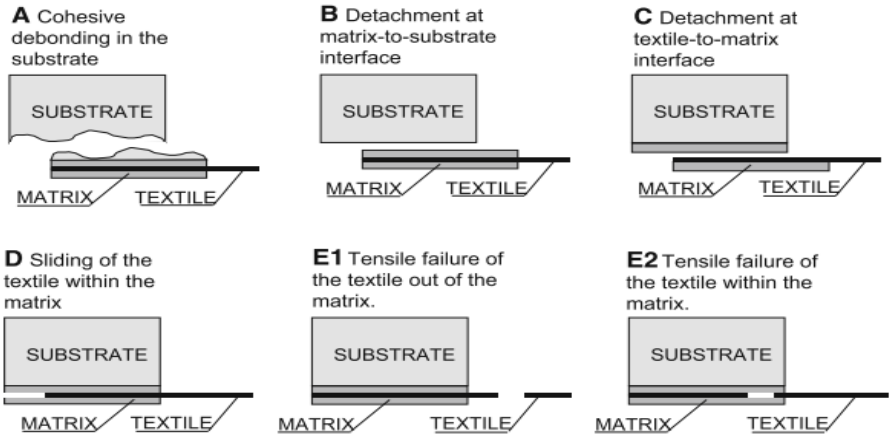


Fig. 1 Failure modes for SLSB (de Felice et al., 2018)

Beyond the ultimate capacity and ductility enhancement provided by textile-reinforced masonry, an equally critical consideration in the design lies within the durability of the constituent materials. Several studies stemming from Europe have sought to study the effect of temperature on similar retrofitting systems by executing SLSB to characterize the temperature-dependent mechanical performance(Ferretti et al., 2022). Ombres et al.(2018) investigated the influence of thermal conditioning on the overall response of four TRM systems by conducting a displacement control SLSB at a rate of 0.003 mm/s to specimens exposed to 20˚C, 100˚C, 150˚C

and 200˚C. The findings showed a clear decreasing trend in peak loads as the temperature increases. Despite the efforts in characterizing effect of temperature on the strengthening systems, a common limitation among the abovementioned studies is that the temperature ranges did not extend below the 0˚C threshold - depicting the conditions typically found in Eastern Canada.

3 Experimental shear lab bond testing

URM and potential PP geogrid reinforcing systems would certainly be exposed to a severe temperature swing and varied environmental conditions in Eastern Canada. The experimental campaign hence comprised of a series of characterization tests on mortar, bricks and proposed geogrid under various conditioning, temperatures and testing protocols. A total of 36 SLSB tests were conducted, using an MTS insight electromechanical testing system equipped with a 5 kN load cell and a temperature chamber. The temperature chamber used was a thermcraft medium-range laboratory oven with both heating and cooling capabilities, a built-in thermocouple and a cryogenic cooling system connected to a tank of liquid nitrogen, figure 2(a) shows the testing setup with the climatic chamber. To adapt the recommendations of RILEM technical committee 250-CSM (2018) to our specific needs and equipment, some modifications were introduced. The guidelines prescribed a bonded length of 300 mm and an unbonded length of at least 400 mm; however, limitations associated with climatic chamber size, dimension of the brick units and the ductile PP behaviour at elevated temperature e.g. 40 ˚C, all risked exceeding the stroke capacity of the MTS machine used. Consequently, the bonded length was reduced to 150 mm and the unbonded length to 300 mm, figure 2(b) and (c) shows a schematic illustration of the specimen configuration in MTS machine and specimen's dimensions.

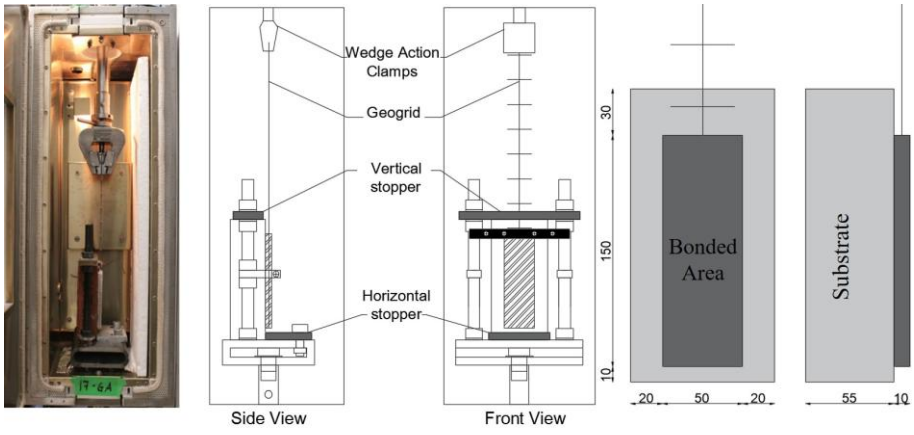


Fig. 2 SLSB test setup: (a) Specimen inside climatic chamber, (b)Schematic front and side view and (c) Specimen's dimensions

3.1 Experimental campaign overview

The SLSB testing samples were prepared in batches corresponding to the six temperature intervals using type O mortar and new moulded clay bricks (Glen-Gery 53 DD) with nominal dimensions of 190 mm x 90 mm x 55 mm. The compressive strength (fm) of twelve 50 mm x 50 mm x 50 mm mortar cubes was determined via uniaxial monotonic loading test as per the CSA-A179 (2014) after a 28-day curing period. The flexural strength (fmf) of 200 mm x 50 mm x 50 mm mortar prisms was assessed according to ASTM C-348-21. A 24-hr absorption and compressive strength (fb) tests were also performed on clay bricks according to the CSA-A82 standards (2018). The results are summarized in table 1. Moreover, the ultimate tensile strength (Ft) of PP single-rib geogrid described by the manufacturer is also reported.

Tab. 1: Measured properties of materials used

Material	Property	Mean compressive strength (COV)	Sample type	No. of samples tested
Brick	fb(MPa)	70.6 (8.30)	Full brick	5
	Ebf(MPa)	17.3 (13.5)	Full brick	5
Mortar	fm(MPa)	3.93 (18)	Cube	12
	fmf(MPa)	0.99 (42)	Prism	10
PP geogrid	Ft(kN/mm)	37.59	Single rib	N/A

Following the 24-hr absorption test and with the intention to improve the substrate - to - matrix adhesion, clay brick are laid down with bed face up, scraped with a metal wire brush and cleaned with compressed air to remove dust. A 5 mm layer of mortar is then applied, after which a single yarn of PP geogrid is gently positioned and pressed into the mortar layer for a total length of 150 mm, leaving 300 mm of bare grid outside the bonded area. Finally, a second 5 mm mortar layer is casted on top of the grid. All the specimens are then left to cure for 28 days in a humidity-controlled chamber (30%-70% RH). Figure 3 (a), (b) and (d) shows the preparation steps. Following the RILEM standards, SLSB specimens restrained by a rigid steel frame in two positions as shown in figure 2(b), preventing overturning or vertical displacements.

With the aim of producing a homogeneous stress distribution among the single-rib geogrid and the mortar matrix, wedge grips were used to clamp the geogrid and were connected to the load frame by means of extension rods to ensure that the whole setup remains within the climatic chamber. All the tests were conducted under displacement control at a of 2 mm/min rate.

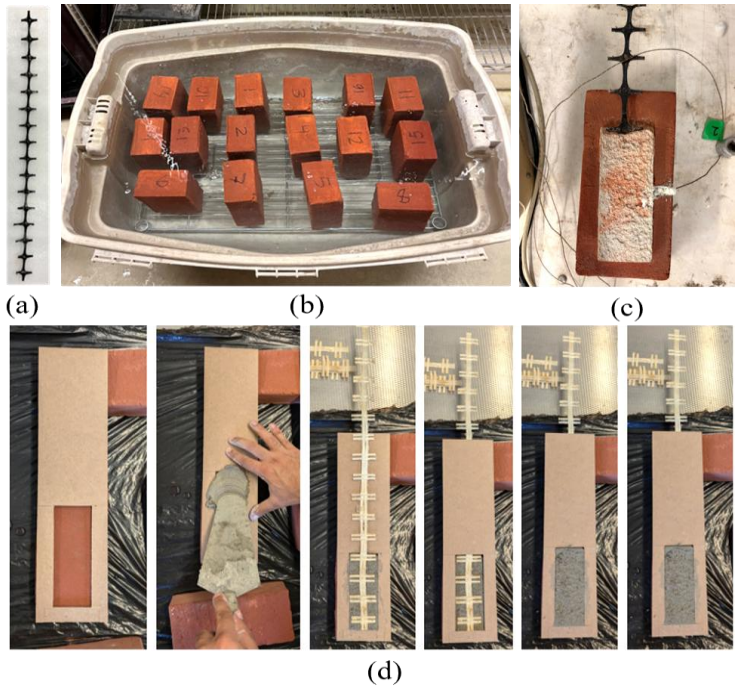


Fig. 3 (a) PP geogrid single yarn, (b) water-soaked clay bricks, (c) Thermocouple embedded in SLSB specimen and (d) Mortar overlay and geogrid application

Furthermore, to capture the temperature profile within the SLSB assemblies and verify the time required for specimens to reach each target temperature, specimens were first placed in a conventional oven to remove residual moisture. Thermocouples were then embedded at the substrate-to-matrix interface to monitor the internal temperature, as shown in figure 3(c), while the climatic chamber temperature was recorded using a built-in sensor. Relying on these data, the time required for each interval was determined.

3.2 Experimental results

During the conditioning process, the temperature evolution showed a rapid initial increase followed by a gradual progress towards reaching the target temperature. This behaviour is consistent with Newton's law of cooling, whereby the instantaneous rate of heat transfer is proportional to the temperature difference between the specimen and the climatic chamber. Notably, the time required for specimens to reach 0 ˚C was nearly three times the time needed to attain -30 ˚C, a disparity that is likely attributed to the presence of moisture within the porous materials. Each specimen was exposed to the respective time for each temperature and immediately tested in accordance with the guidelines of RILEM. The results of PP SLSB specimen tests are reported in table 3 in terms of Peak load, peak displacement and failure modes. Specimens conditioned at sub–zero target temperatures exhibited a notable strength increase relative to RT specimens, with average peak load gains of 9%, 26% and 7 % for samples tested at 0, -20 and -30 ˚C, respectively. This strength enhancement was accompanied with a reduced displacement capacity. Conversely, specimens tested at 40 ˚C experienced a 15% reduction in peak load and nearly double the displacement compared to RT specimens. These trends are displayed in the graph reported in figure 6.

Tab. 2: Reported results for SLSB PP geogrid

Target temp. (˚C)	Peak load (kN)	Peak displacement (mm)	Dominant failure mode
40 ˚C	0.90 (2.19)	84.3	Geogrid rupture (E1)
20 ˚C (RT)	1.06 (6.69)	48.58	
0 ˚C	1.03 (25)	21.02	Mortar debonding (B)
-10 ˚C	0.87 (28)	10.29	
-20 ˚C	1.30 (9.5)	20.63	
-30 ˚C	1.14 (18.3)	11.36	

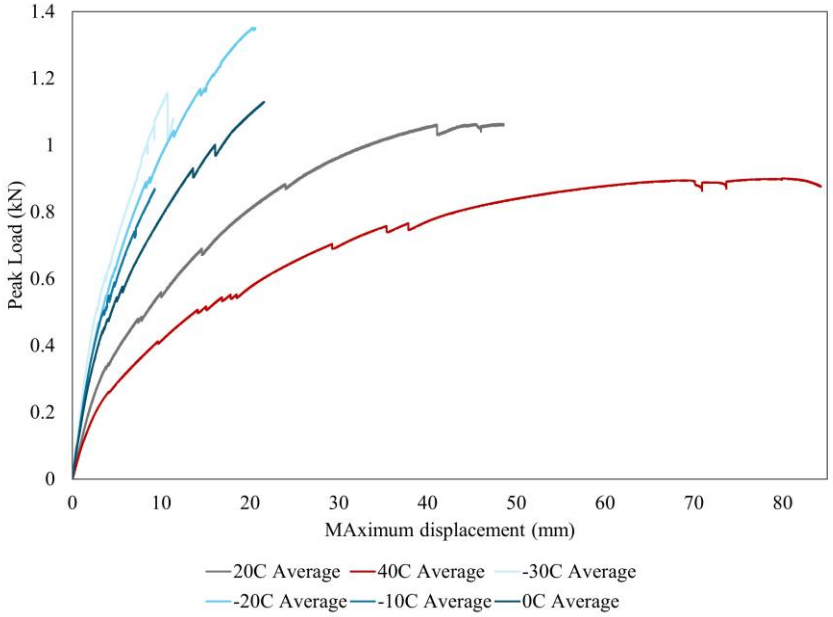


Fig. 4 Peak load vs peak displacement

In table 3, the failure modes are reported corresponding to the dominant mechanism observed during testing, as illustrated in figure 1. At RT and 40 ˚C, specimens predominantly exhibited failure mode E1 with the propagation of multiple cracks prior to complete failure. The elevated temperature allowed a more ductile response, leading to greater elongation before failure, likely associated with the additional ductility could be attributed with the PP behaving in a more viscous manner, with the junctions' exhibiting distortion at failure. At lower temperatures, failure mode B was dominant and occurred with no visible crack prior to failure. This can be clearly seen in terms of peak load and displacement, as the temperature decreased, the peak load increased and specimens exhibited lower displacements. The increase in peak load is attributed to the PP geogrid approaching its glass transition temperature, which restrains molecules mobility and results in an overall stiffer reaction. Additionally, the mortar matrix becomes stiffer which leads to higher initial load capacity but a more brittle and abrupt failure, consistent with mode B.

4 Conclusions

In the present study, the influence of temperature on the shear-bond performance of clay bricks reinforced with PP geogrids is explored through SLSB testing following

the guidelines of RILEM 250-CSM. All tests were conducted inside a climatic chamber at a target temperature ranging from -30 ˚C to 40 ˚C. The selected target temperatures represent the conditions encountered by Eastern Canada's URM building stock due to the climate change effects. The following conclusions were drawn:

- A reduction in peak-axial load was observed with increasing the target temperature, reaching 15% when comparing RT to 40 ˚C. This reduction was accompanied by a clear ductility enhancement with 70% increase.
- Specimens at low temperatures exhibited minimum displacement values indicating a brittle behaviour. Conversely, displacement values increased as the temperature elevated.
- The effect produced by lower temperatures led to reduced ductility and a shift towards a more brittle failure, with specimens predominantly exhibiting failure mode (B). In contrast, at RT and 40 ˚C, the dominant failure mechanism was geogrid rupture outside the mortar matrix (E1).

Preliminary results presented herein confirm the proposed PP geogrid repair and retrofit solution might be a viable (yet under-explored) approach for enhancing the resilience of existing URM buildings in Eastern Canada. Ongoing work aims to investigate large-scale specimens and alternative materials such as fibreglass geogrids.

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