THIN BED MASONRY SYSTEM: REVIEW AND FUTURE PROSPECTS

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Abstract

Masonry is one of the most ancient construction materials in the World. When compared to other civil engineering practices, masonry construction is highly labour intensive, which can affect the quality and productivity adversely. With a view to improving quality and in light of the limited skilled labour in the recent times several innovative masonry construction methods such as the dry stack and the thin bed masonry have been developed. This paper focuses on the thin bed masonry system, which is used in many parts of Europe. Thin bed masonry system utilises thin layer of polymer modified mortars connecting the accurately dimensioned and/or interlockable units. This assembly process has the potential for automated panelised construction system in the industry setting or being adopted in the site using less skilled labour, without sacrificing the quality. This is because unlike the conventional masonry construction, the thin bed technology uses thinner mortar (or glue) layer which can be controlled easily through some novel methods described in this paper. Structurally, reduction in the thickness of the mortar joint has beneficial effects; for example it increases the compressive strength of masonry; in addition polymer added glue mortar enhances lateral load capacity relative to conventional masonry. This paper reviews the details of the recent research outcomes on the structural characteristics and construction practices of thin bed masonry. Finally the suitability of thin bed masonry in developing countries where masonry remains as the most common material for residential building construction is discussed.

Keywords: Thin bed masonry, glue mortar, bond strength, construction, masonry walls

1.0 Introduction

Masonry is still the most common material for housing in the world, both in the developed and developing economies. The construction of masonry is a simple process: - that involves laying of stone, bricks or concrete blocks on top of each other, either with or without the mortar binder. Therefore, Masonry can be regarded as a composite material made of units and mortar. Units can be in the form of bricks and blocks produced from clay, concrete and calcium silicate. Natural stone is also used as units, but in limited applications. Subsequently conventional mortar mixes are based on Portland cement, lime or plasticiser and sand. The main advantage of a masonry wall construction system is that the single element fulfils several functions including structural stability, fire protection, thermal and sound insulation, weather protection and sub-division of space. In addition it can be clearly seen from the historical structures, the durability of masonry is a very positive feature; with the appropriate selection of materials, design methods and construction processes, masonry can remain serviceable for many decades and even centuries.

Similar to concrete, masonry is weak in tension; but unlike concrete, masonry does not require extensive formwork. Therefore, masonry is still cheaper but can suffer from poor quality when traditional masonry is constructed by not well trained labour. Training labour is an exhaustive process; many developed countries find the training scheme is an economic challenge as the society does not adore brick laying as a well regarded profession and many skilled labour do not find time for training jobs.

With the increase in new constructions, demand for skilled labour is on the rise and the availability of such people is on the decline; consequently masonry industry is adversely affected. In the last century with a view to improving productivity and quality of construction of masonry concrete blocks, reinforced masonry, dry stack masonry and thin bed mortar masonry systems have been introduced and they have transformed and broaden the applicability of masonry. In particular thin bed masonry technology originated more than 15 years ago in the Europe. Nowadays thin bed masonry construction is practiced in Europe with autoclaved concrete units, calcium silicate units, perforated clay units and solid clay bricks for load bearing walls applications (Da Porto 2005).

2.0 General concepts of thin bed masonry

Thin bed masonry construction system relies on thin bed mortar joints which are created using a cement glue mortar. This glue mortar consists of cement, very fine inert additives and specially formulated polymers. In accordance with the Australian Masonry Standard (AS 3700) thin bed mortar should have a thickness of not less than 2mm and not greater than 4mm. The construction process of thin bed masonry is more automated than traditional masonry construction.

It is revealed in the literatures that the thin bed construction have been in practice, where the glue mortar bed is formed using a hand-held glue gun, where the glue mortar is pumped from a machine or else a box rolled along the bed ejecting the mortar achieving higher tolerance has also been practice to apply the mortar with accurate thickness (Zeus and Popp 2000). An alternative technique of forming thin bed masonry includes dipping the units in a mix of glue mortar or brushing of mortar on units prior to placing in a specific course of the wall is also practiced. These polymer glue mortar cure faster and allow erection of walls quicker than conventional construction.

Furthermore thin bed masonry wall construction utilise specifically engineered units of higher dimensional tolerance. The resulting product reduces the inconsistency of thin bed masonry construction that against conventional masonry, thus this enhancing the quality and reliability of masonry as a structural material. Furthermore Nicholas *et a.l*, (2008) listed some more advantages of thin bed brickwork, where higher flexural and shear strengths lead to a reduction in the need for structural support, the opportunity for more complex wall shapes, easier lifting and transportation of prefabricated panels and the omission of lintels. In addition Marrocchino *et al.*, (2007) pointed out reduction in mortar joint volume considerably improves thermal resistance since heat flow through masonry walls is predominantly occurring through the mortar joints.

3.0 Structural concept of thin bed masonry

The compressive behaviour of masonry is of central importance for masonry design, since masonry structures are primarily loaded in compression. It is a well established concept that the incompatible lateral deformation characteristics of mortar and unit (at the interface level) cause the initial cracks in masonry under compression. Because of the incompatibility of constitutive materials in masonry, the efficiency factor of masonry (masonry strength/unit strength) is very low, i.e. around 0.3-0.4. However the effect of the mortar joint thickness to the compressive strength of conventional masonry is well studied in the past and it is known that joint thickness adversely affects the compressive strength.

For a given unit height, increasing the thickness of the mortar joint will decrease the strength of the masonry. Da Porto (2005) has conducted thin bed masonry walletes compression tests and observed a 33% increase in compressive strength compared to the conventional masonry with 10mm joint thickness. As the joint thickness reduces from 10 to 2 mm the relative compressive strength is increases from 1 to 1.3 (Hendry *et al.,* 2004). Consequently the efficiency factor for thin bed masonry increased up to the 0.8-0.9 level. Therefore structures made with thin bed masonry walls would sustain under higher compressive loads and have increased stability.

The bond between the mortar and the masonry unit is perhaps the most vital property of masonry construction. Strong and durable bonded walls remain both watertight and strong enough to withstand stresses from winds and vibrations. Moreover the deterioration of masonry structures due to weather usually starts at the level of mortar unit interface. Thin bed masonry system utilising polymer modified cement as mortar, this cement type was primarily developed for improving mechanical aspects of conventional cement such as, the resistance to shrinkage cracking, good adhesion with substrate, and better waterproof qualities of in cement based applications (Ollitrault-Fichet *et al.*. 1998). Therefore polymer modified mortar is a better solution to improve the bond strength of masonry. Furthermore improved bond strength will provide durable masonry walls. It is reported from the studies conducted on thin bed masonry the characteristics of thin layer mortar and those of the block constituents enhance bond strength and in many instances exceed the modulus of rupture of unit.

Flexural tests results of thin bed dense concrete masonry conducted in UK (Kanyeto and Fried 2011) have shown that the flexural strength of thin bed masonry is significantly higher than levels specified in the British Code of Practice and both the mortar properties and the constituents of the parent material forming the block alter the joint strength resulting in enhancement of flexural tensile bond strength. The lateral load capacity of thin bed masonry built using solid dense concrete blocks with a thin layer of mortar, is up to four fold compared to blockwork constructed using conventional mortar. Colville *et al*.,(1997) studied the tensile bond strength of conventional masonry through the use of different polymer additives through direct tensile tests. They reported a significant increase in bond strength through the addition of polymers. However the parameters influencing bond strength of thin bed masonry is not well explored with polymer cement mortar.

Moreover in conventional masonry mortar joints always act as plane of weaknesses and most of the failures of masonry are though joints with high localisation of failure paths see fig 1. Since the bond strength is increased and the mortar thickness reduced in thin bed masonry, it tends to behave more as a concrete plate than conventional masonry, see fig 2. Therefore continuum mechanics that cannot be adopted to explain the behaviour of conventional masonry might well be able to apply reasonably for the analysis and design of thin bed masonry.

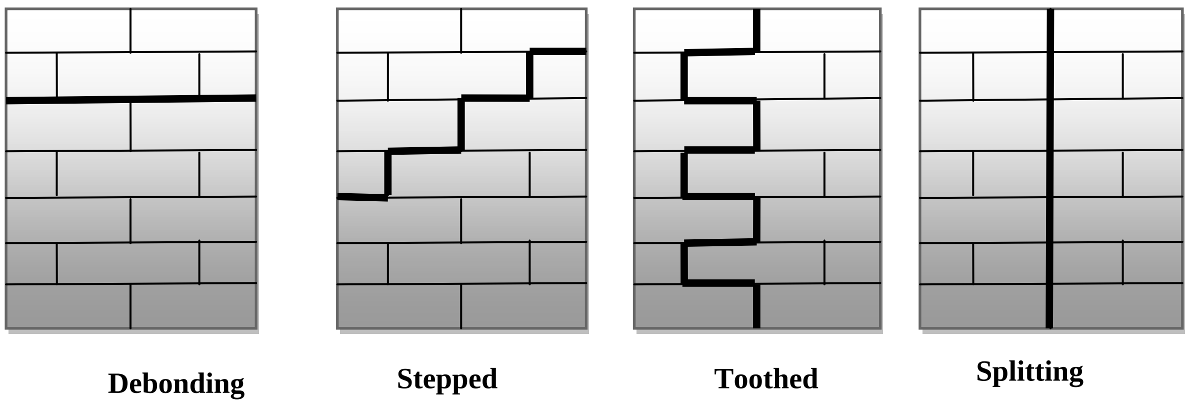


Figure 1: Common flexure failure modes of conventional masonry

In addition, masonry assemblages such as the shear walls, the infilled walls in framed construction or the walls supported on beams will be under normal stresses parallel and perpendicular to the bed joints as well as shearing stress along these joints. In other words, a state of biaxial stress state is common in masonry panels. Vermeltfoort (2005) conducted biaxial compression tests on thin bed masonry panels with different bed joint orientations and presented the strength properties. The following three phenomena were observed in the failure processes of the panels: (a) spalling of the bricks, with fragments of approximately 20mm (b) vertical splitting of specimen and (c) bending of specimen see fig 3.

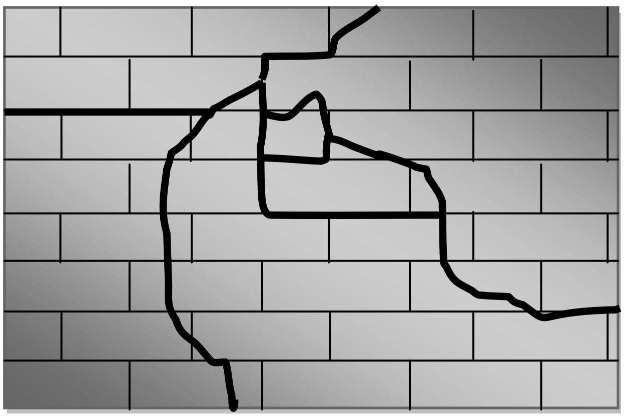


Fig 2: Typical flexural failure of thin bed masonry (Kanyeto and Fried , 2011).

From the specimen failure patterns, it was stated, that the high bond strength of thin layer of mortar created high stress concentration in joints which were not properly filled and spalling of these pieces occurred during the test at those locations. Where joints were better filled, less spalling occurred. Therefore when filling the mortar in thin bed masonry, care should be taken to ensure accurate filling of mortar between units.

Fig 3: (a) Biaxial test rig of thin bed masonry (b) failure of panel in biaxial compression Vermeltfoort (2005)

Conventional masonry exhibits distinct directional properties due to the mortar joints which act as planes of weaknesses; however it is shown from the biaxial compression results, that contribution of bed joint orientation to masonry strength is nominal. Therefore thin bed masonry can be rationally assumed to be an isotropic continuum in modelling, which would lead to computationally less expensive masonry models.

4.0 Present research progress in thin bed concrete masonry

In the Australian masonry standard (AS3700 2001) thin bed masonry design is only referred to with the masonry made with autoclaved concrete blocks (AAC). A short review of building codes in other countries reveals a lack of direct reference to specific codes relating to the thin bed concrete masonry designs. Therefore in order to develop standards relating to thin bed concrete masonry structures, research is underway at the Queensland University of Technology, Australia. However to develop a new masonry system, the research must be started at a basic constituent level, where compatible glue mortar binder should be developed to practice in thin bed masonry construction and the appropriate unit type should be used for the construction. In thin bed masonry dimensional tolerance of a unit is highly controlled, because a small variation in the unit height will alter the uniform application of mortar thickness (2mm).

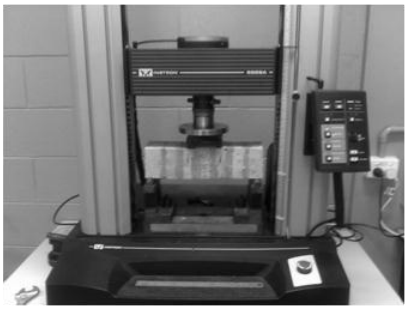
Characterisation of the flexural bond strength of thin bed concrete masonry, which is a part of the progressive research in thin bed concrete masonry, is presented here. Previously few flexural tests have been conducted on thin bed dense concrete masonry walletes and all have concluded that flexural strength of thin bed masonry is significantly higher than conventional masonry. However the above studies were have not taken into account the level of bond characteristics of thin bed concrete masonry, these would likely be different from conventional masonry, as polymer modified mortar is in use with thin mortar bedding thickness in thin bed masonry. Therefore some of the bond parameters would affect bond strength significantly, when compared to conventional masonry. Subsequently an investigation was undertaken to determine some parameters influence the flexural bond strength of thin bed concrete masonry.

In the investigation, three polymer modified mortars were used to determine the most compatible mortar for thin bed masonry application. Mortars were chosen with 2%, 3% and 4 % polymer contents by total weight. Furthermore to study the influence of application tooling, four techniques of mortar dispersion were attempted: (1) Brushing; (2) Roller discharging; (3) Dipping of units into the glue mortar bucket; (4) traditional trowelling. The glue cement mortar is requires only the addition of water. All three glue mortars were mixed to a workable consistency; a ratio of 250ml of water to 1kg of dry mortar mix was used.

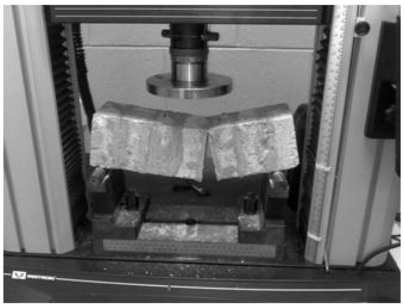
The constructed specimens were fully covered with plastic sheets and left undisturbed until testing fig 4(a). The testing of all specimens was carried out within 7-10 days after construction. Subequently the tests were performed using a 50 kN Instron machine fig 4(b) and the loading was recorded using the displacement speed of (0.3mm/min). The flexural bond strength was determined using four point bending (beam) test as per ASTM E518(2003). A similar procedure is also outlined in AS 3700 (2001).

From the test results, it can be concluded that flexural bond strength of thin bed masonry is higher than that of the conventional masonry. The AS 3700 (2001) specifics the maximum flexural bond strength of 0.2MPa for masonry design and if testing is carried out, the value can be increased up to 1MPa. It is regarded only on special circumstances, testing is carried out; therefore from the test results thin bed concrete masonry falls in to special masonry systems with higher flexural bond strength. For low (2%) polymer content sudden failure through interface was noticed fig 4(c).

(a)



(b)



(c)

(d)

Fig 4: Flexural bond strength test of thin bed concrete masonry carried out in QUT.

Moreover as the polymer content increases to 4%, the specimens did not fail suddenly even after the peak load reached and only cracks developed through the interface fig 4(d), hence better ductility of beam specimens were observed. The conventional masonry has been a quasi-brittle material; though reinforced masonry was introduced to improve the deformation characteristics of masonry. Yet there are some practical difficulties in incorporate reinforcement in masonry blocks and grouting the reinforced cores, which leads to ineffective contribution of reinforcement in masonry. Nevertheless observation of its ductility in thin bed concrete masonry is highly encouraging in structural perspective, which might eliminate the need of reinforcement to improve the deformation characteristics and flexural strength. However more research ought to be conducted on this masonry system to understand the complete structural behaviour.

5.0 Thin bed masonry in developing countries

Although thin bed masonry is regarded as a modern construction system, the concept of laying thin bed mortar in masonry had been in ancient construction practices in developing countries. For an example, studies carried out in ancient temples in My S’on archaeological area in Vietnam, revealed that there was a special construction technique used to bond bricks together with thin glue binder and they are still very strong and preserved with very small biological decay in the joints (Binda *et.al.*, 2006). Followed from the chemical analysis of binder showed that binder material was made from organic matters, and surprisingly same organic resins were found from the trees nearby the temples. This implies that the thin bed masonry construction technique might have had some links to the human civilisation, especially with the usage of bio-glue binders, as evidenced in the cited example, and scores of others in the places of historical importance.

One of the main challenges in developing thin bed masonry technique is to produce accurately dimensioned units – or units of strict dimensional tolerance, especially for their height. To maintain the 2 mm bed joint in thin bed masonry, the dimensional tolerance of the units should be in the order of ±0.5mm. This might be difficult for the fired clay brick units; however, concrete block dimensions can be controlled by proper mix design and curing strategies; through proper quality assurance process and care, with limited production recourses, zero slump concretes with low shrinkage characteristics can be produced in tropical climatic zones. Thin bed concrete masonry can, therefore, be further developed specific to the materials available in developing countries.

Another challenge faced by the construction industries in developing countries arise from the difficulty in maintaining a skilled and competitive work force. These difficulties and the changing demographic characteristics are compounded by rapid changes in the economic, social, organisational and technological environments in developing countries (Jayawardane and Gunawardena 1998). Therefore, many unskilled labourers are employed in their construction industries without proper training. This results in poor quality construction, high wastage and long term productivity decline in the industry. Since masonry construction is highly labour intensive, these factors greatly affect the quality of masonry construction. The studies conducted in labour performance and productivity of the construction industry in developing countries concluded that the labour productivity strategies can be easily improved by applying mechanisation of construction practice with simple equipments (Thomas 2002). In thin bed masonry, glue mortar is applied with specific and simple tools, which can be easily trained for least skilled labours to construct quality masonry walls and increase the labour productivity.

Thin bed concrete masonry can be produced with the desired quality of construction. Da Porto (2005) stated the thin bed masonry construction is two to three times faster than the conventional masonry construction. The 2mm joints will also help achieving the squareness of the walling better than the 10mm conventional joints as the later will tend to spread more than the former. As a result, even though the manufacturing costs of accurately dimensional blocks and polymer cement mortar are marginally higher than conventional masonry, this is more than offset by the reduction in labour, construction time and material requirements. When the system utilises thin bed (or, smaller quantities of mortar), the site wastage will also be reduced, which can lead to considerable material saving. Therefore, thin bed concrete masonry construction practice is an encouraging solution for labour productively and quality challenges in developing countries.

6.0 Conclusion

Masonry innovations were driven by many factors, including structural performance, economics, competition, performance issues, or labour scarcity. Thin bed concrete masonry construction is one such innovation that has the potential of significant structural and economical benefits. The background and research to date of thin bed masonry technology have been reported in this paper and suitability of thin bed construction in developing countries is explored. Further thoughtful research is needed for a complete understanding structural behaviour and to practice thin bed concrete masonry construction utilising local constituent materials and construction methods.

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