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## COMPOSITE MASONRY WALL TIES: Final Report





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# COMPOSITE MASONRY WALL TIES

## **Final Report**



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#### Introduction:

This project aimed at developing a prototype masonry tie using composite materials, which would fulfill structural requirements, be immune to corrosion and manufactured at a lesser cost. The project originated from the fact that current galvanized masonry ties do not meet new Standards. The alternative, stainless steel ties are 80% to 100% more expensive.

#### **Findings of project:**

Several prototypes were developed and tested, concluding that an adjustable tie can be manufactured from Glass fibre reinforced polymer composite (GFRPC). Specifically, the most promising tie would be used between masonry veneer and a concrete block backup wall system with 50 mm air space and 50 mm rigid insulation. The investigator made prototypes that meet current standards and show promise that they could be manufactured competitively.

#### **EXECUTIVE SUMMARY**

Corrosion of steel masonry wall ties, better understanding of their performance and the new standard (Connectors for Masonry: A370-94) call for the increase protection to steel ties led to the idea of developing them from materials which do not corrode and is the subject of this report. New generation of materials called fibre reinforcement polymer composites (FRCP) appeared to be an obvious choice for further investigation. FRCP earned their reputation as excellent materials for repairs and strengthening of concrete structures as well as potential materials to replace steel reinforcement in concrete in corrosive environment. Although their structural use is currently still minimal, it is expected that their use will increase. The potential for their increase in structural applications was made possible through the development of a manufacturing technique called pultrusion, which allows the production of shapes of constant cross-section with a particular fibre orientation at competitive prices.

Chapter 4 of this report provides background for further work in this report and also it is a summary of the state of the art of the current knowledge. Those who are interested in new work on composite masonry ties may want to skip this chapter and proceed to no. 5. Brief description of the content of chapter 4 follows. The history of masonry wall system evolution is described in section 4. 1. It was felt that this is necessary because the term cavity wall and veneer wall are not always properly used, often adopted meaning the same thing. The sight of the difference in behaviour between the two systems should not be lost as it has serious implications for the design of masonry wall ties. Section 4.2 summarizes rather large number of publications on corrosion related to masonry components which were reviewed. Section 4.3 summarizes the design criteria for masonry ties and section 4.4 on FRCP materials was included as a reference for those who are not so familiar with these materials.

Chapters 5 to 8 are dealing with the process of design and development of the prototype composite tie, extensive testing and their results.

Tests indicated that it is possible to design a composite tie which can conform to A370-94. Further, it was established that it is the strength of the material which governs the tie strength over the bond and buckling failures. As the material strength governs the tie design, it may be possible to further optimize the prototype presented in this report by adoption of newer, more advanced manufacturing processes which provide more control over the orientation of fibres.

#### RÉSUMÉ

Les problèmes de corrosion des attaches métalliques pour maçonnerie, la nécessité d'une meilleure compréhension de leur performance, de même que les exigences additionnelles de protection des attaches énoncées dans la nouvelle norme (Crampons pour maçonnerie CSA A370-94) ont incité des chercheurs à mettre au point des attaches faites de matériaux qui ne corrodent pas. Ce rapport traite de ces questions. Les matériaux de nouvelle génération comme les composites en polymère renforcés de fibre de verre semblaient tout désignés pour qu'on les étudie davantage. Ces matériaux jouissent d'une excellente réputation pour la réparation et le renforcement du béton, en plus d'être une très bonne solution de rechange à l'acier d'armature dans un milieu corrosif. Bien que leur emploi dans les structures soit minime à l'heure actuelle, on estime que leur utilisation augmentera. La possibilité des utiliser davantage ans les structures fait suite à la mise au point d'une méthode de fabrication nommée extrusion par étirage qui permet de fabriquer économiquement des sections à géométrie constante et dont les fibres sont orientées dans une direction donnée.

Le chapitre 4 du rapport présente un aperçu des travaux supplémentaires requis dans le domaine, ainsi qu'un résumé de l'état actuel des connaissances. Si vous êtes intéressé par les nouveaux travaux visant les attaches composites pour maçonnerie, vous n'avez qu'à consulter le chapitre 5. Voici un aperçu du chapitre 4. Dans la section 4. 1, on relate l'évolution des murs en maçonnerie, car les termes « murs creux » et « placage de maçonnerie » ne sont pas toujours utilisés correctement et, souvent, ils sont même confondus. La différence de comportement des deux assemblages ne doit pas échapper au concepteur, car celle-ci peut avoir des répercussions importantes sur la conception des attaches. La section 4.2 présente le résumé d'un grand nombre de publications sur la corrosion de composants pour la maçonnerie. La section 4.3 donne un aperçu des critères de conception pour les attaches à maçonnerie, et la section 4.4, qui porte sur les matériaux composites en polymères renforcés de fibre de verre, est fournie à titre de référence pour le lecteur qui connaît peu le domaine.

Les chapitres 5 à 8 traitent de la conception et de la mise au point du prototype, des essais exhaustifs qui ont été menés et de leurs résultats.

Les essais ont montré qu'il était possible de concevoir une attache composite qui répond aux exigences de la norme CSA A370-94. De plus, on a établi que la solidité de l'attache varie surtout en fonction de la résistance du matériau, plutôt que d'une défaillance du liaisonnement ou d'un flambage. C'est pourquoi, il sera peut-être possible d'optimiser davantage le prototype présenté dans le rapport en mettant en place un procédé de fabrication innovant qui permet une plus grande maîtrise de l'orientation des fibres.



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#### 1. INTRODUCTION

A masonry tie is a small piece of steel of many with many different profiles. It is light, easily handled and a fraction of the size of the wall. When installed, it is completely invisible; buried inside the wall.

Of course the tie has a purpose, as does every element used in engineering design. It plays an important role in modern wall systems developed for harsh climates. It connects two layers (wythes) of wall, inner and outer. The outer (exterior) wythe is masonry and the inner wythe is either a concrete block wall or a stud wall of steel or wood. The purpose of the tie is to connect these two layers. The connection fulfills one of the following functions:

- to make the two layers act together to resist the applied loads; either both gravity and lateral loads, or more commonly only lateral loads.
- to allow the outer skin to be thin and act as a first line of defence against the elements of the environment while the tie transfers lateral loads to the inner wall.

Thus masonry ties have an important structural role to fulfill. Their design is governed by national standards and the importance of their placement is recognized (for example Best Practice Guides in Canada). However, the steel tie is embedded in the mortar, exposed to air and pollutants, and passes through the cavity where moisture and air are present. The conditions in both environments are ideal for the corrosion process to occur. The result is the continuous loss of metal, so that eventually the tie loses its load carrying capacity and breaks. The failure of an individual tie is not visible and its manifestation, a local crack, may go unnoticed. During their life, masonry walls are subjected to expansion/ contraction due to temperature changes, wetting and drying, long term effects due to shrinkage, creep and expansion of materials, and carbonation. All these effects eventually lead to cracking. It is only when a number of ties fail that there is a noticeable problem, such as severe cracking or bulging, or even a partial collapse of the exterior wall.

Even when the problem manifests itself visually, its exact extent is difficult to determine without the removal of a large portion of the wall or tedious local investigation using a borescope. The forensic work to determine the state of masonry ties within a wall system is difficult and expensive. The remedial work is very expensive too because it involves large numbers of elements which need replacing. There are many reports of masonry tie failures ([1], [2], [3], [4], [5]) and costly repair work ([6], [7]). The obvious solution to the problem of failures and expensive repairs is to design masonry ties which besides giving adequate structural performance are corrosion resistant.

#### 2. OBJECTIVES

The problem of masonry tie failures has not remained unnoticed. The researchers, designers and contractors have looked into this problem and come up with a performance approach to the design of ties, rather than the design criteria which are more common for the other structural elements. This approach is now common in Europe and other English speaking countries. Corrosion is addressed by the specification of the minimum level of protection to base steel. The Canadian standard A370-94 [17] is based on a 50 year effective life for connectors and relates the level of protection to the environmental exposure. It recommends that all steel masonry ties in

buildings of less than 11 m in height, subjected to moderate and severe exposures, and those in sheltered exposures greater than 11 m in height be hot-dip galvanized to the prescribed coating mass. For buildings higher than 11 m in moderate and severe environmental exposures, the standard specifies stainless steel ties. The impact of the change from galvanized to stainless steel tie is a considerable increase in cost, 80 to 100%. It is this increase in the cost of the tie which prompted research into the application of a new generation of materials, known as "composites", to replace the stainless steel. The objective was to develop a prototype tie using the composite material, which would fulfill the tie's intended function without the corrosion problem.

#### 3. METHODOLOGY

To design a prototype tie, it is necessary to understand the function it performs, the properties of the material from which it is to be developed and current construction practices. The various stages of the project are outlined below:

- 1. Search of cavity wall construction literature and problems associated with this wall system.
- 2. Study of performance problems associated with the corrosion of steel anchors and ties in masonry.
- 3. Review of design standards for masonry ties and development of design criteria for masonry ties.
- 4. Study of properties of fibre reinforced polymer composites (FRPC) and their structural application.
- 5. Application of the design criteria for ties prepared above to fibre reinforced polymer composites (FRPC). Design of tie prototypes.
- 6. Testing of the FRPC prototypes to determine their properties. This study includes the impact of surface treatment and
- 7. profile variation.
- 8. Discussion of test results.
- 9. Conclusions and recommendations.

This report addresses each stage of the project in the section carrying the corresponding number except for items 1. to 4. which are discussed in sections 4.1. to 4.4. respectively.

#### 4.1. HISTORICAL OVERVIEW

Historically, masonry ties are relatively new inventions. They started to be used in the United Kingdom in the first half of the nineteenth century, when wrought iron was already accepted in bridge design in Europe and was making its way into the construction industry. The cavity walls, consisting of two wythes of masonry separated by a cavity, were made to act together by header courses. Wrought iron ties replaced the header courses. At that time a typical cavity wall in the United Kingdom consisted of two 110 mm  $(4^{1}/_{2} \text{ in})$  masonry walls spaced 50 mm (2 in.) apart, connected by ties [8]. Whether the replacement of header courses by wall ties was intentional and introduced to reduce the potential of water penetration into the building interior remains to be answered, as many wall cavities at that time ended up being filled with "rubble." This loose material in the cavity may have helped by absorbing water, rather than sending it directly to the

interior wythe. However, this rubble fill did not help to keep the cavity dry.

The introduction of wall ties in the United States [9] followed tests which indicated that the water penetration to the interior of walls with ties was reduced compared to header-bonded walls. The tests also indicated that cavity walls with ties, when tested in compression, behaved comparably to masonry-bonded and solid walls. In other words, the ties acted as shear connectors between the wythes.

Cavity walls have continued to be used since then. The cavity was partly filled with insulation, leading to better thermal performance, while waterproofing on the exterior face of the interior wythe directed water to the outside, resulting in a good waterproof construction. Typically this wall system adopted masonry for both wythes. The definition of a cavity wall system comes from this period. It refers to a system in which the inner and outer wythes are sufficiently connected to share (in proportion to their lateral flexural stiffnesses) lateral loads.

Linking of the two wythes became more difficult to implement, due to changing construction techniques, resulting in greater tolerances, deformations and geometric differences of units selected for each of the wythes. With waterproofing on the cavity side of the inner wythe, the exterior wall acted as a first level of protection from rain and very importantly as a cladding, an important architectural feature of the building. This was the philosophy behind the development of the rainscreen wall principle, resulting in a veneer wall system. This system consists of a non-structural exterior wythe (supports its own weight and local wind load) and a structural backing (which supports lateral loads and may be loadbearing). The structural backing further evolved from the traditional masonry to steel and wood studs, and currently all these backing systems are being used. The space between the veneer and its backing contains an air space, insulation and air/vapour barrier.

There is no apparent difference between cavity and veneer wall systems, as both have the same components. However the properties of one component will make the two wythes behave differently. This key component is a "connector", or simply a "tie". When the tie is not able to carry direct forces as well as shear forces, walls do not interact with each other in sharing lateral loads. This is the difference between the cavity wall and veneer wall systems. The cavity wall is stronger and stiffer than the veneer wall due to the shear transfer between wythes.

Many problems with these new wall systems started to appear in the nineteen eighties and led to extensive work on the design of such systems and their components, such as masonry ties. This included testing programs for the ties combined with a theoretical approach, in an attempt to understand their behaviour and to come up with a rational selection of the appropriate tie for the selected system.

#### 4.2. CORROSION OF MASONRY TIES

Wall ties can corrode either in the cavity or embedded in the mortar. The process of steel corrosion is oxidation of iron ions resulting in a more stable chemical bond. For this process to

take place, oxygen and water (electrolyte) must be present at the same time and there must be electrochemical potential difference within a tie or between a tie and another metal ([7]). The potential difference in the case of a tie is due to the difference in the environmental exposure, resulting in different oxygen concentrations. Even the embedded portion of a tie is subjected to a difference in concentration, due to variation in pore sizes and availability of water and oxygen. The resulting hydrated iron oxide (Fe<sub>2</sub>O<sub>3</sub>.H<sub>2</sub>O) is what is known as rust. The coating of a surface with rust may not be so bad, as it can provide a protective layer against the corrosion if evenly distributed. The mortar in which the tie is embedded, which is initially a base (pH 12.5 - 13.2), leads to the formation of a rust coating. Due to the carbonation of cement in mortar in the presence of atmospheric carbon dioxide and moisture, the alkalinity drops to about pH of 8.5, leading to further corrosion ([10]). Air pollutants, such as sulphur dioxide, nitrogen oxide, and chlorides, are responsible for the acceleration of the corrosion process.

The rust forming on the surface of the metal results in a decrease in the thickness of the material available to carry the load. In the case of masonry, where the tie is partially embedded, there is also an increase in volume. The increase in volume of four atoms of iron to two molecules of hydrated iron oxide is 4.9 times (de Vekey [1]). This means that the surrounding mortar is subjected to tensile forces, leading to cracking. The cracks allow egress of water and oxygen and other pollutants, thus producing an environment for further corrosion. The field methods, such as half cell potential, which have been successfully used to identify corrosion of reinforcement in concrete may nor represent the conditions in mortar [10]. Moore [11] observed that the amount of water required to support corrosion is less than the amount causing visible dampness. Unprotected mild steel corrodes rather rapidly, from 25 to 125  $\mu$ m/year ([7]). Zinc coating gives a sacrificial protection, oxidizing over time at a rate of 2.1 m/year ([1]) and in this way protects the steel. The advantage is that the resulting product of corrosion causes a volume increase of 1.6 to 2.4 (half to one third of the volumetric expansion of steel due to corrosion ([7]).

The fact that different portions of a tie (embedded in mortar, passing through air space and insulation in the cavity, embedded in or attached to the inner wall) are subjected to different conditions, makes them more susceptible to corrosion than a metal fully enclosed by mortar. The complexity of a tie's condition, combined with great variation in its exposure condition, makes it very difficult to predict its life span.

#### 4.3. DESIGN CRITERIA for MASONRY TIES

#### 4.3.1 Review of Loading

The cavity wall concept evolved and significantly changed over the years. The cavity remained but began to be utilized to improve the thermal and air/ vapour performance of the wall system. The performance problems appearing in new buildings with a masonry veneer exterior prompted researchers and designers to evaluate the current design and construction of masonry wall systems.

Much effort was put into understanding the behaviour of new systems in comparison with the classical concept of the cavity wall and development of the structural design criteria. Research included ([12], [13]) cavity wall systems, loadbearing or non-loadbearing, subjected to lateral

loads, and veneer wall systems under lateral loads. The two wythes masonry wall with metal ties exhibits a more complex behaviour. It depends on the axial and shear stiffness of the metal tie, the support conditions of the exterior wythe, the axial compressive load acting on the wythes and, very importantly, on the pressure within the cavity. In the simplest case, both wythes can be forced to deform together, thus sharing the lateral load in proportion to their out-of-plane bending stiffnesses. The compressive load (applied to a loadbearing system) favours the inner wythe, delaying its cracking and increasing its stiffness. This results in lateral load shift from outer to inner. The ability of the vented cavity to respond to the external wind loads results in a very complex problem from the load distribution point of view. In conclusion, the exterior wythe can carry loads in the range of the outer wind load reduced by the load carried by the ties to just the load transferred by the ties, while the inner wythe may loads in the range of the interior wind load increased by the load transferred through the ties to the total wind load reduced by the load transferred through ties.

In the case of veneer walls, the design philosophy for the strength of the veneer is that it should support its own weight and to transmit lateral loads to the backup wall. The resulting loads in the ties vary depending on the stiffness of backup wall and ties and on the conditions at the lateral supports (floors). The resulting tie forces vary along the unsupported height of the wall. Generally, the pressure equalization in the cavity, results in uneven load distribution amongst the ties with load sharing in the other direction (typically horizontal) disregarded (DD 140 - 1987 gives the most comprehensive summary [14]). The tie force is based on the external lateral load acting on the tributary area of the tie. This assumption is possible because of the load sharing under the local condition of higher loads and redistribution. In most cases the strength of an individual tie is not as important as the performance of the wall.

In summary, the loads carried by the ties, unless specifically identified as cavity wall ties, are compressions and tensions based on the tributary wind load (the area of the wall between the ties) acting on the wall.

#### 4.3.2 Performance Specification for wall ties

Designers around the world are not faced with the design of masonry ties, their physical sizing and stiffness assessment, but with selecting an appropriate tie for a particular wall system and applying it according to the recommendations (for tie thickness and spacing).

The accepted performance specifications ([15], [9], [14], DR 99027 CP) [16]) summarize the criteria for masonry tie performance. All categories are listed below including explanations and references:

#### 1. Strength considerations

Transfer of forces from the exterior to backup wall. Force in the tie due to the wind load on the exterior should be compared to the resistance of the tie. It should be noted that even the Canadian Standard allows for both ultimate and working stress design. Most standards dealing with connectors provide descriptions of testing methods to determine the ultimate strength and stiffness (section 12 of CSA A370 - 94 [17]). The minimum strength of ties is often specified (cl. 7.1. od CSA A370 - 94 [17]). Generally, the selection of ties will be based on comparison of the tie's

capacity with actual load or on the selection of a tie type and compliance with the criteria for its application and placing. The test and sampling population are defined in the standards (eg., cl.12 of CSA A370-94 [17]).

- 1. Tension
- 2. Compression and associated pullout/ pushout and bond failures.
- 2. Allowance for differential movements. Both short and long term deformations should be accounted for. These include creep, shrinkage, thermal and moisture expansion and contraction.
  - 1. Horizontal
  - 2. Vertical
- **3. Ability to perform 1. and 2. during fire.** Canadian Standard (CSA A370 94 [17]), as well as others, does not give any specific recommendations for achieving this requirement. Elevated temperature should not adversely affect the performance of a tie.
- 2. Stiffness considerations. There are typically limits set on masonry wall deformations and "free play" (cl. 8.3 of CSA A370-94 [17]).
  - 1. No excessive deformation in tension
  - 2. No excessive deformation in compression
- **3. Durability**. Tie durability must be compatible with the design life of the building. It should be noted that the standards recognize the importance of durability and corrosion resistance. They recognize that the corrosion protection requirements depend on the exposure (eg., cl. 4 of CSA A370-94 [17]).
- 4. Water migration into interior. The tie's shape should be such that it allows water to drip into the cavity before it reaches the interior wythe. There may be a conflict between these requirements and the compressive strength. In order to facilitate the drainage of water, ties are often crimped to provide a drip. The provision of this "kink" results in a significant reduction in compressive resistance of up to 50% (Drysdale, 1994 [20]). The Australian draft standard (DR 99027 CP [16]) describes a method to test for resistance to water penetration.
- 5. Minimum protrusion into cavity space. Anything projecting into the wall cavity has a potential to act as a bridge between the exterior and interior, acting as a thermal bridge, a conductor for a water passage and a collector of mortar droppings. Consequently, the wider the projection into the cavity, the more potential there is for the tie to act as a conductor and collector.
- 6. Construction tolerances. It is important that the wall ties accommodate some of the tolerance resulting from the construction process. These can be divided into two categories: construction tolerance and vertical alignment due to the application of materials with different geometric properties. Adjustable ties, usually treated as a special kind of tie, are excellent in accounting for construction tolerances, but at the same time they result in an increase in free play (defined by cl. 8.3.2 of CSA A370-94 [17]). Also it is very important that the ties are not easily damaged during construction, do not cause injuries to workers, and allow for ease in installation of the membrane and insulation.
- 7. Retains insulation and membrane. The support for both decreases the possibility of

separation from the substrate which can increase the possibility for accumulation of water.

- 8. Economy. The cost of the ties is insignificant in comparison with the total cost of the building. The improvement in the performance of masonry ties resulting from the change from standard galvanized steel to stainless steel carries only a 1% increase in the construction cost. The production of ties should be economical and of a consistent outcome.
- **9. Workmanship**. As this wall system is a man made system, it is important to follow a good practice guide so that the proposed properties in various standards can be achieved.

Standards in most cases allow for application of new materials by reiterating a compliance clause calling for equivalent durability and for meeting the strength and stiffness requirements. The only standard allowing plastic/ composite ties for light use is (DD 140 - 1987 [14]). The Canadian Standard (CSA A370-94) deals with ties by type, stating its requirements for application rather than by designation, such as type by application or loads (DR 99027 CP [16]and DD 140 - 1987[14]) as used in other standards.

#### 4.3.3 Wall tie testing

An extensive testing program was carried out ([9], [21], [22], [23]) on the compressive and tensile behaviour of ties, with some programs reporting deformations and stiffness of ties. Canadian testing efforts were driven by the development of a national standard for masonry connectors (CAN3-S370 -M84), the first standard of its kind in North America. It provided the first comprehensive set of information on the strength of basic connectors and testing methods for determining their strength. It did not deal extensively with adjustable connectors. Britain where the ties were used for the first time did not lag behind and there has been extensive work on the rationale for the design and specification of wall ties by the Building Research Establishment (EC6 1991). De Vekey, 1984 [15] summarised very well all the criteria to be considered when evaluating the performance specifications for wall ties, looking comprehensively at their performance in masonry rather than at strength and stiffness.

Since then much work has been done, namely in Europe (EC6 -1996 [24] and DD140 -1988 [14]), in Australia on masonry wall ties and accessories (DR 99027 CP [16]), and in Canada on masonry, connectors for masonry and durability guidelines (CSA A370-94 [17], CSA S304.1-94 [18] and CSA S478-95 [25] respectively).

#### 4.4. FIBRE REINFORCED POLYMER COMPOSITES (FRPC)

#### 4.4.1 Introduction

These new age materials have been used extensively in the aerospace, transit, car and chemical industries and are very popular with sports' equipment manufacturers. However their structural use is only beginning to be recognized. The structural application is associated with problems related to road and bridge infrastructure in cold climates worldwide and the research associated with it. The corrosion of steel reinforcement in concrete and steel bridges with concrete decks, due the use of de-icing chemicals, is resulting in very expensive repairs, which in turn have led to extensive research into new materials, with the main focus on their performance. FRPC is gaining popularity in the refurbishment of bridge decks, the repair and strengthening of concrete members, and for

structures subjected to sea water. The application of this new material in pedestrian bridges (the first being Aberfeldy Footbridge, Aberfeldy, Scotland, built in 1990) has increased and is being used in highway bridges subjected to heavier vehicular loads (eg, Tom's Creek Bridge, Blacksburg, Virginia), but currently is still limited to modest spans. Composites is the term used for materials which are produced from components differing in composition or form, but in their final state the components do not merge or dissolve and can be identified in the final product. This is not to suggest that the components act independently, as they are interconnected and therefore interact with each other.

#### 4.4.2 Fibres

Composites use high strength fibres in many different forms, combined with a variety of resins. There are a number of different manufacturing processes, but very important, and common to all, is the application of controlled heat and pressure after laying. The most commonly used fibres are glass (e-glass or s-glass), aramid (also known as Kevlar) and carbon. Common to all these materials is high tensile strength . Table 1 gives the tensile strength properties; and for reference structural steel is included.

Fiber	Specific gravity	Tensile Strength (MPa)	Tensile Modulus (GPa)	Tensile Strain at breaking load (%)	Cost/ kg (\$ CND)
E-glass by Owens Corning	2.6	3100 - 3800	75 - 78	4.5 - 4.9	2.7 - 3.6
S-glass by Owens Corning	2.4	4600 - 4800	88 - 96	5.4 - 5.8	21.4 - 28.6
Aramid (Kevlar) by Dupont	1.4	3600	41 - 186	2.9 - 8.7	42.8 - 107.1
Carbon by Hexcel	1.78	4200 - 6100	230 - 300	1.8 - 2.0	32.0 - 250.0
Structural steel 350W	7.8	450 - 650 (350 Yield)	200	0.2 at yield 18 at ultimate 25 at failure	60.0

#### Table 1 - Fibre Properties

The materials used for reinforcement come in a variety of forms such as rovings (a number of strands consisting of a large number of untwisted filaments gathered in a parallel bundle), mats (randomly laid long and chopped fibres held together by a binder), woven (fibres woven into a

fabric) or simply strands (in the case of carbon fibres usually referred to as "tow"). These materials are also available in so called "prepreg" form, which means in sheets containing the fibre material with the bonding agent. The sheets are protected by a peel-off layer and come in polyethylene bags. They must be at least refrigerated; storage in subzero temperature increases the shelf life. In this case the material is ready for processing by one of the methods which uses pressure and raised temperature to fabricate the desired product.

#### 4.4.3 Resins

A variety of resins can be used with each fibre type to form a composite. Generically the following resins are used: epoxies, phenolics, bismaleinide and cyanate esters. The resins are responsible for the classification of the material (thermosetting or thermoplastic) and the basic properties of the material as far as the response to the environment (corrosion, fire, flame spread) is concerned. The division into two groups, namely thermosetting and thermoplastic products, is very important as far as the behaviour of the material when heated is concerned. A thermosetting material is "locked" into its form due to the cross-linked relationship of resin molecules. Very importantly, the shape cannot be bent. Vinyl esters, phenolics, urethanes, epoxies and unsaturated polyesters are the most common thermosetting resins. A thermoplastic material, on the other hand, can be altered when heated and retain its new shape when cooled. The common resins which exhibit this property are some polyesters, polycarbonates, polyethylene, polypropylene, polystyrene, polyurethane.

#### 4.4.4 Manufacturing Process

The following processes are most commonly used to manufacture composites: lay-up, lamination moulding and pultrusion. The lay-up process is done by hand by placing fibres (any variety is possible) into an open mould and impregnating them with a resin. This process is repeated after the resin sets. Lamination is used to manufacture flat or corrugated sheets from resin impregnated fibres which are rolled between two plastic sheets. Moulding is a general term for manufacturing sometimes very complex shapes in preset moulds. Some of the moulding processes use short or milled fibres, which are mixed with a resin and injected into a mould (injection moulding) while others use the same fibres made into a sheet compound or a prepreg mat, which is squeezed between the male and female parts of the mould (compression moulding). More sophisticated moulding processes use a combination of laid fibres (woven or mat) in the mould with a two part resin (hardening occurs only after the two parts are mixed together) injected into it. Pultrusion is a very economical process used to produce a variety of shapes of a constant cross section, unlimited length, and relatively constant properties. In this continuous process a number of layers of rovings with alternating layers of mats are fed through the guide into the resin bath. Before the impregnated material enters the preformer, the veil (finishing surfacing material) is added. The excess resin is squeezed out in the preformer. This layered material is pulled through the heated steel die. This initiates the hardening process, and after the passage through the die, the material is cured. The fact that the process is continuous, means that the quality of the material is dependable and the production cost is lower. This process enables the manufacturing of structural shapes. Typically the materials produced by this process are thermosetting. It was virtually impossible to produce a thermoplastic material by this method until now. The problem lay with the thermoplastic resins' high viscosity, which required very high pressure to impregnate the fibres. It is only very recently that a new resin has been developed which has the characteristics suitable for the pultrusion

process. The pultrusion process is limited by the width of the material which can be produced, related to the physical size of the die, the forces required to pull the material, and the curing equipment.

#### 4.4.5 **Properties of Composites**

Because of variation in fibre content and orientation, resin type, fillers, additives, catalysts (optional) and differences in manufacturing process, it is difficult to talk about the properties of composites. Also moulded materials often have specific performance requirements rather than the standard strength and mechanical properties. Obviously there is a great variety of moulded shapes and therefore properties. In Table 2, the typical composites' properties are based on pultruded shapes. Only the direct tensile properties are noted, as these can be used for comparison to the strength of initial fibres. Composites are non-homogeneous and anisotropic materials. In other words their properties are directional and related to the orientation of the fibres in the resin matrix. The highest strength is for rods with unidirectional strands. When considering a structural application for composite materials, the directional behaviour must be taken into account. The modulus of elasticity and shear strength are low in comparison with those of metals. The material is elastic up to failure and can be classified as a brittle material. A further problem not encountered in most other material is the crack formation at the free edge between the layers of impregnated fibres, which can rapidly propagate and cause premature failure. The strength is temperature dependent. At 95° C the strength of approximately 50%, the ultimate, is reached. But the strength is not impacted by low temperatures.

Composites	Fibre by volume	Tensile Strength (MPa)	Tensile Modulus (GPa)	Tensile Strain at breaking load (%)	Cost/ m <sup>2</sup> (\$ CND)
Glass Fibre RPC	40% e-glass	138-206(LW) 69 (CW) 685 (rod)	12-17.2(LW) 6.5 (CW) 41.5 (rod)	1.15	7 - 16 (3.18mm thick)
Aramid RPC	58% aranid	1900 (rod)	118 (rod)		NA
Carbon RPC	50% carbon 55% carbon	600 (both directions) 1100 (rod)	70 (both directions) 120 (rod)	0.85 1.1 (rod)	4,444 <sup>1)</sup> (2mm thick)
Structural steel 350W	7.8	450 - 650 (350 Yield)	200	0.2 at yield 18 at ultimate 25 at failure	2.6 (3mm thick)

<sup>1)</sup> May not be available in 1m width.

#### Table 2- Properties of Composites

Composites have a lower coefficient of thermal expansion than metals (strain of  $8 \times 10^{-6} / {}^{0}$  C), are corrosion resistant, typically to both acids and bases and ultraviolet. The choice of the resin, veil and surface coating material impacts the resistance to corrosion. The composites are self extinguishing (ASTM D635), have a rating of 650 (ASTM E662) and VO (UL 94) and a smoke generation and flame spread value of 25 (ASTM E84).

#### 5. **PROTOTYPE DESIGN**

#### 5.1 FRCP Ties History

Plastic ties have been proposed in the past in the United Kingdom (Posi-Ties) and Australia (Ni-Tie [36]). They are referred to as "plastic" ties but the exact material is not given [36]. Both anchors seem to have been of a similar type, based on old English cavity wall anchors, namely a rod with flat V-ends. The characteristic load for Ni-Ties is quoted ([36]) as 1.07 kN in tension, 1.25 kN in compression, and stiffness of 1 kN/mm. Recent research in the USA ([37]) investigated fibre reinforced plastic wall ties which were made by the pultrusion process but the properties of the material are not given. The paper indicates a satisfactory performance of the ties, made of 4.76 mm (3/16") thick reinforced plastics, for a design load of 1.2 kN (270 lb) based on three samples per test. The extent of variables investigated is not clear. Work on a very small number of samples at the University of Calgary ([38]) studied the use of GFRP as wall connectors. This paper provides some information on the GFRP bond in masonry.

#### 5.2 Design Criteria for Prototype

- 1. The literature researched and review of construction practices clearly indicated that nonadjustable ties are either not placed or deformed to suit if they do not "fit". Any consequence of this is most likely not life threatening, but seriously impacts the integrity of the building's envelope. Even when the construction sequence and interaction between the outer and inner layers are taken into consideration, the construction tolerance accumulates and results in a problem. The use of flexible materials which can be bent to suit is not acceptable, as it results in a tie performing well below its design capacity, if effective at all, and may result in damage to the tie's coating. The ease of installation is another consideration when discussing the adjustment. It is also very important to consider the impact of a poorly placed strip tie which slopes towards the interior, thus directing potential water into the interior. It was decided to pursue the development of an adjustable tie.
- 2. The ultimate strength of the tie was adopted from clause 7.1 of CSA A370-94 to be 1000 N. The requirements of cl. 8.2 of the same standard require that the ultimate strength be the least value of failure of the tie material under any possible loading conditions, tie embedment failure or tie buckling failure.
- 3. Cl. 8.3 of CSA A370-94 defines the total free play as a maximum of 1.2 mm, and under the compressive load of 0.45 kN it must not exceed 2 mm. These stiffness conditions were accepted as one of the design criteria.
- 4. Corrosion resistance is the main reason for using an alternate material and considered as very important.
- 5. The construction practices of masonry contractors and their training material were reviewed

and taken into consideration as important factors for a satisfactorily performing masonry wall system.

Other criteria outlined in section 5 above were not considered in the development stage.

#### 5.3 **Prototype Development**

The focus on the adjustable tie led inevitably to a tie which consists of two parts. The problem with two parts and a material which is directional became obvious. Further, the initial design consideration was to have both parts embedded in respective bed joints, namely brick and block. Not much consideration was given at this time to the structural backing, as it was assumed once the tie worked with concrete block backing, it would be possible to alter it to suit a steel or wood backing system.

A couple of promising ideas which were, to some extent influenced by the state of the art of masonry ties, are shown in Figure1. Both earlier schemes relied largely on the bond developing in bed joints, which are easier to construct and therefore more predictable, and there is a gravity load from the wall above to give extra resistance. It was difficult to make either of these two shapes work with the pultruded FRPC available.

In Fig. 1a) the L-piece in available FRPC was cut from the section which has a primary fibre direction parallel to the wall. This resulted in the brick tie transferring the pull due to suction to the short leg of "L" in bending, which results in stresses in a weak direction. Consequently, the L-piece ended up wide, potentially a surface to collect mortar droppings and water. Another problem with this design was a lack of restraint to the veneer under the exterior wind pressure.

The design in Fig. 1b) is an improvement as far as the material performance is concerned. The vertical plate has prime fibres in the direction of block thickness. There is a problem, however, with the horizontal part embedded in the concrete block. Further it was realised that there is a tolerance in the slot which accommodates the U-shape. The problem (when the longer side of a rectangle is smaller than its diagonal) is to allow for tie insertion and at the same time not to oversize (allowing free play under the load).

In both cases it was noted that the U-shaped part has a problem of fibre orientation if unidirectional material is used. Apparently the FRPC market does not produce anything suitable and therefore the prototype had to be made in the laboratory. This way the orientation of the fibres could be controlled to result in the most efficient material. The process of making the FRPC material was lengthy and with the available equipment (a vacuum table) only a flat sheet of a small size could be produced. There was a concern about the control of consistency from sheet to sheet and how to test for it. The large quantity of samples required led to the decision to abandon this direction and focus on focus on what is available in terms of FRPC materials on the market.

The FRPC material most readily available is produced by the pultrusion process. The resulting product has a dependable quality and is reasonably cheap. The problem is the limitation in shapes produced and a predetermined strong direction along the length of a material. There is a difference in strength between the lengthwise direction and the perpendicular direction of approximately 2-3.

Initially, it was intended to investigate different fibres, namely glass, aramid, and carbon as the reinforcement. It was expected that more costly stronger fibres could result in smaller sections and offset the material cost. The most common pultruded FRPC material on the market uses e-glass as reinforcement. This product is readily available at low cost. It was found that aramid (usual trade name Kevlar) is significantly more expensive and considered as a special order. The same applies to carbon FRPC with the cost still higher than aramid FRPC. It was decided to carry out the testing using the e-glass reinforced polymer composite (GRPC) for further study.

Adopting the limitations of the manufacturing process, the basic design was developed based on pultruded material properties (see Figure 2). No other suitable shapes other than flat strips or plates were found. Initially, two material thicknesses were considered: 3.18 and 4.76mm (1/8" and 3/16"). Both parts of the tie were cut from flat strips. The thicker material was theoretically acceptable for embedment into mortar joints (being less than one half of nominal mortar joint thickness); however, working with the material and masonry, it was found that the thickness was unacceptable. It was very difficult in the laboratory to place the tie and keep the mortar joint to 10 mm. It should be noted that the testing reported by Burdette [37] used only 4.76 mm thick ties in all tests. However problems encountered in trial masonry sample preparation led to the decision to carry out further development with 3.18 mm thick material only. The material properties are included in Table A1 in Appendix A; Figure A1 and show the internal orientation of fibres.

The bond of the tie in masonry mortar was considered. The surface layer of pultruded products has very little roughness. As anticipated, previous published work ([38]) indicated that FRPC materials do not bond very well to mortar. Therefore, part A of the tie, which is embedded in the head joint, was modified to increase the bond by profiling (creating "keys"), by cutting holes in the material within the width of block flanges and by roughening the surfaces with a coat of silica sand. Part B was modified by providing the returns at the ends and by the increase in roughness with a coat of silica sand. The sketches of modified design are shown in Figure 3 and 4.

At this stage it was decided to carry on with the tests on the tie prototype, based on the traditional veneer wall system, namely concrete block backing. If another backing system is used, part A could be attached to the side/ web of the stud, but this results in some difficulty in sheathing installation.

#### 6. **PROTOTYPE TESTING**

#### 6.1. Test Description

The tests were based on a wall assembly consisting of brick veneer, 50 mm cavity, 50 mm rigid insulation, air/vapour barrier and 190 mm concrete block backup (see Figure 5). Each test consisted of five samples which were statistically evaluated. Tests involving masonry included the standard mortar tests on 50 mm mortar cubes.

#### 1. Strength test

The purpose was to determine the tensile strength of the tie by testing part A and part B together in a tensile testing machine. Part B was located in the centre of the slot in part A for one set of five tests, and at the end of the slot for a second set of tests. Load and corresponding deformation were recorded for each test. The strength of the connector in each test corresponds to the load at which first failure occurred. The ultimate strength from

this set of tests is evaluated according to cl. 12.1.3.of CSA A370-94.

#### 2. *Tie pull out from masonry*

Samples of 2 bricks using standard metric clay brick (see Figure 6) with running bond assembled using Type S mortar with part B of the tie in the bed joint were tested according to part.12 of CSA A370-94. The test w carried out with a constant compressive load of 170 N. The applied load and corresponding slip were recorded during the test. The following variations to basic U-shape were investigated:

- 1. U-shape tie (Fig 4a).
- 2. Silica sand coated U-shape tie.
- 3. Free end return (Figure 4b)

In this test, the tie could only fail by pulling out of the mortar (the material failure of the part B is prevented by clamping). The purpose of the variation in shape and texture was to study their impact on the bond in mortar.

#### 3. Plate pull out from concrete block 190 mm

The block samples three blocks high (see Figure 7) were prepared using type S mortar and tested according to part.12 of CSA Standard size 20 concrete block was used. Some units had both ends square while the others had both ends frogged. The applied load and corresponding slip were recorded during the test. The following variations to basic part A were investigated:

- 1. Rectangular (Fig. 3a).
- 2. Profiled (Fig. 3b) in 2 positions
- 3. Profiled and silica sand coated
- 4. Profiled with hole (Fig 3c)

In this test, the tie could only fail by pulling out of the mortar (the material failure of the part B is prevented by clamping). The purpose of the variation in shape profile and texture was to study their impact on the bond in mortar.

#### 4. *Compression test*

The test samples shown in Figures 6 and 7 were used again, but in this case the compressive load was applied at the end of the tie. Possible failure mechanisms were tie push through, material strength failure or tie buckling.

#### 6.2. Test Results

#### 1. *Tie tensile strength*

The strength tests were carried out on the assembly of a two part tie in a MTS testing machine with a maximum static load capacity of 22.5 kN. The rate of loading was 1mm/minute. The load and corresponding displacements were recorded for each load increment. The test set up is shown in Figure 8.

#### 1. U-shaped piece (part B) placed in the centre of the slot (ref. Test 1)

A typical load deformation curve is included in Figure 9a). The failure of all samples was initiated by the formation of a notch in the centre of the slot in part A (i.e., the location of part B) and occurred by tearing through the entire depth of material towards the free end of part A. The typical failure mode is shown in Figure 9b).

#### 2. U-shaped piece (part B) placed at the end of the slot (ref. Test 2)

A typical load deformation curve is included in Figure 10a). The failure mode was typically as previously described for the central location, but in two cases the U-shaped piece (part B) failed first. The typical failure mode is shown in Figure 10b).

#### 3. Tensile strength of part B (U-shaped piece) (ref. Test 3)

After the previous two sets of tests were completed, it was decided to carry out the tensile strength test on part B alone to determine its strength. A typical load deformation curve is included in Figure 11. The failure occurred through the bottom of the "U"by delamination.

The tensile strength of a tie is taken as the peak load (maximum load) of the load-deformation curve. The summary of the test results is given in Table 3.

	Mean Maximum Tensile Load (N)	Standard Deviation (N)	Displacement at Max.Load (mm)	ψ - Factor A370-94 (12.1.3)	Comments
Test 1	2574.8	297.4	1.5 - 2.5	0.827	In all cases part A failed by notching and cracking at the centre.
Test 2	2802.4	298.49	1.25 - 2.43	0.84	Notching and cracking of part A at slot end (4 samples); part B failed(2 samples).
Test 3	2888	91.4	1.62 - 2.2	0.953	All failed through "U", notching and cracking.

#### Table 3 - Tensile Strength Test Results.

#### 2. Pull out from brick

The samples were prepared by a certified mason. No special instructions were given to the mason, other than to follow the standard practice promoted by the Ontario Masonry Contractors Association. The mason was reminded that the tie should embedded in the mortar. The result was a range of tie locations, from the middle of mortar joint to no mortar cover on the tie. The projection of the tie into the bed joint was specified but range of positions was found. The tie (part B) was placed on the mortar at the time of testing of some samples was 7.6 MPa and for majority of samples 11.8 MPa. The mortar strength of 7.6 MPa was in excess of 28 days strength for type N mortar of 5MPa. The 28 days strength

of mortar of 11.8 MPa (with coefficient of variation of 12.5%) is below the 28 days strength of 12.5 MPa for laboratory prepared mortar (Table 5 of CSA A179-94) but well in excess of strength for job prepared mortar. The mortar was cured under the laboratory conditions while the brick samples cured in the laboratory but no special protection or curing was adopted. It should be noted that no extreme hot weather occurred during the curing period. In order to simulate the conditions in the wall, A370-94 (12.4.4) prescribes a uniformly distributed surcharge of 10 kPa over the bearing surfaces. This surcharge was converted into the load of 17.5 kg over the bearing surfaces. The load was applied by springs, which were calibrated to deliver the required surcharge. The strength tests were carried out on the assembly of a two part tie in a MTS testing machine with a maximum static load capacity of 22.5 kN. The rate of loading was 1mm/minute. The load and corresponding displacements were recorded for each load increment. It should be noted that the tie was clamped and therefore tie failure was prevented. The test set up is shown in Figure 12. The deformation recorded is a combination of pull-out displacement and deformation of the material.

#### **1.** U-shape tie (ref. B. Test 1) (*Fig. 4a*))

The failure occurred by the tie pulling out of the mortar in all cases. There was no failure along the brick/ mortar interface except for sample 2. All faces of the tie over the length which was pulled out are noticeably clean and free of mortar. Hair line cracks developed from the tie through mortar to the brick interface (see Figure 14). It was noted that the failure load drop significantly when the tie was not embedded in the mortar but one face was directly in contact with the brick (sample 2). After the maximum load is reached, the loads starts to drop while the deformation increases (see Figure 13). The pre-compression was released for samples 3 to5 without any noticeable difference in the failure load.

#### 2. U-shaped tie coated with silica sand (B. Test 2) (Fig. 4a))

After an initial slight pull (1 mm approx.) of the tie, the stronger bond between the tie's coating and the mortar initiated a crack along the part of the tie which then proceeded at approximately 45<sup>°</sup> through the mortar towards the free end. Mortar cracked vertically and the final failure occurred along the brick/ mortar interface, separating two bricks. Only sample 4 experienced different mode of failure, namely a direct splitting at the brick/ mortar interface adjacent to the embedded end. This tie projected at least 5 mm more into the joint than other samples. The significant improvement in the pull out capacity can be attributed to the sand coating which provides excellent bond between the mortar and the tie, forcing the failure at the brick mortar interface.

See Figure 15 for a typical load - deformation curve and Figure 16 for details of the failure.

#### 3. U-shaped tie with end returns (ref. B. Test 3) (Fig. 4b))

The end returns acted as an additional anchorage. Hairline cracks formed along the tie just outside the returns, probably initiating the debonding between the tie and the mortar. The returns anchored the tie and caused the failure along mortar/ brick interface, separating the two bricks. In sample 3, the failure of the tie occurred at one its returns; the return broke away from the main body of the tie. It was noted that the failure along the mortar/ brick interface occurred at the closest tie location to this interface.

See Figure 17 for a typical load - deformation curve and Figure 18 for the details of the failure.

The test results are summarized in Table 4.

	D Sample 1	Maximu isplacement Sample 2		S. Deviation [C. of V. (%)] Load Displacement			
						Mean	
<b>B. Test 1</b> U-Shaped tie	4709 0.91	2639 1.3 1)	4709 1.3	4591 0.91	5572 1.12	4444 1.11 4895 <sup>a)</sup>	1083.1 [24.3] 0.2 454.6 (9.3)
<b>B. Test 2</b> U-shaped tie - sand	6729 0.86	6769 0.86	7279 0.99 1)	6573 0.72 2)	5229 0.5 2)	6516 0.79	766.7 [11.8] 0.19
<b>B.Test 3</b> U-shaped tie - returns	6210 2.35	6533 0.98	5778 0.99	5494 1.04 2)	6053 1.59 2)	6014 1.39	398.6 [6.6] 59.4

Notes:

1) Tie rests directly on the brick; no mortar between the brick and the tie.

2) Tie is not placed centrally in the mortar joint; cover is twice the amount on the other side.

<sup>a)</sup> Neglecting the lowest reading.

#### Table 4 - Brick Pull out Test Results

#### 3. Pull out from concrete block

The samples were prepared by a certified mason. Only concrete block flanges and webs were mortared; voids between the frogged ends remained unfilled. Some head joints had both ends squared, others one squared and one frogged or both ends frogged. The mason was instructed to follow the standard practice promoted by the Ontario Masonry Contractors Association and reminded that the tie should have mortar cover on both sides. The tie was placed sitting on the bed joint against mortared head joint. The adjoining unit was placed with a mortared head joint. The samples were tested at 28 days. The mortar strength was 11.8 MPa (with coefficient of variation of 12.5%). The 28 days strength of 12.5 MPa for laboratory prepared mortar (Table 5 of CSA A179-94) but well in excess of strength for job prepared mortar. The mortar was cured under the laboratory conditions while the brick samples cured in the laboratory but no special protection or curing was adopted. It should be noted that no extreme hot weather occurred during the curing period. For this set of tests, the pre-compression in the direction perpendicular to the application of

the load was not applied. The test set up is shown in Figure 19.

#### 1. Rectangular tie (ref. C.B. Test 1) (Fig. 3a))

Typically, the failure occurred by the tie pulling out of mortar. The load was steadily increasing up to the maximum level when the load dropped off and increase in deformation followed while load was dropping. The conditions at head joint (combination of frogged and square heads) did not seem to have a significant impact on the maximum pullout load (see Table 5). Because this tie is rectangular, it probably was not easy to place it in the head joint even if it was placed sitting on the bed joint. The ties were found to project out various amounts and had a variety of positions in the head mortar joint from zero mortar cover to being reasonably central. For failure details see Figure 20.

#### 2. Profiled tie (ref.C.B. Test 2 -series 1 and 2) (Fig. 3b))

Similar type of failure as described in 6.2.3.1 above generally applied. Another mode of failure initiated from the crack along the bed joint (where the tie was sitting) which caused mortar separation from the flanges. The total of ten samples was tested because the testing arrangement did not allow to test the tie in other than central position. In one instant, the rear "key" broke from the main body of the tie. The results were would be pretty consistent if the two extreme values were ignored. For failure details see Figure 21.

#### 3. Profiled tie with sand coating (ref.C.B. Test 3) (Fig. 3b))

Strong anchorage due to the increased bond and profiling led to different modes of failure. The result was material failure at the face of the block or initial cracking at the embedded rear end which spread through the head joint, leading to mortar block separation. Strong bond was evident from the ties recovered after the testing; few ties had mortar attached to them. The failure load was significantly increased in comparison with the untreated tie. For failure details see Figure 22.

#### 4. **Profiled tie with holes (ref.C.B. Test 4)** (*Fig. 3c*))

The failure modes are similar to those described for profiled tie (6.2.3.2). It appears that the presence of the holes (these get filled with mortar) adds to the pull out resistance in decreasing the pull out deformation. Unfortunately the results for this set of tests are very inconsistent, making it very difficult to conclude. For failure details see Figure 23.

The test results are summarized in Table 5.

#### 4. Compression tests

The samples used for these tests are the same as described above for brick (6.2.2) and block (6.2.3) pull out tests. The same testing equipment was used but the test was altered so that axial compressive load was applied to the tie. Block and brick samples were tested separately. A3 type tie were used for concrete block samples and B1 type ties were used for brick samples.

	Dis Block conditi	Maximu splacement a ions at head		S.Deviation			
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Mean	C.of V.
C.B. Test 1 Rectangular tie	9000 2.83 (1F)	6000 2.28 (1F)	5750 3.2	5500 2.05 (2F)	6000 2.04	6450 5812.5 <sup>a)</sup>	1440.5. 22.3% 239.4 (4.1)
<b>C.B.Test 2</b> Profiled tie series 1	8675 2.2	6100 2.15 (1F)	5650 2.09 (1F)	3075 1.7 (2F) 2)	6250 1.46 (1F)	5950 6000 <sup>b)</sup>	1993.3 33.5% 312.3 (5.2)
<b>C.B. Test 2</b> Profiled tie series 2	6950 2.45 (1F)	6450 2.5 (2F)	4750 2.5 (2F) 1)	4800 1.2 (1F) 1)	5000 2.4 (1F)	5590	1032.8 18.5
<b>C.B. Test 3</b> Profiled with sand coating	10,500 0.995 6)	10,125 1.23 (2F)	12,650 1.55	12,500 1.65 (2F)	16,250 1.89 (2F)	12,405 11,443.8 <sup>a)</sup>	2433.1 19.6 1316.6 (11.5)
C.B. Test 4 Profiled with holes	6000 0.965 (1F) 5)	3725 1.6 (2F) 3)	2250 0.35 4)	7250 1.35	5825 1.40	5010	1995.7 39.8

Notes:

- 1) Poor workmanship overspills; poor mortar/ block bond
- 2) Initial crack along the bed joint at tie location. Failure by mortar separation from the block.
- 3) No mortar at the rear end of the tie (embedded end). Plane of the tie not at right angle to the bed joints. Block sample face was not plane bow was noticed.
- 4) No mortar between the tie and block in head joint, i.e., tie is directly against the block.
- 5) No mortar at the rear end of the tie (embedded end). Tie not vertical. Mortar joint vary from 10 -15 mm.
- 6) Tie tilted pointing down. Cracks along the bed joint; along front (cavity side) along one mortar/ block interface and on the opposite both interfaces appeared to be cracked.
- a) Neglecting the highest reading.
- b) Neglecting the highest and the lowest results

#### Table 5 - Concrete Block Pull out Test Results

#### 1. Brick test

The load was applied to the free end of the tie; see Figure 24 for the test set up. The failure load was consistently due to buckling of the tie outside of the mortar. In two cases, the buckling also caused splitting along mortar/ brick interface (see Figure 25).

#### 2. Block test

The tie was not placed in head joints but not resting on the bed joint. Consequently, the ties ended up not being horizontal or vertical. In case of a sample 5, the entire sample was bowed and the tie was placed directly against the block. As a result, it was not possible in most tests, to apply load directly to the free end but the end clamps were used. The impact was the restraint of the tie projection outside of the masonry. The test set up is shown in Figure 26. The typical failure occurred by the tie pushing through the mortar joint and resulting in the separation of the blocks along both, head and bed joints. Alternatively, the failure occurred by the tie buckling in the cavity between the frogged ends.

The test results are summarized in Table 6.

	Seconda 1	Fa M	Mean Failure	S. Deviation			
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Load (N)	Cof V %
Brick	7602 buckling	9427 buckling, split	8093 buckling, split	9309 buckling	9005 buckling	8687.2	801 9.2
Block	13,150 pushed through, twisting	15,000 pushed through	14,575 pushed through, buckling	16,000 buckling in cavity	Failed due to handling	14,682	1,182.7 <i>8.1</i>

#### Table 6 - Compression tests on Brick & Concrete Block Sampl

#### 7. DISCUSSION of TEST RESULTS

- 1. The tensile strength of the material proved to be the limiting factor in the design of the prototype. The weakest component is part A of the tie which therefore governs the ultimate strength.
- 2. It was found that, contrary to the expectation, the bond is not a problem, even when using a basic material without any treatment to the surface. The bond strength is well in excess of the strength of the tie. Although the surface roughness and mechanical anchorage result in an increase of bond capacity, their implementation is not necessary.
- 3. The snug fit of the two parts of the tie results in negligible free play.

- 4. The displacement under load of 450 N is less than 0.5 mm. This is well below the limit of 2 mm stipulated in A370-94 (8.3.2).
- 5. The tensile failure of part B was either in the corner of the "U" by delamination initiated from the crack at the inside corner or by formation of a notch followed by a. crack propagation to free face. Both types of failure are indicated in Figure 11.
- 6. The strength failure of part A is consistently a bearing/ shear type failure, resulting in complete tearing through the narrow part adjacent to the slot (Figures 9 and 10).
- 7. Most strength failures causing delamination were brittle, occurring suddenly without any warning. When the material failed by notching before a crack occurred, the increase in deformation was noted while the notch was being formed, followed by cracking through the material.
- 8. It appeared that the compressive strength of mortar did not impact the bond between the tie and masonry.
- 9. The push through/ compressive tests indicated that this mode of failure is very unlikely to occur.
- 10. The brick samples were more consistent than the block samples. Perhaps this was due easy of handling of bricks due to their size and weight. All possible positions of ties within the mortar joints which may occur on site were encountered amongst the test specimens.
- 11. The material, namely pultrude glass fibre reinforced polymer, used on this porject came form two different manufacturers, Pultrall and Strongwell. The properties of the material from both sources are similar. It is not possible to identify whether this could be responsible for rather high coefficient of variation.

#### 8. CONCLUSIONS and RECOMMENDATIONS

- It appears that an adjustable tie can be manufactured from GFRPC. to be used as a tie between masonry veneer and a concrete block backup wall system with 50 mm air space and 50 mm rigid insulation.
   Failure load: 2574.8 N
   Free play: less than 0.25 mm
   Ultimate load: 2128.7 N (as defined in A370-94 12.1.3)
   Recommended design load: 710 N (the ultimate load divided by a factor of 3)
   Adjustment: 30 mm
   Maximum deformation under recommended design load is 0.5 mm.
   For a design wind load of 1 kPa, pressure or suction, 1.5 ties would be required per 1 square metre of wall area, or ties at 800 mm on centres in vertical and horizontal directions.
- 2. The safety factor of 3 is recommended for the design of GFRP composites. In the context of the limit state design, this is compatible with a material factor of 0.5 (low but reasonable, accounting for manufacturing and fabrication) and a load factor of 1.5 applied to wind load.
- 3. Surface treatment to increase bond strength of GFRP is not required.
- 4. Tie production at the moment is a two stage process, namely material manufacturing and precision cutting to the desired shape. This labour intensive process should be simplified.
- 5. The cost of the tie is of the order of the order of \$5. The material cost is only 36c.

However, the estimate is based on precision cutting of the material in very small quantities. Automating the process should decrease the cost. The cost should be compared to the cost of a stainless steel tie of adjustable type by Fero is \$6.25 (based on a medium size job) and the same tie galvanized costs \$3.35.

- 6. Part A is narrow, flat and rigid; it is assumed that the same process as for other ties can be followed to install the air/vapour barrier and rigid insulation.
- 7. Positive feedback regarding the handling of the ties was received from the mason who manufactured the specimens. Admittedly each part of the tie was used separately, thus reducing the complexity.

There are number of issues which should be investigated further:

- 1. Fire performance of the GFRPC tie. The material performance appears to be satisfactory. The material is not combustible, does not burn and when subjected to the flame, does not appear to soften. However it becomes warm and this impacts the strength of the glass fibres. It is necessary to research the area of properties the tie must possess when subjected to fire. It will be important to determine the temperature gradient throughout the assembly and determine the impact on the tie properties. At the same time it will be necessary to define the loads which have to be carried by the tie when exposed to fire. It may be possible to improve the properties of the material by selecting different resin, veil and finishing materials.
- 2. Material: three areas need to need to be investigated.
  - 1. Investigate whether the pultrusion process can be altered so that more beneficial properties are obtained. This is typically not a problem with a large order.
  - 2. An obvious alternative is to investigate moulding techniques to produce ties. This issue was looked at but because there are so many processes, so many manufacturers, and there is a need to explain what the parts do, it is difficult to determine at this stage whether it is a viable alternative. The most common injection moulding process uses short fibres and this process is not suitable for the production of the tie. However, a new moulding process which incorporates laid fibres may be applicable.
  - 3. Investigate new thermoplastic material produced by pultrusion. It may be a possibility to develop a one-piece tie because the material is bendable.
- 3. The adjustable tie which was developed is for brick veneer on a concrete block backup wall. It is possible to adjust the tie and fasten it to the side of a steel or wood stud. In the case of wood studs conventional screws could be used or GFRPC screws are available.

#### 9. Acknowledgments

This research project was supported under the external research program by the CMHC (Canadian Mortgage and Housing Corporation). GFPRC pultruded sections were kindly donated by Creative Pultrusions and Strongwell. The Ontario Masonry Contractors Association donated the time of a mason for the production of all samples. The author would like to express sincere thank you to

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Figure 1 - Prototype Evolution



3.15mm (1/8") Plate material



3.15mm (1/8") Plate material

Figure 2- Basic Prototype



3.15mm (1/8") Plate material



3.15mm (1/8") Plate material

Figure 3b)





3.15mm (1/8") Plate material

Figure 3c)

**Figure 3 - Block Ties** 



3.15mm (1/8") Plate material

Figure 4a) - Basic brick tie



#### Figure 4b) - Brick Tie with end returns

Figure 4 - Brick ties



Figure 5 - Wall Assembly



![](_page_35_Picture_1.jpeg)

![](_page_35_Picture_2.jpeg)

Figure 6 - Brick Tie Pull Out Test

![](_page_36_Picture_0.jpeg)

Figure 7 - Block Tie Pull Out Test

![](_page_37_Picture_0.jpeg)

![](_page_37_Picture_1.jpeg)

![](_page_37_Picture_2.jpeg)

Figure 8 - Tie Tensile Test Setting

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![](_page_38_Figure_0.jpeg)

Figure 9a) - Tie Tensile Test (1.1.) :Load - Deformation Curve (Sample 1)

![](_page_38_Picture_2.jpeg)

Figure 9b) - Tie Tensile Test(1.1.): Typical Failure

![](_page_39_Figure_0.jpeg)

Figure 10a) - Tie Tensile Test (1.2.) :Load - Deformation Curve (Sample 4)

![](_page_39_Picture_2.jpeg)

![](_page_39_Picture_3.jpeg)

Figure 10b) - Tie Tensile Test(1.2.): Typical Failures

![](_page_40_Figure_0.jpeg)

Figure 11 a) - Tie Tensile Test (1.3.) :Load - Deformation Curve (Sample 1)

![](_page_40_Picture_2.jpeg)

Figure 11 b) - Tie Tensile Test(1.3.): Typical Failures

![](_page_41_Picture_0.jpeg)

![](_page_41_Picture_1.jpeg)

Figure 12 - Pull out from Brick: Test Setting

![](_page_42_Figure_0.jpeg)

Figure 13 - Brick Pull out Test (2.1.) :Load - Deformation Curve (Sample 1)

![](_page_42_Picture_2.jpeg)

![](_page_42_Picture_3.jpeg)

Figure 14- Brick Pull out Test (2.1.): Typical Failure

![](_page_43_Figure_0.jpeg)

Figure 15 -Brick Pull out Test (2.2.) :Load - Deformation Curve (Sample 4)

![](_page_43_Picture_2.jpeg)

Figure 16 - Brick Pull out Test (2.2.) : Typical Failure

![](_page_44_Figure_0.jpeg)

Figure 17 -Brick Pull out Test (2.3.) :Load - Deformation Curve (Sample 5)

![](_page_44_Picture_2.jpeg)

Figure 18 - Brick Pull out Test (2.3.) : Typical Failure

![](_page_45_Picture_0.jpeg)

![](_page_45_Picture_1.jpeg)

Figure 19 - Pull out from Block: Test Setting

![](_page_46_Picture_0.jpeg)

![](_page_46_Picture_1.jpeg)

![](_page_46_Picture_2.jpeg)

Figure 20 - Block Pull out Test (3.1.) - Rectangular tie: Typical Failure

![](_page_47_Picture_0.jpeg)

![](_page_47_Picture_1.jpeg)

![](_page_47_Picture_2.jpeg)

Figure 21 - Block Pull out Test (3.2.) - Profiled tie: Typical Failure

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![](_page_48_Picture_0.jpeg)

Figure 22 - Block Pull out Test (3.3.) - Profiled tie with sand: Typical Failure

![](_page_49_Picture_0.jpeg)

![](_page_49_Picture_1.jpeg)

![](_page_49_Picture_2.jpeg)

![](_page_49_Picture_3.jpeg)

Figure 23 - Block Pull out Test (3.4.) - Profiled tie with holes: Typical Failure

![](_page_50_Picture_0.jpeg)

Figure 24 - Compression test for Brick Samples: Setting

![](_page_50_Picture_2.jpeg)

Figure 26 - Compression test for Concrete Block Samples: Setting

![](_page_51_Picture_0.jpeg)

![](_page_51_Picture_1.jpeg)

![](_page_51_Picture_2.jpeg)

Figure 25 - Compression Test (4.) - Brick Samples: Typical Failures

![](_page_52_Picture_0.jpeg)

![](_page_52_Picture_1.jpeg)

![](_page_52_Picture_2.jpeg)

Figure 27 - Compression Test (4.) - Block Samples: Typical Failures

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**APPENDIX A** 

## MATERIAL PROPERTIES

#### Pultex<sup>®</sup> Fiber Reinforced Polymer Flat Sheets

Metric Version

1500 Series - Thermoset Polyester Olive Green 1525 Series - Thermoset Polyester Class I FR Gray 1625 Series - Thermoset Vinyl Ester Class I FR - Beige

#### The following data was derived from ASTM coupon and full section testing. The results are average values

based on random sampling and testing of production lots. Composite materials are not homogeneous; and therefore, the location of the coupon extraction can cause variances in the coupon test results. Creative Pultrusions publishes in average value of random samples from production lets.

Property				
(compon values)	ASTM Test	Units	1500/1525 Series	1625 Series
Mechanical				and the second sec
Flexural Strength, Flatwise (LW)	D790	MPa	240.6	240.6
Flexural Strength, Flatwise (CW)	D790	MPa	103.1	103.1
Flexural Modulus, Flatwise (LW)	D790	GPa	13.7	13.7
Flexural Modulus, Flatwise (CW)	D790	GPa	7.6	7.6
Tensile Strength (LW)	D638	MPa	137.5	177.6
Tensile Strength (CW)	D638	MPa	68.7	68 7
Tensile Modulus (LW)	D638	GPa	12.4	12.4
Tensile Modulus (CW)	D638	GPa	6.9	6.0
Compressive Strength, Edgewise (LW)	D695	MPa	165.0	165.0
Compressive Strength, Edgewise (CW)	D695	MPa	110.0	110.0
Compressive Modulus, Edgewise (LW)	D695	GPa	12.4	12.4
Compressive Modulus, Edgewise (CW)	D695	GPa	6.9	6.9
Notched Izod Impact (LW)	D256	Lim	1067.6	1067.6
Notched Lord Impact (CW)	0256	1/m	266.9	266.9
Bearing Strength (LW)	0953	MPa	220.0	270.0
Bearing Strength (CW)	D953	MPa	220.0	220.0
Poisson's Ratio (LW)	D3039	much/much	0.35	0.35
Poisson's Ratio (CW)	D3039	munt/mum	0.12	0.12
Physical				
Barcol Hardness	D2583		40	40
Water Absorption	D570	% Max	0.6	0.6
Density	D792	Mg/m*3	1.65-1.93	166.101
Specific Gravity	D792	Configuration of the	1.66-1.93	1 66 1 91
Coefficient of Thermal Expansion (LW)	D696	10^-6K^-1	14.5	14.5
Electrical				
Are Resistance (LW)	D495	seconds	120	120
Dielectric Strength (LW)	D149	kV/mm	1.58	1.58
Dielectric Strength (PF)	D149	kV/mm	79	7.0
Dielectric Constant (PF)	D150	GIGOH	5.3	5.7

"Puliex." uses a synthesiat surface well that reduces the Barcol Handness, but does not reflect lack of core.

	ASTM 1est	Value	Value
Property		1525	1625
Flammability Classification	UL.94	(VO)	(V0)
Turnnel Test	ASTM E-84	25 Max	25 Max
Flammability Extinguishing	ASTM D635	Self extinguishing	Self extinguishing
NBS Smoke Chamber	ASTM E662	650	650
Flame Resistance (Ignition/Burn)	FTMS 406-2023	55/30 (seconds)	55/30 (seconds)

Note: Creative Pultrusions, Inc. manufactures Pultex\* Standard Structural and Structural profiles that meet the requirements of both the E17 and E23 grades of new Euronorm, EN 13 706.

#### Figure A1 - Material Properties by Creative Pultrusions

#### EXTREN® SERIES 625 PLATE ULTIMATE COUPON PROPERTIES

Below are the test results for the minimum ultimate coupon properties of EXTREN® Series 625 plate as per the referenced ASTM procedures. Designers should refer to Section 11 — PLATE for the recommended design equations for EXTREN®. The actual geometry and application of the plate will determine its ultimate usability.

			THICKNESS			
	ASTM			4.76mm	9.5mm	
PROPERTY	TEST	UNITS	3.175mm	6.35mm	25.4mm	
MECHANICAL						
Tensile Stress, LW	D638	N/mm²	138	138	138	
Tensile Stress, CW	D638	N/mm²	51.7	68.9	68.9	
Tensile Modulus, LW	D638	10º N/mm²	12.4	12.4	12.4	
Tensile Modulus, CW	D638	10 <sup>9</sup> N/mm <sup>2</sup>	6.89	6.89	9.65	
Compressive Stress, Edgewise, LW	D695	N/mm <sup>2</sup>	165	165	165	
Compressive Stress, Edgewise, CW	D695	N/mm <sup>2</sup>	114	121	121	
Compressive Modulus, Edgewise, LW	D695	10 <sup>3</sup> N/mm <sup>2</sup>	12.4	12.4	12.4	
Compressive Modulus, Edgewise, CW	D695	10 <sup>9</sup> N/mm <sup>2</sup>	6.89	6.89	6.89	
Flexural Stress, Flatwise, LW	D790	N/mm <sup>2</sup>	241	241	207	
Flexural Stress, Flatwise, CW	D790	N/mm <sup>2</sup>	89.6	103	124	
Flexural Modulus, Flatwise, LW	D790	10º N/mm²	12.4	13.8	13.8	
Flexural Modulus, Flatwise, CW	D790	10 <sup>9</sup> N/mm <sup>2</sup>	6.89	7.58	9.65	
Bearing Stress, LW	D953	N/mm <sup>a</sup>	221	221	221	
Perpendicular Shear Stress, LW <sup>®</sup>	D3846	N/mm <sup>a</sup>	41.4	41.4	41.4	
Perpendicular Shear Stress, CW	D3846	N/mm <sup>2</sup>	41.4	41.4	41.4	
Poisson's Ratio, LW	-	mm/mm	0.320	0.320	0.320	
Poisson's Ratio, CW		mm/mm	0.240	0.240	0.240	
Notched Izod Impact, LW	D256	J/mm	0.988	1.07	1.07	
Notched Izod Impact, CW	D256	J/mm	0.267	0.267	0.267	
PHYSICAL						
Barcol Hardness	-	-	40.0	40.0	40.0	
24 hr Water Absorption®	D570	% Max	0.60	0.60	0.60	
Density	D792	10° g/mm <sup>3</sup>	1.66-1.88	1.66-1.88	1.66-1.88	
Coefficient of Thermal Expansion	D696	10 <sup>4</sup> mm/mm	n/C* 14.5	14.5	14.5	
ELECTRICAL						
Dielectric Strength, LW	D149	KV/mm	1.38	1.38	1.38	
Dielectric Strength, PF <sup>3</sup>	D149	volts/mil	250	N.T.	N.T.	
Dielectric Constant, PF	D150	at 60Hz	5	5	5	

.....

LW= lengthwise CW= crosswise

PF= perpendicular to the laminate face

N.T.= not tested

#### NOTES:

The notches are oriented to be perpendicular to the mat and roving. This is measured in the compressive mode.

Measured as a percentage maximum by weight.

Typical values for shape and composite dependent tests.

#### M-11

#### Figure A2 - Material Properties by Strongwell

![](_page_58_Picture_0.jpeg)

![](_page_58_Picture_1.jpeg)

![](_page_58_Picture_2.jpeg)

![](_page_58_Picture_3.jpeg)

Figure A3 - Internal Structure of GFRP