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ASSESSING THE MECHANICAL PERFORMANCE OF AN INNOVATIVE EPOXY ADHESIVE CONNECTOR FOR TIMBER AND CONCRETE JOINTS

BY

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RESUMEN

Ante una catástrofe como los incendios forestales, donde se genera una gran pérdida de viviendas, es crucial actuar rápidamente en la construcción de viviendas de emergencia con el objetivo de proporcionar refugio a las personas afectadas, permitiendo así un inicio más rápido de los esfuerzos de reconstrucción de viviendas permanentes. En respuesta a esta necesidad, es necesario ofrecer técnicas de construcción que cumplan con las necesidades de las personas afectadas en cuanto a habitabilidad.

Este estudio tuvo como objetivo presentar un nuevo conector de cizallamiento en base a resina epóxica, para viviendas de emergencia, con el fin de proporcionar una solución rápida y de alta calidad que no permitiera la filtración de agua en la madera durante las temporadas de lluvia y no dañara la estructura de hormigón, que podría ser colocada en una etapa temprana.

Debido a lo anterior, se llevaron a cabo pruebas de tracción, cizallamiento inclinado y cizallamiento doble en piezas de hormigón y madera adheridas con este adhesivo con el fin de obtener valores de resistencia para este compuesto. Las piezas de hormigón fueron sometidas a curado durante 7 y 28 días para establecer tanto un valor estándar como un valor de edad temprana, dado que la velocidad de construcción era una consideración principal en situaciones de emergencia.

Los resultados arrojaron valores tanto positivos como negativos en comparación con otros adhesivos encontrados en la revisión de la literatura, habiendo resultados mayores y menores que lo revisado. Cuando se compararon con elementos de fijación mecánica se pudo concluir que el adhesivo podía competir con otros métodos de anclaje mecánico en el mercado. Sin embargo, se sugirió llevar a cabo más pruebas y análisis de factores adicionales, como la humedad de instalación y el tiempo de almacenamiento del adhesivo, para igualar los valores en diferentes pruebas. En cuánto al análisis sísmico se puede concluir que el adhesivo supera los esfuerzos de corte demandados por la norma sísmica chilena.

Se recomendó continuar avanzando en la investigación sobre este adhesivo, llevándolo a un escenario del mundo real con paredes de cizallamiento y buscando formas de compararlo con anclajes tipo Hold-down con el fin de explorar más a fondo las características del adhesivo.

ABSTRACT

In the face of a catastrophe such as wildfires, where there is a loss of homes, it is crucial to act quickly in the construction of emergency housing with the goal of providing shelter to the affected people, thus enabling a faster start to the permanent housing reconstruction efforts. In response to this need, it is necessary to provide construction techniques that offer satisfaction to the affected people in terms of habitability.

This study aims to introduce a new adhesive epoxy shear connector for emergency industrialized wooden housing to deliver a fast and high-quality solution that does not result in water leakage into the wood during rainy seasons and does not damage the concrete structure, which may be placed at an early age.

Due to the above, tensile, inclined shear, and double shear tests will be conducted on pieces of concrete and wood adhered with this adhesive in order to obtain resistance values for this compound. The concrete pieces will undergo curing for 7 and 28 days to establish both a standard value and an early-age value, given that construction speed will be a primary consideration in emergency contexts.

The results yielded both positive and negative values when compared with other adhesives found in the literature review, as there are tests that produce values higher than those in the literature and others that yield values lower than what was reviewed. When compared with mechanical fasteners, it can be concluded that the adhesive can compete with other mechanical anchoring methods in the market. However, further testing and analysis of additional factors, such as installation humidity and adhesive bucket storage time, are suggested to equalize the values across different tests. When compared to the seismic analysis this study concludes the adhesive can overcome the shear inducted by the demands given in the Chilean earthquake code.

It is recommended to continue advancing in research on this adhesive, taking it to a real-world scenario with shear walls and seeking ways to compare it with Hold-down-type anchors in order to further explore the characteristics of the adhesive.

DEDICATED TO

To my family, for never quit the high positivity and always being there where I needed.
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CHAPTER 1: INTRODUCTION

1.1. Motivation

The Chilean government with the president Gabriel Boric has a housing emergency plan that commits to provide 260.000 new houses for people without house during his mandate to provide a roof for the people who most need it being an estimate of 650.000 houses in deficit. That makes a high demand in housing construction and by that new techniques of construction are needed with the purpose of achieve the numbers committed in the time estimated, one of those techniques is industrialized housing construction (MINVU, 2022).

The housing deficit increased during the devastating wildfires in the Bio-Bio region of Chile, more than 2.600 houses were tragically destroyed and then the government committed to restore all the damaged houses and start right after the catastrophe (Gobierno de Chile, 2023). The construction process of these houses revealed a series of issues with far-reaching implications. Firstly, the roofs proved incapable of withstanding the strong winds of the region, resulting in their collapse. Secondly, the anchoring systems utilized to secure the houses to the ground did not perform as expected, leading to instability under various forces such as winds, earthquakes, or the weight of the occupants. These problems were primarily attributed to poor connections between the house foundations and the structure of the house, and the inadequate type of foundation designed for the houses (Carrillo, 2023).

There is a wide range of construction materials for single family units and new materials and techniques are being proposed for this type of construction constantly. For single unit housing construction there are three types of building techniques for single-family housing in the range of emergency housing which are Masonry (Thomas et al., 2018), Metal framing and Timber (Diaz, 2020). The focus of this study is to analyze the advantages of disadvantages of a novel type of connection for timber framing that provides a faster installation time in an emergency context, where the time and quality are the most important factors. The traditional timber framing construction is faster than the masonry housing (Thomas et al., 2018) and the metal framing is a 9% faster than traditional timber framing (Arias, 2017), but at the same time the prefabricated timber framing has a faster construction time than the traditional timber construction (Alvarado, 2010), Which means the prefabricated timber framing with the adhesive on this study can reduce by far the required time to finish the emergency houses helping the affected people to have quicker a temporary roof to start rebuilding their new houses after a catastrophe and can compete with the construction times of metal framing.

Furthermore, water infiltration through the mechanical connectors of the structure in the concrete foundation emerged as an additional challenge. This led to a more humid environment inside the houses, negatively impacting the overall structural integrity of the projects. (Carrillo, 2023), which motivates to go further the common standards of prefabricated housing construction and use a new material as a shear connector based on an epoxy adhesive to cover these needs. Also, the production commitment for the houses was not reached by the contractors, which led to a big delay in the installation of the emergency houses (Lorca, 2023).

One big advantage of this adhesive against other type of materials as mechanical fasteners is the capability to make a surface linkage between the concrete and timber giving the possibility to distribute the shear strength along all the surface without making holes in the structure and making damage to it. That advantage can make a cleaner structure without weaker points and less drainage in the interphase.

The principal challenges of this new type of adhesive connection for prefabricated housing is a design that brings workability in the use of this product and the need of specific calculations for this adhesive because there is not any code that establishes a design for adhesive connectors. At this moment it is expected to see a failure mode in the concrete interphase because of the brittle mechanical properties of the concrete.

The motivation of this study is to provide a connection that brings a faster time installation with less deficiency in the habitability for emergency timber housing. The main aim is to use this connector for single family housing and there is where the need becomes, this connection is also useful for a higher scale market that is rapidly growing up and those are the Timber-Concrete composites, which give more information about connections for both.

1.2. General Objectives

The general objective is to establish the mechanical performance of a new epoxy adhesive as a novel type of connection to link the structure of prefabricated timber houses to their foundations.

1.3. Specific Objectives

a) Characterize the epoxy adhesive on its mechanical properties as tension and shear resistance.
b) Compare the adhesive strength at various curing times.
c) Identify the failure mode of the connections.
d) Compare the resistance of the adhesive with the resistance of the studies by Fu et al. (2021) and Nemati Giv et al. (2021).
e) Compare the resistance of the adhesive with the effects of an earthquake according with the Chilean code NCh433of.96 mod 2012(INN,2012) using as a reference the blueprints of a single store house.
f) Compare the resistance of the adhesive with the resistance of mechanical fasteners as nails and screws with the calculations given by the Chilean code NCh1198(INN,2014).

1.4. Work Methodology

The first part of this study was a bibliographical review about timber concrete composites (TCCs) and their relationship to prefabricated housing. There it will be a state of art of both TCCs and prefabricated housing where the materials involved in this study will be defined with their constraints to understand what can limit the values given by the further tests. There also will be a definition of the parameters to work and compare guided by the specific objectives according to the different information reviewed.

The second part of the study is an experimental work that begins with the characterization of this adhesive with its tensile strength. Then it was considered an experimental work consisting of two stages consisting of each test done in this study. In every stage of this part the fluidity of the concrete made for the study was measured, and then with 7 and 28 days of casting the shear strength was tested.

Finally, the results of the experimental work are compared with the values of the past studies, with mechanical fasteners and finally with the seismic demands given by the Chilean earthquake code.

1.5. Principal results and conclusions

1.5.1. Composite resistance

The resistance of the composites has a difference between the two types of pieces that are being tested in this study, where the 40x40x160mm pieces have more resistance than the cubical 40x40x40mm pieces in both cases timber-concrete-timber and concrete-timber-concrete with an average resistance of 5,16 MPa for the 28 days glued bars and the cubes had 1,16 MPa and 0,53 MPa for the previously mentioned arrays.

For 7 days casting the resistances are less than 28 days except the wood-concrete-wood array having 0,95MPa (0,83 MPa more than the 28 days), 2,51 MPa for the other array and 2,79 MPa in average resistance for the bars.

It can be concluded that the concrete casting can affect the resistance of this connection and so the dimensions affect positively with more resistance for bigger surfaces.

1.5.2. Failure mode

After testing all the different pieces, it was noticed a high influence of the composite to have a brittle failure in the concrete side, there were no failures in the side of the wood and the two types of failure noted in this study were removal of the facial cover and concrete failure with a 90% for the facial cover and a 10% of concrete failure in the bars and a 100% of facial cover removing for the two arrays of cubes.

The wood does not affect the resistance of the composite being the concrete the weaker side of the pieces, even though the resistances in the tests were bigger than the shear tensile strength of the concrete by itself, with that can be concluded the composite gets more resistance once it is glued with this adhesive.

1.6. Memory order

The following report consists of five chapters. The second chapter consists on a literature review with previous studies related to timber concrete composites, along with a definition based on the bibliography of the materials to be used and the standards and codes that establish their strengths. The third chapter shows the methodology that will be followed throughout the research, detailing the materials used, the work strategy (Stage 1 and Stage 2), and the experimental procedures tested. The fourth chapter presents and analyzes the results obtained in the research, and finally, the fifth chapter provides the main conclusion.

CHAPTER 2: TIMBER CONCRETE COMPOSITES

2.1. Introduction

This chapter begins by explaining the relationship between timber concrete composites and prefabricated housing, particularly in terms of shear connectors. Additionally, it includes definitions of the materials under study, namely timber, concrete, and epoxy adhesives, along with a review of various parameters. These parameters encompass the tests guidelines based on literature reviews for epoxy adhesives and codes for timber and concrete, the purpose of the definition of parameters is to ensure the efficiency of the testing and higher results based in the methodology. Furthermore, the chapter delves into construction systems for foundations, strength calculations for mechanical fasteners and examines seismic loads to enable further analysis and comparison. All of these aspects contribute to the core focus of this study, allowing for the definition of the values and insights that it yields.

2.2. Why timber concrete composites?

In this study, a critical question arises: why is there a blend of new foundation connection concepts for single-story houses, even though previous research primarily focuses on high-rise buildings and slab systems involving timber beams beneath concrete toppings? This potential inconsistency might bewilder readers and impede a comprehensive understanding of the core focus of the study. The rationale for this approach is rooted in the concept of scalability. The aim of the study is to first develop materials suitable for prefabricated single-story housing, with the intention that they can later be adapted for multi-story constructions in compliance with relevant design codes.

In the subsequent sections of this chapter, there are referenced studies conducted by Fu et al. (2021), Nemati Giv et al. (2021), and others. These studies provide valuable insights into shear connectors for two distinct materials: concrete and wood. They primarily pertain to timber concrete composites and a structural system consisting of a timber slab atop reinforced concrete beam. The objective of the study is to leverage the findings from these studies, which are focused on wooden slabs and reinforced concrete beams, and apply them to the context of reinforced concrete foundations beneath wooden houses.

The Chilean code for timber structures, NCh1198 (INN, 2014), exclusively offers calculation methods for mechanical fasteners as shear connectors to join timber and concrete. It lacks information on adhesives. As a result, this study will rely on test data provided by Fu et al. (2021) and Nemati Giv et al. (2021) to establish reference values for epoxy adhesive as a shear connector.

In summary, both timber concrete composites and prefabricated houses necessitate shear connectors to establish a strong connection between the concrete and timber components. This common requirement propels our effort to develop a versatile shear connector that can cater to the needs of both structural systems.

To address any potential inquiry regarding why is this problem intended for single-story houses when prior research focuses on multi-story building solutions, the answer is simple: this represents the initial step towards ascending the ladder of scalability within these systems.

2.3. Definition of Timber-Concrete Composites

Timber concrete composites (TCC) originated in the 1920s due to steel shortages during the Great Depression and wartime expenses (McCullough, 1943). This composite merge timber and concrete, placing concrete for compression strength and wood for tensile strength, improving acoustic and fire performance (Dias et al., 2018). Using timber in TCC also lowers the stiffness-to-weight ratio (Hamid Mirdad, 2021).

This kind of composite started to be used in bridges in the United States (Wacker et al. 2020) and then this technique arrived to multi store buildings. In these days many countries are fighting to have the tallest skyscraper made of timber-concrete composite (TCC) as the Brock Commons made by the University of British Columbia in 2017 with 18 stores (Pilon, 2018).

Timber and concrete have complementary properties. Timber is lightweight and has high strength-to-weight ratio, while concrete is heavy and possesses high compressive strength. By combining these materials, timber-concrete composites can achieve enhanced structural efficiency and load-carrying capacity with a lighter structure (Hamid et al. 2021).

2.4. Load considerations for prefabricated timber housing

In this section the loads involved in timber structures are analyzed and discussed with the purpose of understand the less strong side in the composite and having knowledge about the resistance of the timber side on it to prevent the failure mode on the tests. This section is divided in two types of loads, the first one is the load capacities where the load comes from the strength of the timber and the second section is an analysis on quake loads to estimate a base shear load to then compare it with the results of this study based on the tests to conclude if the strength of the composite overcomes the base shear load.

2.4.1. Load capacities

In the study, the capacity of the connector is assessed for shear capacity to prevent slippage. The resistance serves as a benchmark for evaluating the novel adhesive connector against common shear connectors.

The load capacity adheres to the Chilean code NCh1198 (INN, 2014), governing design principles for timber construction. Table 2.1 lists multiple load resistance values, and modification factors influencing these capacities are emphasized. This study specifically focuses on Pinus radiata, providing resistance values solely for this species.

Table 2.1 Different Values of Resistance for Pinus radiata species according to different structural grades in MPa.

Grado estructural	Tensiones admisibles de:					Módulo de elasticidad en flexión	Indice de aplastamiento en compresión normal
	Flexión 1)	Compresión paralela	Tracción paralela 1)	Compresión normal	Cizalle		
	F_f MPa	F_{cp} MPa	F_{tp} MPa	F_{cn} MPa	F_{cz} MPa	E_f 2) MPa	$E_{cn,h}$ MPa/mm
a) Visuales							
GS	11,0	8,5	6,0	2,5	1,1	10 500	5,65
G1	7,5	7,5	5,0	2,5	1,1	10 000	
G1 y mejor	9,5	7,8	5,5	2,5	1,1	10 100	
G2	5,4	6,5	4,0	2,5	1,1	8 900	
b) Mecánicos							
C24	9,3	8,0	4,7	2,5	1,1	10 200	5,65
C16	5,2	7,5	3,5	2,5	1,1	7 900	
MGP 10	8,4	10	4,0	2,5	1,3	10 000	
MGP 12	13,5	15,5	6,0	2,5	1,3	12 700	

1) Valores aplicables sobre piezas de altura de sección transversal ≤ 90 mm, excepto en los Grados Mecánicos MGP 10 y MGP 12, para los que el límite se incrementa hasta 160 mm.

2) Valores aplicables sobre piezas de altura de sección transversal ≥ 180 mm, excepto en los Grados Mecánicos MGP 10 y MGP 12, cuyos valores son aplicables sobre cualquier altura de sección transversal. El módulo de elasticidad característico inherente al percentil del 5%, E_{fk}, se puede estimar como 0,60 E_f.

Source: NCh 1198 (2014).

As it is going to be specified later in the methodology, the structural grade of the timber species that will we used is G2 as visual classified and it has a bending resistance of 5,4 MPa and a shear strength (Cizalle) of 1,1MPa.

A) Load Duration Modification Factor K_D

Wood has the property of resisting higher loads if they are applied for short periods, compared to those applied over long durations. The load duration modification factors are presented in the Table 2.2. The different types of loads are permanent (D) for more than 10 years, Live floor (Lf) for 10 years, Snow (S) for 2 months, Life roof (Lr) for 7 days, Wind or Earthquake (W or E) for 10 minutes and Impact (I) for 2 seconds.

These values are the result of the equation 2.1 that describes the value of K_D for any value of time.

$$K_D = \frac{1{,}747}{t^{0{,}0464}} + 0{,}295 \qquad 2.1$$

With t the value of the time of load duration in seconds.

Table 2.2 Different types of loads according to their duration and their values of K_D.

Type of load	Duration	***KD***
Permanent (D)	more than 10 years	0,9
Live load on floor (LF)	10 years	1
Snow (S)	2 months	1,15
Live load on roof (Lr)	7 days	1,25
Wind (W) or Quake (E)	10 minutes	1,6
Impact (I)	2 seconds	2

Source: NCh 1198 (2014)

B) Modification factor for moisture content, K_H

The assignment of allowable stresses and the elastic modulus for pieces of sawn wood with thicknesses equal to or less than 100 mm, and which are constructed with a moisture content (Hc) between 12% and 20%, can be obtained through linear interpolation between the allowable stress values for green wood and dry wood shown in table 2.3. This is done by applying the factor noted in equation 2.2 to the allowable stress in the dry condition:

$$KH = (1 - \Delta H \times \Delta R) \qquad 2.2$$

Where:

KH: Modification factor for moisture, applicable to allowable stresses and elastic modulus, defined for a moisture content of 12%.

ΔH: Difference between the value of service moisture content (Hs) and 12%.

ΔR: Variation of strength per 1% variation of moisture content shown in table 2.3.

For pieces of sawn Radiata Pine in green condition (H ≥ 20%), the allowable properties and elastic moduli in the dry condition should be modified by the factors shown in Table 4.

Table 2.3 Variation of strength properties for a moisture content variation of 1%

Tensión admisible o módulo elástico	**Variación de la resistencia para D*H* - 1%** **D*R***	
	Especies en general	**Pino radiata**
Flexión	0,020 5	0,025
Compresión paralela	0,043	0,048
Tracción paralela	0,020 5	0,025
Cizalle	0,016	0,015
Módulo de elasticidad en flexión	0,014 8	0,017
Indice de aplastamiento en compresión codeal $E_{cn, h}$	-	0,029

Source: NCh1198 (2014)

Table 2.4 Modification factor for moisture content for green Radiata Pine wood.

Tensión admisible o módulo elástico	K_H
Flexión	0,750
Compresión paralela	0,520
Tracción paralela	0,750
Compresión codeal	0,670
Cizalle	0,850
Módulo de elasticidad en flexión	0,830
Indice de aplastamiento en compresión codeal $E_{cn, h}$	0,478
1)Este valor debe ser aplicado además para especies en general.	

Source: NCh1198 (2014)

2.4.2. Maximum shear strength of timber pieces

This point will give an image on how it can be estimated the maximum shear strength of a sawn wooden piece according to a one specific kind of timber piece. The calculations for these strengths are made according to the Chilean code NCh1198 (INN, 2014) in the parallel shear point.

To design a wooden piece the most important point for the designed structures is to overcome the loads affecting the structure and is by that the design strength must be greater than the work loads, this equation is shown in equation 2.3.

$$f_{cz} \leq F_{cz,dis} \qquad 2.3$$

With:

f_{cz} : Existing shear load in MPa

$F_{cz,dis}$: Design load based on the properties of the wooden piece in MPa

Each component of the equation depends the first in the load analysis and the second in the parameters given by the code.

The existing shear load can be calculated as in equation 2.4.

$$f_{cz} = \frac{3V_{max}}{2bh} \qquad 2.4$$

With:

$Vm\acute{a}x$: Maximum shear load (N), depending on the load configuration

b: Piece width (mm)

h: Piece height (mm)

For effects of the study, the existing shear load does not need to be calculated due to this load comes from the hydraulic gauge on the tests.

The strength of a sawn wooden piece is given by:

$$F_{(cz,dis)} = F_{cz}\ x\ K_H\ x\ K_D\ x\ K_r \qquad 2.5$$

With:

Fcz: Tensile shear strength

KH: MF for wet content (general use)

KD: MF for load duration (general use)

Kr: MF for lowering

The final modification factor is determined by the presence of a lap in the wooden piece. According to the code, this factor equals 1 when there is no lap. Since this study does not specifically address lap modifications, we will assume a factor of 1 in this context.

To estimate the maximum shear strength, we need to equate the two equations and determine the value of Vmax based on the dimensions of the wooden piece. Afterward, the appropriate modification factors specific to the wooden piece are applied, which depend on factors such as moisture content and load duration. Using a humidity content of 14% with a load combination of live load on floor and without any lowering for a G2 pinus radiata species, the values of maximum shear loads are the next ones according to the different dimensions used in this study:

a) 40mm by 160mm: Vmax = 4.57 kN
b) 40mm by 40mm: Vmax = 1.78 kN

2.5. Shear strength of reinforced concrete

Concrete is a material commonly used around the world for any kind of building like houses, bridges, highways and multi store buildings. The constitutive material for concrete is pozzolanic and clinquer coming from Portland cement. This can come from mortar and mixed with gravel and sand or can come from a ready mix with all the materials already and just add water to make the mix.

In this study the shear resistance of the concrete is highly important because it gives an idea on how the performance of the composite will be. The shear resistance of the concrete is given by the equation of the American Concrete institute (ACI) in the Building Code Requirements for Structural Concrete ACI CODE 318-19(ACI, 2022), the equation for the shear resistance of the concrete is 2.6:

$$V_c = 0.17\sqrt{f_c'}b_w d \qquad 2.6$$

Where:

f_c': Specified compressive strength of the concrete in MPa

b_w : Width of the concrete piece in millimeters

d : Distance from the extreme compression fiber to the centroid of longitudinal tension reinforcement is a key parameter. In cases where there is no concrete reinforcement, the value of 'd' is equal to the height of the concrete piece in millimeters.

It must be noted that this equation is applicable solely in the context of reinforced concrete design. The results are intended for understanding the specific point to which the values apply.

For concrete with a compressive strength of 20 MPa and the two different dimensions to test in this study, the shear resistance values of the concrete are as follows:

c) 40mm by 160mm: Vc = 4.8 kN
d) 40mm by 40mm: Vc = 1.2 kN

These two values are be compared to the results of the further tests done in this study. The tensile shear strength for both cases will be 0.76 MPa.

2.6. Types of connections for a TCC

Shear connectors play a crucial role in this structure to enhance composite action, as illustrated in figure 2.1. This allows the concrete to efficiently handle compressive forces while the timber manages tensile forces effectively (Fragiacomo et al., 2011).

Two types of connections are designed based on the condition of the concrete when connected to the timber. Considering that timber typically retains some level of moisture (Schiere, 2018), it is treated as a 'dry' connection. Meanwhile, the condition of the concrete can vary from 'wet' to 'dry.' In summary, we have 'Dry-Dry' connections when solid concrete connects to the wood and 'Dry-Wet' connections when wet concrete mix is poured directly into the timber (Nemati et al., 2022).

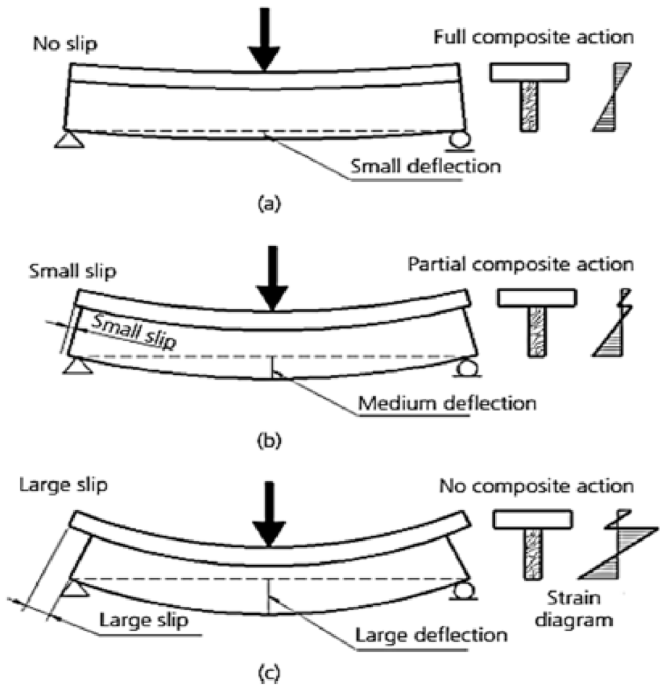

Figure 2.1 Strain distribution of timber–concrete composite system
Source: Fragiacomo et al. (2011)

The connection between the two materials in timber concrete composites (TCC) relies on various methods, including mechanical connectors, adhesives, or interlocking systems. Shear connectors play a vital role in transferring loads between timber and concrete. These connectors come in different forms, such as steel dowels, nails, screws, or connectors specially designed for timber-concrete composites. On the adhesive front, popular options include epoxy and polyurethane adhesives (Siddika et al., 2021).

Mechanical connectors have certain limitations, such as the necessity to drill into the structure, which can impact the structural integrity and potentially lead to future cracks in concrete or timber. Additionally, mechanical connections usually take more time compared to adhesive connections (Nemati et al., 2022).

2.7. Glued connections

The glued connections can be used with epoxy or polyurethane adhesives, both adhesives are a two-component structural adhesive. Epoxy and polyurethane adhesives have a gelation point, which is determined by oscillatory tests using a rheometer to find a viscoelastic area where the adhesive is in a rubbery state (Nunez et al., 2005).

A glued connection can distribute the shear forces uniformly over the entire surface and thus avoid the local force concentrations which are inevitable when mechanical connections are used (Brunner et al., 2007).

2.7.1. Epoxy adhesives

Epoxy adhesives polymerize into an amorphous and highly crosslinked material, offering numerous advantages. These include a variety of curing methods, minimal shrinkage during curing, excellent wet-tability resulting in strong bonds with most substrates, high corrosion resistance, good mechanical and cohesive strength, and acceptable chemical and thermal resistance (Ahmadi, 2019).

Epoxy adhesives can have their properties modified by incorporating various types of nanoparticles. In particular, inorganic nanoparticles are commonly used to reinforce epoxy adhesives. Examples of these inorganic nanoparticles include clay nanoplates, halloysite nanotubes, and metal oxides, which are naturally occurring mineral nanoparticles used in epoxy adhesive formulations (Hochella et al., 2012).

Epoxy adhesives are a type of two-component adhesive consisting of a resin and a hardener. These components are mixed in specific proportions prior to application, and the ensuing chemical reaction results in a highly durable and strong material.

Notably, epoxy adhesives are recognized for their exceptional bonding capability across a wide range of materials, including metals, plastics, ceramics, glass, and wood. They are also known for their resistance to temperature, chemicals, and moisture, making them a popular choice for a diverse array of applications.

Some of the common uses of epoxy adhesives include:

a) Metal repair and construction: Epoxy adhesives are widely used in the metal repair and construction industry as they provide a strong and durable bond for applications such as joining metal parts, repairing steel structures, and bonding pipes.
b) Electronics industry: Epoxy adhesives are used in the manufacturing of electronic components, such as printed circuit boards and electronic device assembly. They provide excellent adhesion to electronic substrates and protect components from moisture and vibrations.
c) Crafts and DIY projects: Epoxy adhesives are also used in crafting and DIY projects, such as jewelry making, model building, and bonding materials in artistic endeavors.

These are just a few examples of the numerous uses of epoxy adhesives. Their versatility, strength, and bonding capabilities make them a popular choice in various industries and applications.

2.7.2. Types of failure in epoxy adhesives

Two types of failure when it comes to the adhesive itself, cohesive and adhesive failure (Ahmadi, 2019). The first cohesive happens in the bulk layer of the adhesive of one of the adherents and the second adhesive occurs in between the interfacial surface. In most cases the failure mode is a mix between both of those mentioned cases.

The preferable failure mode is the cohesive because of high fracture toughness in joint stability and with that it does not make a bridge material between the adherents and takes off the need to get calculations for the quantity of adhesive required to do not get to the adhesive failure.

Another type of failure occurs when the adhesive bond is stronger than the resistance of the concrete or wood (Fu et al., 2021). In wood, two distinct failures are observed: fiber tearing and wood failure. In concrete, failure manifests as concrete breakage or facial cover tear-off, identifiable through crack lines or by analyzing the remaining quantity of coarse aggregate on the adhesive surface.

2.8. Mechanical connectors

In constructing mechanical connectors for Timber Concrete Composites (TCC), the initial step involves placing components like nails, dowels, or screws into the timber. Following this, the concrete is introduced. It can be in the form of a prefabricated concrete slab, known to prevent shrinkage and minimize permanent deflection, or as a wet concrete mix. Mechanical connectors offer the advantage of precise placement as designed, showcasing high stiffness and resistance. An effective combination involves using steel tubes inserted into the concrete slab with screws (Ø20x160mm) and notches in the glulam beam.

Lukaszewska et al. conducted a study focused on addressing the shrinkage issue in timber concrete composites. They achieved this by employing prefabricated components to enhance load-carrying capacity and system stiffness. By utilizing a set of two steel tubes inserted into the concrete slab with screws Ø20x120mm and maintaining a 250mm distance between tubes, longer screws can be utilized. The findings of this study indicate the feasibility of establishing a ductile system with mechanical fasteners.

2.9. Definition of resistance of mechanical fasteners

The Chilean code NCh1198 (INN, 2014) provides shear resistance values for mechanical fasteners. For a standard screw of ½" diameter placed in double shear within three 2 by 10-inch wooden pieces, the minimum resistance is 3.28 kN. Similarly, for 3.5” length nails placed in a central piece of 5 by 6 inches with two lateral pieces of 2 by 6 inches, the minimum resistance is 0.4 kN, according to their respective failure modes. Both types of union methods are depicted in figures 2.2 and 2.3. The calculation of strengths for these mechanical fasteners with all their failure modes is detailed in appendix 4.3 and 4.4, while the comparison with the test results is presented in appendix 4.5.

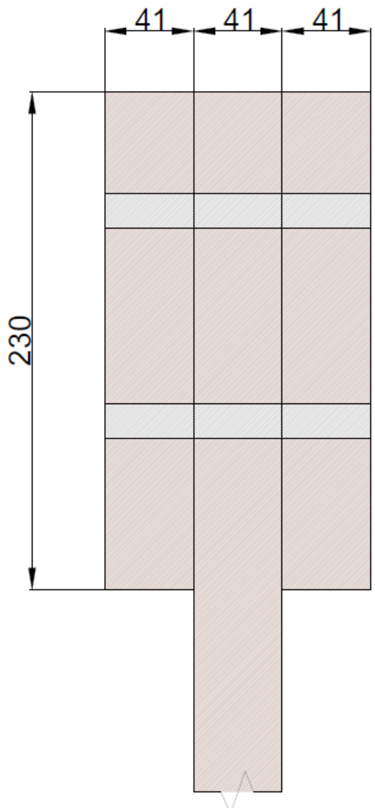

Fig. 2

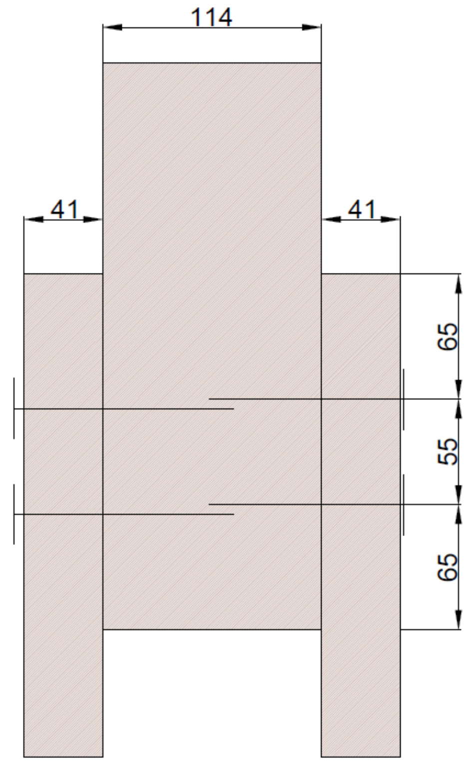

Fig. 3

Figure 2.2 **Scheme of the double shear union with ½” bolts which links three sawn timber pieces of 2 by 10 inches dimensions.**

Figure 2.3 **Scheme of the double shear union with 3.5” nails which links two sawn timber pieces of 2 by 6 inches with a central piece of 5 by 6 inches.**

2.10. Effect of concrete surface treatment on resistance and failure mode of the composite

A surface treatment is applied to the concrete, involving sandblasting the area to be bonded with timber. This surface treatment enhances the adhesive strength of the connection compared to a non-sandblasted surface, resulting in improved adhesive penetration into the concrete substrate. This improvement can lead to an improvement of the composite strength of the 30% (Fu et al., 2021).

In cases with a surface treatment, the failure mode primarily occurs on the concrete, in contrast to a failure mode involving the tearing of the concrete facial cover or an adhesive/concrete interface failure when the surface lacks treatment. Figures 2.4 and 2.5 illustrate the contrast between these two surface conditions. Notably, a sandblasted surface exhibits a cleaner, textured area that facilitates deeper adhesive penetration, ultimately leading to a stronger bond between the concrete and adhesive.

Figure 2.4 Concrete bar without surface treatment.

Figure 2.5 Concrete bar with surface treatment.

In conclusion, both figures clearly illustrate a significant contrast in the porosity of the contact surfaces. This disparity contributes positively to the interlocking system, enhancing both resistance and the preferred failure mode. This outcome aligns with one of the primary objectives of this study, which is to prioritize concrete failure over adhesive interphase failure.

2.11. Effect of bonding thickness on the resistance of the composite

The choice of different equivalent thicknesses for adhesively bonded timber concrete composite (TCC) joints can significantly affect how the adhesive penetrates the concrete substrate. These thicknesses typically range from 0.25 mm through 1mm to 3 mm where the stronger bonding is evicted with 1 mm of equivalent thickness with a predominant failure in the concrete (Nemati Giv et al., 2022).

For the study, the equivalent adhesive thickness was set at the specified thickness by the manufacturer which value is 1 mm. While achieving an exact 1 mm thickness can be challenging, an additional 1 mm margin will be incorporated as a precaution. This thickness will be accurately measured when the two pieces are positioned face-to-face.

2.12. Effect of waiting time on the resistance of the composite

Gelation time (tgel), defining the transition of wet adhesive from liquid to rubbery during crosslinking (Nemati et al., 2022), is pivotal for adhesive workability. This polymer property, assessed through techniques like dynamic mechanical analysis (DMA), dielectric analysis (DEA), and rheological measurement, significantly affects adhesive performance.

Regarding epoxy adhesives, precise timing of concrete placement following adhesive application is crucial. Gelation time, determined via oscillatory testing (Nunez et al., 2005), has three key intervals: initial adhesive application (t0), the midpoint of crosslinking (0.5tgel), and the gelation point (tgel). Proper timing in sample preparation is paramount for maximizing adhesive efficacy in timber concrete composites. Nemati et al. (2021) emphasize that optimal results are attained by placing concrete immediately after adhesive application (t0).

2.13. Influence of the different type of concrete on the resistance of adhesively bonded TCC

Adhesively bonded connections offer a uniformly strong linkage across the contact surface, contrasting with mechanical connectors limited to specific points (Fu et al., 2021).

Variations in concrete type, surface conditions, and wood species significantly impact adhesive connection resistance. Fu et al. (2021) examined three concrete types: Normal Strength Concrete (NSC), Ultra High-Performance Concrete (UHPC), and High-Performance Concrete (HPC) under sandblasted and non-sandblasted conditions. These were bonded to Beech wood and European Spruce Glulam (GL24) using Polyurethane and Epoxy adhesives.

The study showed that the most common failure mode occurred at the adhesive-concrete interface, with resilient concrete enhancing composite strength. Therefore, emphasizing concrete strength assessment is crucial.

In summary, concrete resistance should be a primary focus, leading to a more robust composite due to the brittle nature of the concrete. Surface treatment also played a vital role in enhancing composite resistance and adhesive-concrete interlocking.

2.14. Foundation system for prefabricated housing

This section provides an overview of the foundations used in single-unit houses, aiming to facilitate the understanding of how the house and its foundations interact. To achieve this, a practical guide for timber construction housing with a platform system (Infor, 2011) will be referenced.

Foundations serve the crucial role of transferring the structural loads from the house to the underlying soil. They can be broadly categorized as deep or shallow foundations.

For the specific case study at hand, only shallow foundations are considered. This choice aligns with the relatively light weight of the houses, which does not necessitate the use of deep foundations. The key components of shallow foundations will be explained in the following figure 2.4 for reference.

The foundations in a house unit can be simple spread footings or stripped footings. These strips connect the footings, and they can be placed in the foundation wall or in the foundation itself.

Then to finish on understand the foundation system of a timber house, appendix 2.1 shows figures with a cross-section of a connection between the foundation and the structure.

To connect the footings with the timber structure there now different kinds of mechanical fasteners. Then after in the discuss section there will be analyzed the performance of this novel adhesive connection with this kind of foundation for single unit houses.

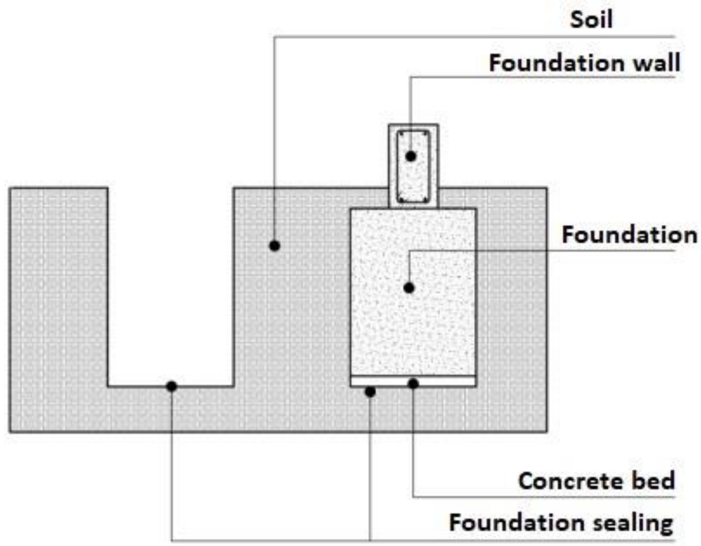

Figure 2.6 Parts of a foundation footing.
Source: Infor (2011)

2.15. Earthquake Loads

Understanding earthquake loads is critical in evaluating the performance of adhesive connectors during seismic events. Shear forces introduced by earthquakes affect the connectors, necessitating an assessment to determine their compliance with design standards. The study estimates earthquake loads following Chilean codes NCh433 (INN, 2012) and NCh1198 (INN, 2014). The analysis focuses on timber components and utilizes a static linear analysis according to Chilean code NCh433 (INN, 2012), incorporating seismic parameters. The seismic analysis considers seismic zone III, foundation soil E, building classification as II, importance factor of 1, R value of 5.5, and Cmax value of 0.208, from Manual de diseño edificaciones en madera de 1 a 3 pisos (Infor, 2021).

The floor plan of the model house is shown in Figure 2.7, as provided by the manual (Infor, 2021), with the shear walls described to analyze their direction and lengths. Subsequently, table 2.5 displays the values of the base shear on each wall with the purpose of comparing them with the results of the study.

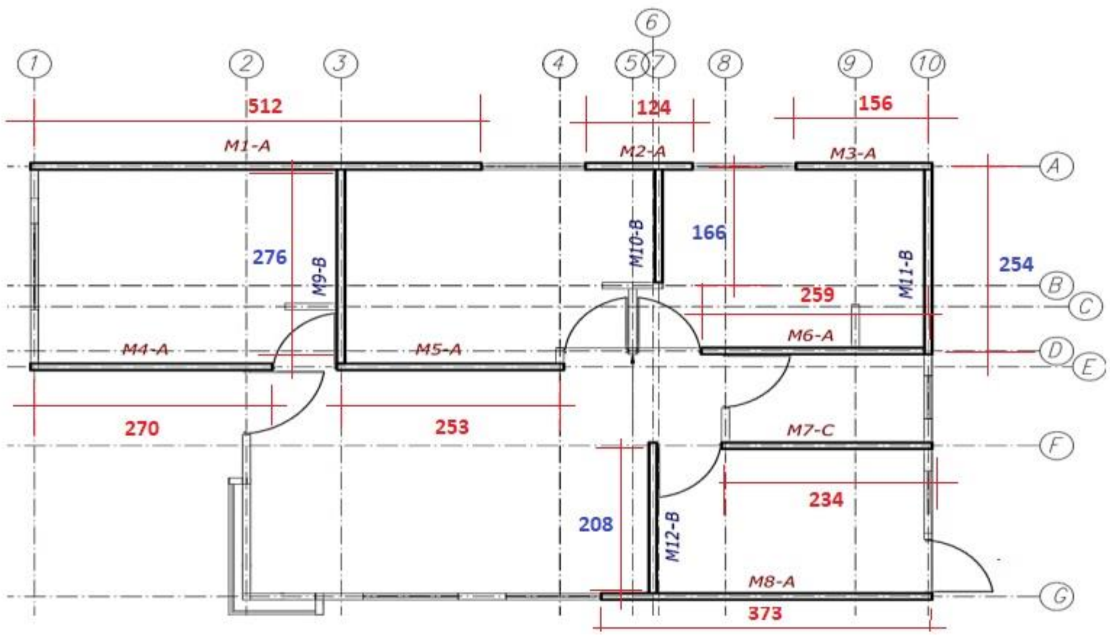

Figure 2.7 Roof plan with details of every wall of the model house enumerated.
Source: Infor (2021).

Table 2.5 Basal shear for each wall in the building of example.

Wall	Lenght (m)	Vmax (tf)	base shear(tf/m^2)	base shear (MPa)
M1-A	5.12	0.45	0.43	0.004
M2-A	1.24	0.05	0.19	0.002
M3-A	1.56	0.06	0.20	0.002
M4-A	2.7	0.17	0.32	0.003
M5-A	2.53	0.16	0.32	0.003
M6-A	2.59	0.17	0.32	0.003
M7-C	2.34	0.11	0.24	0.002
M8-A	3.73	0.41	0.55	0.005
M9-B	2.76	1.18	2.13	0.021
M10-B	1.66	0.56	1.69	0.017
M11-B	2.54	0.39	0.76	0.007
M12-B	2.08	0.57	1.37	0.013
			Maximum (MPa)	0.02

Source: Infor (2021).

2.16. The need to replace concrete structures with more sustainable materials

Timber, as a construction material, serves as an eco-friendly choice that can counter the environmental impact of the concrete industry, currently responsible for 8% of global carbon dioxide emissions (Andrew, 2017). Combining timber with concrete creates a more environmentally friendly construction material due to the renewable nature of the timber, low embodied energy, and carbon sink capacity (Skullestad et al., 2016). This combination enhances energy efficiency through natural insulation and the thermal mass of concrete. Timber-concrete composites exhibit superior acoustic properties, reducing noise transmission (Siddika et al., 2021). These composites offer both natural aesthetics and structural rigidity, fostering diverse architectural possibilities and innovative designs (Petruch et al., 2021).

2.17. Conclusion

Due to the similarity of the loads and their nature it can be feasible to compare studies focused on timber concrete composites with a prefabricated timber housing union method. Those two building systems use the base of a concrete piece at the bottom and timber structures at the top, although, both needs a union method that ensures minimum slippage and a correct load transfer.

The shear strength values of the timber specimens under are calculated in 4.57 kN and 1.78 kN for both compressive shear and double shear test conditions, respectively. The calculated shear strength of the concrete is 4.8 kN and 1.2 kN for both different dimensions of the tests. However, it is prudent to acknowledge that the concrete strength values are estimations due to the code gives calculations for reinforced concrete. The calculated shear strength of the concrete is compared with the test results in chapter 4.

Ensuring a standardized testing approach and confirming the compatibility of results for subsequent comparisons necessitates the sandblasting of all adhesive interfaces on concrete and wood with 150-grit sandpaper, the equivalent adhesive thickness is determined as 1 mm and both adhesive faces are placed one to each other right after the adhesive is made.

In the context of seismic analysis, the determined maximum shear load is found to be 0.02 MPa. This value is observed to be lesser than the findings of Nemati Giv et al. and also falls below the results reported by Fu et al. The comparison of this seismic shear load with the shear strength of the tested specimens is explicated in the results section.

Adhering to the guidelines of the Chilean code Nch1198(2014), shear strength values of 0.4 kN and 3.28 kN are attributed to a singular nail. These values are methodically compared with the outcomes of the conducted tests, as detailed in the results section.

CHAPTER 3: MATERIALS AND METHODOLOGY

3.1. Introduction

This chapter outlines the timeline of this study, material specifications, and organizational structure. The goal is to provide a detailed and standardized overview processes of the study.

The chapter begins with the technical specifications of the materials used to document their mechanical properties. The chapter concludes by presenting a methodological flowchart that outlines the process for creating the test pieces and the associated time requirements, the tests involved in the study and finally with a gantt chart showing the time that takes for every production of specimens and tests.

3.2. Materials

In this section the materials for this experimental phase are specified with the technical characteristics such as dimensions and strengths.

3.2.1. Timber

The wood used for this study comes from a regular hardware store. It will be a 2 by 2 inches timber. The strength of these pieces it is shown in table 2.1 as a G2 structural class.

3.2.2. Concrete

The concrete mix used for this study consists of pozzolanic cement (H20 ready mix) along with additives and graded sand with small-sized gravel. The compressive strength, as stated by the manufacturer is 20 MPa with a 90% reliability(Weber, 2022). Therefore, there is no need to specify the exact proportions of gravel and sand. The brand chosen for this case study is Weber because the primary objective is to utilize this adhesive for the foundation-structure interface of a prefabricated timber house. This Weber concrete is specifically designed for foundations, is more suitable for this purpose than other common cement brands such as Bio-bio and Polpaico.

The shear strength of the concrete is determined previously in chapter 2.

3.2.3. Water

The water used during the preparation of test specimens came from the tap. This water meets the current regulations for water quality according to NCh 409/1 (INN, 2005).

3.2.4. Epoxy Adhesive

The epoxy adhesive is an A+B epoxy adhesive. The provider is Lorenzini.

3.3. Methodology

3.3.1. Concrete making

To assess concrete performance and ensure optimal resistance, a flow test is conducted. The desired outcome is a circular shape with a diameter of 20 centimeters, as measured from the inner diameter of the 10-centimeter bronze cone (Fig. 8). This workability test involves cranking the table lever 25 times in 15 seconds. ASTM standards governing this test include ASTM C230 for the flow test table description and ASTM C1437 for mortar mix preparation.

The flow table test is chosen over the slump test due to the specific molds and concrete piece dimensions. Two concrete dimensions will be used: 40x40x160 mm following ASTM C348 standards (ASTM international, 2021), and 50x50x50 mm following ASTM C109/C109M standards (ASTM international, 2020). Both standards recommend using the flow table test in place of the slump test, the flow table test setup is shown in figure 3.1.

Figure 3.1 Flow test table setup.

The flow table test in the ASTM standard ASTM C1437 (ASTM international, 2015). When the fluidity of the concrete is tested on the table the lectures cannot be less than a 90% from the inner diameter and cannot exceed the 110% from the inner diameter. For this study the inner diameter is 10 centimeters and by that all the lectures of the diameters must be between 19 and 21 centimeters. If the lecture exceeds the maximum then the mix is discarded.

Once the mix is ready it is placed into metallic molds which dimensions are 40x40x160mm for one type of testing and 50x50x50mm as are shown in fig.10 and 11. These two dimensions due to the two different types of tests that will be done in the study. Also, these dimensions were used to link sawn timber pieces to the concrete samples.

After one day of placing the concrete in the molds and staying in a controlled environment (23ºC and RH = 55% +/- 2%) they are demolded and placed in a pool saturated with calcium hydroxide for the next 6 or 27 days in order to each study according to NCh1017 (INN, 2009).

After the mentioned pool curing period, the concrete pieces are taken out of the pool and stay drying for 24 hours inside the climate chamber so it is ensured they will not have any water in the surface.

Figure 3.2 Concrete mix after applying the flow test

Figure 3.3 Steel molds for 40x40x160mm pieces.

Figure 3.4 Steel molds for 50x50x50mm pieces.

In both tests, two different concrete casting times are used: 7 days and 28 days. This variation aims to explore the impact of casting time on concrete strength and its implications for construction. It is important to note that both casting times include an additional 7 days for curing the epoxy adhesive with the purpose to have the same procedures and compare results with Nemati Giv et al. (2021) and Fu et al. (2021).

3.4. Gluing process

After the curing of the concrete the pieces are sandblasted with a 150-grit to remove the loose parts. The epoxy adhesive is an A+B adhesive that has to be in a 1:1 ratio from each part of both components and placed into the concrete surface with 1mm of thickness and then the timber piece is place on it, once it is done the glued pieces are placed back in the climate chamber with the timber piece facing up and with a heavy thing on top so it is sure the substrate will not slip out of the face.

The glued pieces are left in the climate chamber for 7 days and then in the eighth day the pieces are brought under testing.

3.5. Test Prog ram

This section details three tests conducted in the study, outlining the procedures, associated standards, equipment used, and the equations employed to calculate tensile strength in each case. The tests aimed to determine the resistance values of the bond between concrete and timber, as described in the document titled 'Testing Methods for Shear Strength of Bond Line Between Concrete and Different Types of Engineered Wood' by Fu et al. (2021).

3.5.1. Pull-Off Strength test

This method assesses the adhesion strength of a coating system on metal substrates by measuring the pull-off strength. It involves pulling off a bearing ring adhered to a flat surface to determine the adhesive strength of the glue to the substrates. The study utilizes a fiber cement surface with three different bearing rings to calculate the average adhesion strength based on these specimens. Figure 3.5 depicts the bearing ring adhered to the surface and various substrates. The test follows the ASTM D4541 standard (ASTM International, 2022). Additionally, Figure 3.6 demonstrates the setup with the bearing ring in the test.

Once the test is done the value of the maximum resistance in MPa are shown with the average and the substrate where the failure was done for each case. Three substrates are identified and used for this test which are the next ones:

A: Bearing ring
B: Glue
C: Fiber cement plate

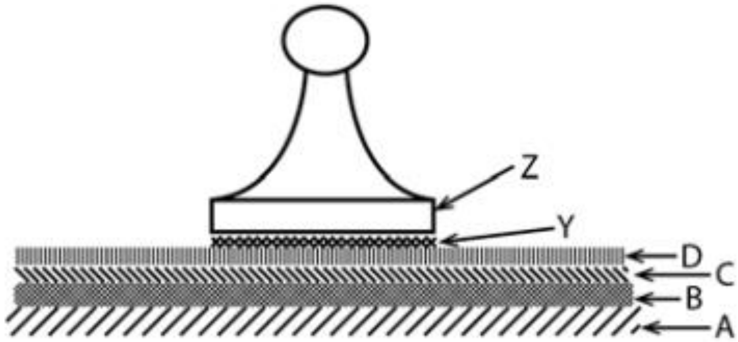

Figure 3.5 Pull off test specimen with the different substrates.
Source: ASTM international (2022).

Figure 3.6 Bearing ring glued to the fibre cement plate.

The modus of appliance of the adhesive for this test is to use first three bearing rings linked to the same 20cm by 20cm fiber cement plate with 10 centimeters of distance, the adhesive is place into the surface of the bearing ring with 1 millimeter of width as it is defined previously and the specimens are left into a climate chamber for 24 hours, after that time the specimens are tested under tension load.

When the results are tabulated, it must be registered the substrate where the failure was to identify the adherence of the adhesive. Finally, the average value of tension is used to compare the strength of the adhesive with the load capacities of Hold down ties according to the catalog provided by Simpson in table 3.1.

Model No.	Material		Dimensions (in.)							Fasteners (in.)		Minimum Wood Member Size (in.)	Allowable Tension Loads (160)		Deflection at Highest Allowable Load
	Base (in.)	Body (ga.)	HB	SB	W	H	B	CL	SO	Anchor Dia. Bolt	Stud Bolts		DF/SP	SPF/HF	
HD3B	—	12	4¾	2½	2½	8⅝	2¼	1 5/16	⅜	⅝	(2) ⅝	1½ x 3½	1,895	1,610	0.156
												2½ x 3½	2,525	2,145	0.169
												3 x 3½	3,130	3,050	0.12
												3½ x 3½	3,130	3,050	0.12
HD5B	3/16	10	5¼	3	2½	9⅜	2½	1¼	2	⅝	(2) ¾	1½ x 3½	2,405	2,070	0.153
												2½ x 3½	3,750	3,190	0.129
												3 x 3½	4,505	3,785	0.156
												3½ x 3½	4,935	4,195	0.15
HD7B	3/16	10	5¼	3	2½	12⅜	2½	1¼	2	⅞	(3) ¾	3 x 3½	6,645	5,650	0.142
												3½ x 3½	7,310	6,215	0.154
												3½ x 4½	7,345	6,245	0.155
HD9B	⅜	7	6⅛	3½	2⅞	14	2½	1¼	2⅜	⅞	(3) ⅞	3½ x 3½	7,740	6,580	0.159
												3½ x 4½	9,920	8,430	0.178
												3½ x 5½	9,920	8,430	0.178
												3½ x 7¼	10,035	8,530	0.179

Table 3.1 Hold Down list with allowable tension loads.
Source: Simpson (2021).

3.5.2. Inclined shear test

The aim of this test is to determine the maximum shear values for specimens bonded with Wood and Concrete using an epoxy adhesive, following ASTM D1037 (ASTM International, 2020). The compression-shear test provides a quick, reproducible, and accurate way to assess bond quality.

This test leads the load in two different directions due to the angle where the load from the gauge is applied to the test specimens. The first component is a compressive load perpendicular to the bond line and the second one is a shear load parallel to the bond line, the equation that describes the maximum shear load in the specimens is shown in equation 3.1.

$$\tau = \frac{F}{lb} \cos(15^{o}) \qquad 3.1$$

Where F is the maximum load in kN, ‘l’ is the length of the bod lines and ‘b’ is the width of the bond line. This test is also set up to have the direction of the shear load in the same direction as the wood fiber.

The test specimen placed in the gauge is shown in figure 3.7.

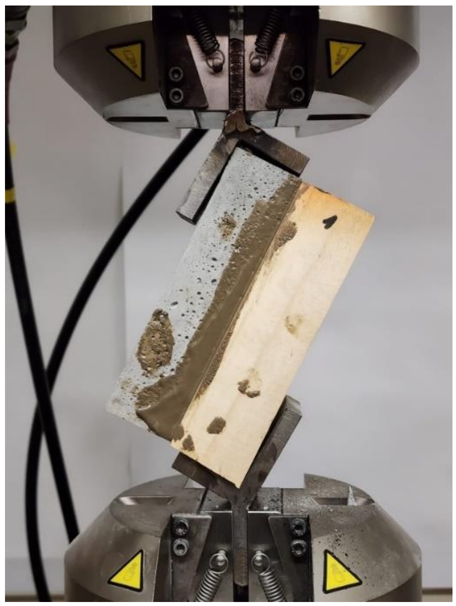

Figure 3.7 Specimen of a compression-shear test.

3.6. Double lap shear test

This test is conducted to identify the strength of the bonding between adhesive bonded multiple pieces in composite materials such as glue laminated timber. For this case there is only going to be three layers of materials and there are going to be two different, concrete and timber. In this case the load applying to these pieces will be in the direction of gravity, also the wood is placed according to have the load in direction of the fiber.

The arrays of pieces to study are going to be in three cubes of 50x50x50mm for concrete and 40x40x40mm for wood bonded by this glue Where they will be placed as the ratio 2:1 in both different arrays, concrete-wood-concrete(C-W-C) and wood-concrete-wood(W-C-W). The scope to have these two different arrays is to understand the influence of every different material in the resistance of the composite. The code that governs this test is the European code DIN-EN-392.

As there is a double surface in this case, the weakest side of the composite will break first one after the other so there is expected to have one side broken and the rest of the piece still glued. The equation to calculate the strength of this composite is shown in 3.2:

$$\tau = \frac{F}{2lb} \tag{3.2}$$

Where F is the maximum load, ‘l’ is the length of the bond line and ‘b’ is the width of the bond line. For both test cases the values of l and b are going to be 40mm according to the dimensions of the wooden cubes of 40 by 40 by 40 mm.

The test setup is shown in figure 3.8.

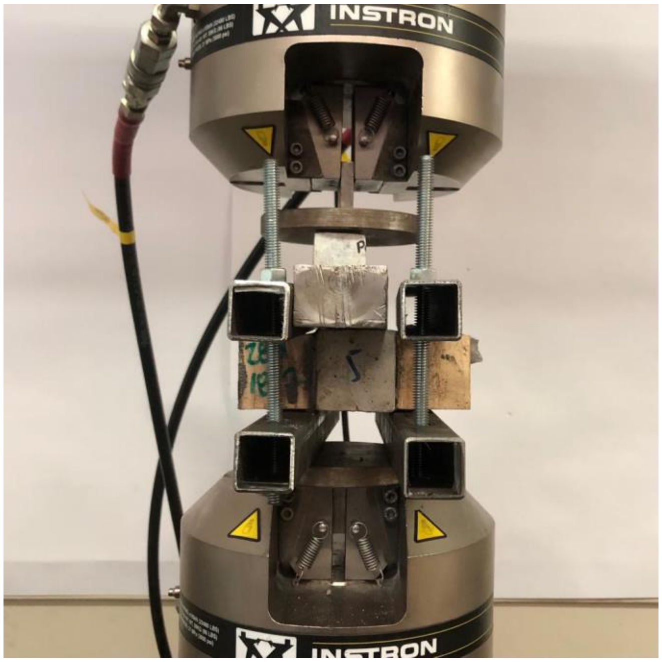

Figure 3.8 Setup for the double lap shear test.

3.7. Work strategy

The experimental work consists in one stage with two different tests. First the 40x40x160mm concrete bars will be make and left in the pool for the right casting. After the time the pieces will be glued and left in a fresh and dry environment for 7 days to finally be tested in the eight day. 1 month will be considered for each study and they will have 2 weeks of gap to get the study focused in both parts. Table 3.2 shows a gantt chart will specify the time for each making a testing of th pieces. Finally, the whole process takes 2 months with 3 weeks.

After finishing this stage of the study, the next stage is to analyze the data recovered from the tests giving a statistical analysis and then a comparation with different kinds of shear connectors and a calculation of the enough adhesive to resist the equivalent shear loads as an earthquake.

There are two stages on this study:

-The first one is a resistance analysis of the adhesive connector

-The second one is a numerical analysis of the resistance of the adhesive bringing it to a practical case as a difference between the adhesive and mechanical fasteners and the calculation of the shear loads in a house down an earthquake.

Table 3.2 Gantt Chart of the experimental phase of the study.

	May				June				July			
Week	1	2	3	4	1	2	3	4	1	2	3	4
40x40x160 making												
50x50x50 making												
40x40x160 testing												
50x50x50 testing												

3.8. Conclusion

The study revolves around the utilization of two distinct materials, concrete and timber, connected via an epoxy adhesive using a shear connector. Notably, the concrete component demands a considerable amount of time due to the intricacies involved in its preparation.

The concrete is manufactured according to ASTM standards, conforming to the required dimensions for the test specimens: molds of 50x50x50mm for the double shear test and 40x40x160mm for the compression-shear test. Once poured into their respective molds, the mixtures are stored in a climate chamber for 24 hours before being demolded and placed in a curing pool for a duration of 7 and 28 days.

After the completion of the curing periods, the specimens are removed from the pool and placed in a controlled environment for 24 hours to ensure their dryness, a crucial precondition for applying adhesive to their faces. Applying adhesive necessitates the removal of any loose concrete parts on the face to enable optimal penetration of the adhesive into the substrate. An adhesive layer, 1 mm in width, is meticulously applied to the concrete face to optimize its behaviour based on insights from the literature review. Subsequently, the composite is left in the climate chamber for 7 days.

Upon reaching the designated time frame, the testing phase start s with a Pull-off test, followed by the compression-shear and double shear tests. The obtained shear strengths and failure modes are meticulously analyzed and compared. Initially, the results are compared with two closely related studies conducted by Fu et al. and Nemati Giv et al. Following this, comparisons are made with Chilean codes NCh433 for earthquake resistance to evaluate the slippage shear strengths, and with NCh1198 for mechanical fasteners in order to assess the results comprehensively.

CHAPTER 4: RESULTS

4.1. Introduction

In this chapter, the results of the tests are presented, including the key parameters of interest such as resistance and failure modes, observed at different curing ages and arrangements. Additionally, the maximum resistance values obtained from the tests, along with their corresponding averages and standard deviations are showcased to highlight the dispersion of data. These values represent the highest achieved in each test, offering a comprehensive overview of the results.

Furthermore, a comparative analysis is conducted, aligning the outcomes of the study with the findings from the literature review presented in Chapter 2. This comparison will extend to the seismic loads calculated earlier and the strength of mechanical fasteners. Each set of test results go analysis to assess their correlation with the aforementioned aspects. Ultimately, the analysis enables the reader to evaluate the quality and significance of the results in the context of existing research and practical applications.

4.2. Pull off test

The values of the pull off test give values of the tension strength of the adhesive, for this case the values are shown in Table 4.1.

The three specimens had a failure in the substrate C, which means the fracture trespasses one layer of the substrate and go deeper as in figure 4.1 with an average tension strength of 1.39 MPa for the three specimens tested resulting.

This tension strength can be compared to pieces that are also working at this kind of strength as Hold-down ties, but there is a challenge comparing this two different due to the different geometry of both different systems as Hold down ties and the adhesive. It is left to further studies a way to compare the tension strength of the adhesive with Hold-down ties.

Table 4.1 Results of the pull off test.

Test specimen	Tension Value (MPa)	Failure zone
A	1.39	C
B	1.41	C
C	1.38	C
Average	1.39	
standard dev	0.02	

Figure 4.1 Failure modes of the pull off test specimens.

In conclusion, the experimental tests on the resistance of the new material revealed an average strength of 1.39 MPa, equivalent to 1.74 kilonewtons or 391.22 pounds. When compared to the established Hold Down Ties in the load tables (Simpson Strong Tie, 2021), the results did not reach the same level of strength. However, further research is suggested to explore ways to replicate the geometry and utilize similar testing methodologies for a more precise comparison of the adhesive in this bonding method.

There is also a full behaviour of failure to the substrate zone C, meaning the adhesive can carry greater loads with more cohesive materials.

4.3. Inclined Shear test

4.3.1. Resistance Values

The average values of strength of the composite are 2.87 MPa and 5.32 MPa for 7 days and 28 days specimens. The stress-strain curves are shown in appendix 4.2 where the 28 days casting specimens permits more strain than the 7 days specimens with a range from 2.5% to 3% of displacement for the 7 days pieces and a range from 3% to 6% to the 28 days casting.

Both values of resistance for each casting times are shown in figure 4.2.

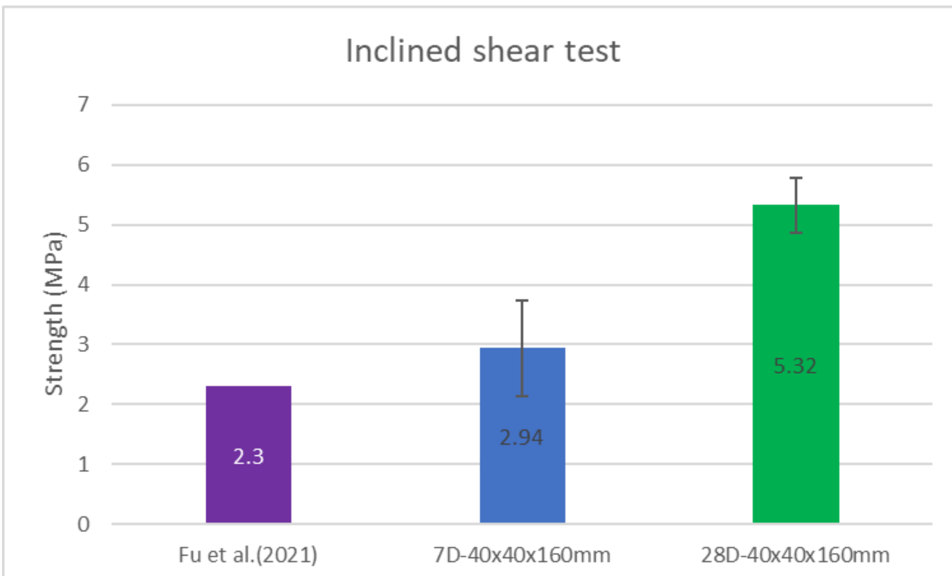

Figure 4.2 Inclined shear test strengths.

The comparison of results with previous studies demonstrates a considerable performance improvement in the adhesive used in this study, notably surpassing earlier findings by Fu et al. (2021) by 27.67% after 28 days of casting. Additionally, the standard deviation in this study is markedly lower (0.45) compared to Fu et al. (2021) reported value (1.49). The strength results on the 28th day closely align with Nemati et al. (2021) findings, with only a marginal 6.1% difference observed.

Regarding shear forces, the range falls between 30-40kN for 28-day cast specimens, comparable to Fu et al. (2021) results using larger specimens. Strain measurements differ, with this study reporting higher values than previous works, suggesting greater deformation capacity in the adhesive used here.

In seismic performance, both casting times display significant advantages due to low basal shear values. Mechanical fasteners show a substantial increase in strength when compared to nails and bolts. Axial strength values at 7 and 28 days surpass the concrete's shear strength, indicating the adhesive's robustness.

In conclusion, this analysis demonstrates the adhesive has remarkable strength and resilience, making it a highly suitable choice for a prefabricated house system.

4.3.2. Failure modes

At the initiation of the test, initial cracks emerged in the concrete, forming a triangle with dimensions matching those of the supports. These cracks were consistently evident in 100% of the cases. Figure 4.3 illustrates the fracture line that resulted in test failure. The fracture behaviour observed in this study aligns with findings in Fu et al. (2021), where cracks initiated at the supporting end.

Two different failure modes in this test were identified. The more predominant is a failure of removal of the facial cover with a 74.07% of the total failure modes, this occurs when the adhesive and the concrete faces are both splitted by the load. The other mode is a complete failure of the concrete with a 25.93%, this happens when the adhesive keeps both pieces together but the concrete starts to get cracks. The two resulting types of failure are shown in figure 4.4 and figure 4.5.

Figure 4.3 Fracture lines in the test.

Figure 4.4 Failure mode of removal of the facial cover. It can be appreciated in the red circles the variety of failure along the whole piece.

It can be noted in figure 4.4 the removal of the facial cover with a layer of concrete at the top. There is also a small percentage of removal of this concrete and adhesive topping leaving only a wooden face and in the other side, a deeper piece of concrete as it is marked in the red circles.

It can be showed in figure 4.5 how the crack described by figure 4.3 took the whole piece out and the main concrete piece is still sticked to the wood and there are more broken pieces of concrete falling out of the main piece. This failure mode is also related by Fu et al. (2021) Where he had a predominance of the failure mode removal of the facial cover.

Figure 4.5 Failure mode of concrete failure.

4.3.3. Conclusion

The test results indicate that a high shear performance of the adhesive was observed, as evidenced by a significant adhesive capacity and elevated shear strength numbers. Furthermore, good penetration into the side of the wood was achieved, with no failures noted on that side of the composite. This test can also show the seismic competitive capacity of the adhesive and the same or even higher strength comparing to mechanical fasteners.

The adhesive can penetrate to the concrete through the pores and give more strength to the concrete in terms of shear strength due to the higher resistance of the composite compared to the shear strength of the concrete.

4.4. Double lap shear test

Once the specimens were made to test a different behaviour was observed with the adhesive coming from the past test with a different viscosity appearance. It can be shown in figure 3.7 with the different specimens the glue slips from the adhesive face and fall from the sides of the prism, opposite to the figures as figure 4.6 where the glue does not have a paste appearance and it does not slip from the face of the adhesive.

Unfortunately, providing a comprehensive characterization of the adhesive viscosity for each specific test exceeds the scope of this study. This aspect can serve as a reference for future research. Additionally, the duration required to create all the specimens up to the storage time remains unmentioned in the reviewed studies.

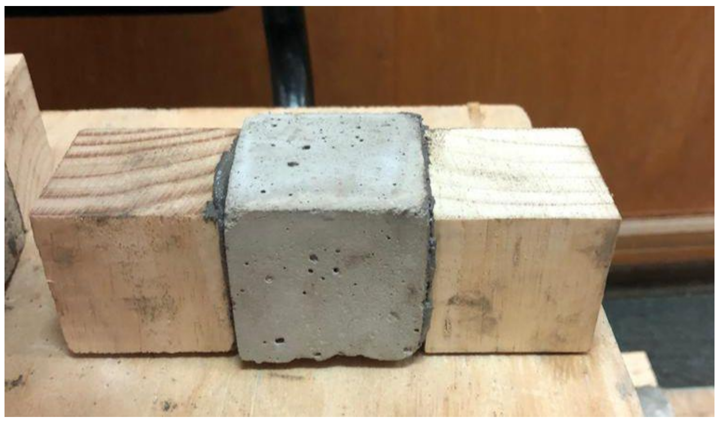

Figure 4.6 Example of test specimen for the W-C-W array for the double lap shear test.

4.4.1. Resistance values

The results indicate a decline in the strength of the composites as the test duration progresses, with the highest strength observed in the 7-day casting of the C-W-C array, measuring at 1.26 MPa. Figure 4.7 illustrates the composite behaviour, highlighting the strength differences between using two pieces of concrete versus two pieces of wood. Notably, specimens with two pieces of concrete demonstrated higher strength. Interestingly, as the duration increased, the standard deviation of the tests decreased, showing a trend similar to findings in Fu et al. (2020). Their study revealed a more uniform distribution of results when the bonding lines were shorter.

The results show how a 7-day casting concrete pieces have more strength than the 28-day casting.

The results diverge from those reported by Fu et al. (2021) and Nemati et al. (2021), as the numbers fall short of the values they identified. Specifically, when comparing the 28 days casting W-C-W array with a larger deficit, there is a significant difference of 77% and 81%, respectively, compared to the findings in the two mentioned studies.

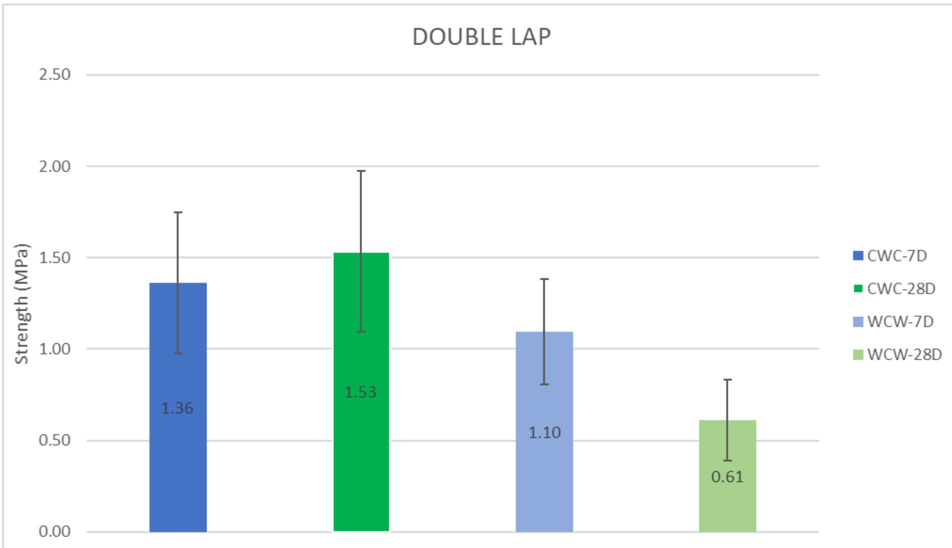

Figure 4.7 Double lap shear test results for different curing ages and arrays.

Figure 4.7 illustrates the higher strength of the 7-day casting specimens compared to the 28-day casting.

Comparing seismic load results, all four arrays surpassed previously calculated quake loads, with the lowest average strength recorded by the 28-day WCW array at 0.61 MPa, while the maximum induced earthquake shear stress was 0.02 MPa. The adhesive displayed sufficient seismic performance per NCh433 (INN, 2012).

In comparison to mechanical fasteners, the adhesive outperformed 3.5” nails, while lagging behind a ½" reference bolt. It appears the adhesive sits between nails and bolts for anchoring systems.

The composite resistance exceeded concrete shear strength except for one instance - the 28-day W-C-W array. However, this array's weakest test result coincided with the only value falling below concrete shear strength. A deeper analysis into this failure is discussed in the following section.

Although not meeting target values, the variability of results based on specimen geometry was notable. The adhesive demonstrates competitive strength against seismic loads and mechanical fasteners, slightly surpassing concrete shear strength due to enhanced substrate strength through adhesive penetration.

A diminishing trend in results over time was observed, possibly due to a one-month difference between the first and last specimens and non-uniform adhesive application. Future studies should use adhesive uniformly across all specimens simultaneously to avoid time-related discrepancies. This trend is visible in Figure 4.7 and may stem from changes in adhesive behaviour, likely due to varying viscosity between initial and subsequent samples.

The stress-strain curves presented in appendix 4.2 reveal negligible differences in strength and strain between concrete-timber-concrete arrays at both casting times.

The 7-day casting showed higher load-bearing capacity and deformation compared to the 28-day casting. The majority of specimens displayed greater strength than concrete shear strength (97%), indicating increased shear strength due to adhesive penetration. This suggests the underestimation of ACI equations for concrete shear strength in this composite. The standard deviation aligns with Fu et al. (2021) for smaller specimen dimensions.

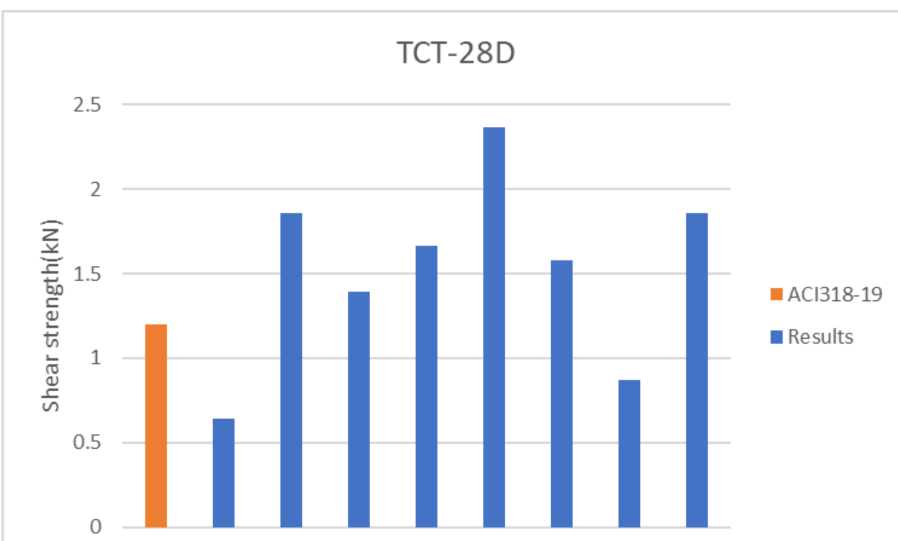

Figure 4.8 Comparative between strength of the Timber-concrete-timber array for 28 days and the shear strength of the concrete by ACI 318-19.

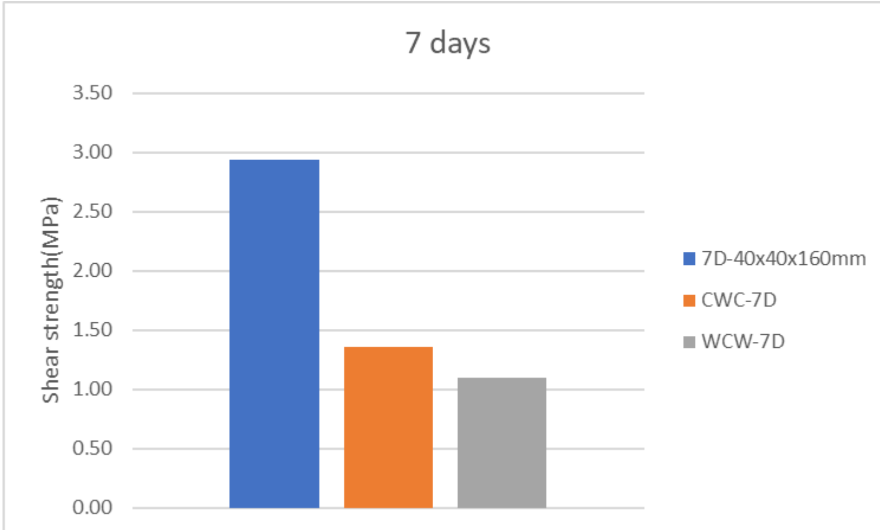

Figure 4.9 7 days casting shear strength for both shear tests.

4.4.2. Failure modes

It was witnessed a dominance of the removal of the facial cover in this study with an 78% of that failure in the number of tests done for the timber-concrete-timber array. This behaviour in the failure mode is very similar to Nemati et al. (2021) where the major failure mode was the cohesive failure with a removal of the facial cover and the other one noticed was a concrete failure. There were no major cracks noted in the test and that can be concluded due to the geometry of the assembly of the arrays and the test machine. All the arrays of Concrete-Wood-Concrete had a failure of removal of the facial cover, and with that it is concluded as the load was not laying on the concrete, the removal goes into the adhesive face.

For the concrete-timber-concrete array there was only failure in the removal of the facial covers, that can be attributed to the way the concrete was attached to the machine making a frictional restraint.

Figure 4.10 shows the failure mode of the concrete failure in the timber-concrete-timber array, figure 4.11 shows the failure mode of the removal of the facial cover in the concrete-timber-concrete array.

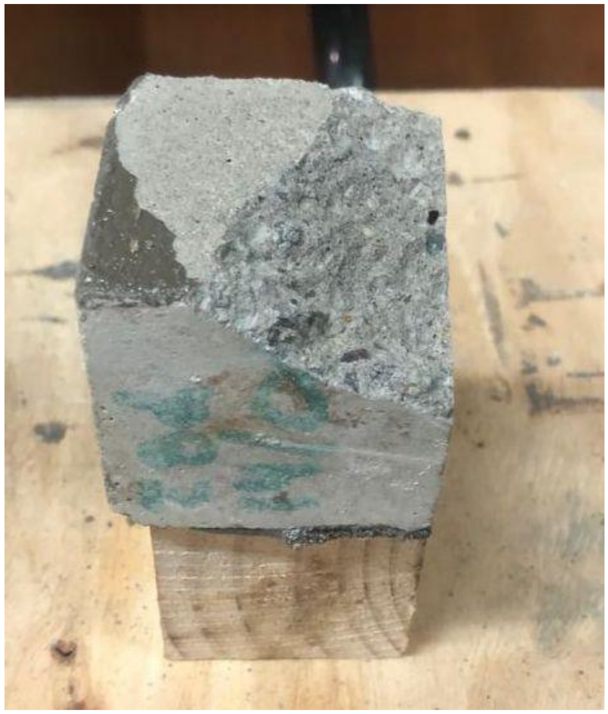

Figure 4.10 Timber-concrete-timber specimen

Figure 4.11 Concrete-timber-concrete specimen

4.4.3. Conclusion

Following the double lap shear test, it is recommended to alter the adhesive application method in terms of timing. Instead of creating specimens over more than a month, producing them all simultaneously can prevent result discrepancies seen in this study. Additionally, the adhesive exhibits sufficient shear performance for seismic design, warranting further exploration in seismic studies using a shear timber-framed wall. In Table 2.5, the gathered shear strength values in each wall are lower than the minimum results obtained in this study, supporting the adhesive's seismic capacity. It is proposed to experiment in a real scenario with a shear wall and varying adhesive surface area percentages.

The study concludes that composite shear strength increases as the adhesive penetrates the substrate, resulting in higher resistance compared to concrete shear strength. Although differing from the findings of Nemati giv et al. (2021) and Fu et al. (2021), the results obtained never fell below concrete shear strength in 97% of cases.

For future studies, using this adhesive in specific humidity conditions is recommended to determine if environmental moisture influences result variations.

When the concrete is within the composite, there is a minor concrete failure percentage, contrasting with no concrete failure when the concrete is positioned alongside the composite.

Continued testing is suggested to align results more closely with compression shear test values, following the conclusions of Fu et al. (2021).

CHAPTER 5: CONCLUSIONS

Primarily, the focus of this study is to evaluate the adhesive's viability as a rapid solution for emergency prefabricated house construction. The aim is to provide those affected by disasters such as wildfires or floods with temporary housing. The adhesive shows promising results on its performance in this study, as evidenced by its comparison with typical mechanical fasteners used in similar construction and its ability to meet seismic demands outlined in the Chilean code. To ensure closer alignment between compression shear and double lap shear tests, further exploration and refinement of parameters is recommended.

For preciser results, standardizing two unobserved parameters is advised to eliminate doubts about its impact on adhesive strength. Firstly, controlling the humidity during adhesive application. Secondly, it's recommended to apply all adhesive at once instead of over a month. During the specimen creation period, variations in humidity due to climate changes in Concepcion, Chile, occurred. Therefore, specifying the environmental humidity during specimen creation in future studies can be beneficial.

Significant differences between inclined shear and double lap shear test results suggest that the compression shear test incorporates a frictional component aiding adhesive interlocking into substrates. Additionally, the adhesive showed varying behaviour in the first specimens, possibly due to a more fluid application, resulting in better penetration into concrete, enhancing their shear strength. To avoid such variations, applying the entire adhesive amount at once is suggested for future studies discarding the storage time.

The results affirm positive seismic performance, indicating a high strength ratio to resist seismic demands. To further ascertain real seismic performance, conducting studies using a real timber-framed shear wall is recommended. Additionally, a more detailed analysis of adhesive tension strength, particularly in comparison to Hold-down ties, should be pursued by tailoring geometries and loads relevant to these connections.

The tests showed that timber, being hygroscopic, allows easier adhesive penetration, contributing to a higher frictional component, thereby reinforcing timber's shear strength. The tests also exhibited failure modes in cohesive facial cover removal without any timber failure. Moreover, the concrete remained intact due to the test machine's restraint. Thus, it is concluded that timber does not significantly impact composite strength and concrete is the material that limits the strength of the composite.

Conclusively, the adhesive effectively facilitates rapid union methods for emergency prefabricated timber house construction. However, further studies are recommended to achieve more precise and specific resistance values for this adhesive, ensuring greater accuracy in its application.

CHAPTER 6: REFERENCES

A. Alvarado. (2010). CONSTRUCCIÓN INDUSTRIALIZADA PARA LA VIVIENDA SOCIAL EN CHILE: ANÁLISIS DE SU IMPACTO POTENCIAL.

A. Nemati Giv, Q. Fu, L. Yan, B. Kasal. (2021). Interfacial bond strength of epoxy and PUR adhesively bonded timber-concrete composite joints manufactured in dry and wet processes, Construction and Building Materials. Volume 311.

A. Nemati Giv, Qiuni Fu, Libo Yan, Bohumil Kasal. (2022). The effect of adhesive amount and type on failure mode and shear strength of glued timber-concrete joints, Construction and Building Materials, Volume 345.

Ali Nemati Giv, Q. Fu, L. Yan, B. Kasal. (2021). Effects of concrete type, concrete surface conditions, and wood species on interfacial properties of adhesively-bonded timber – Concrete composite joints, International Journal of Adhesion and Adhesives, Volume 107, 2021.

ACI 318-19. (2022): Building Code Requirements for Structural Concrete and Commentary (Reapproved 2022).

ASTM C109/C109M (2016) Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens). ASTM International, West Conshohocken, PA.

ASTM C348 (2021) Standard Test Method for Flexural Strength of Hydraulic-Cement Mortars. ASTM International, West Conshohocken, PA.

ASTM C1437 (2007) Standard Test Method for Flow of Hydraulic Cement Mortar. ASTM International, West Conshohocken, PA.

ASTM D1037 (2020) Standard Test Methods for Evaluating Properties of Wood-Base Fiber and Particle Panel Material. ASTM International, West Conshohocken, PA

ASTM D4541 (2022) Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers. ASTM International, West Conshohocken, PA

Carrillo, C. (April 29th, 2023). Gobierno exigirá boleta de garantía por viviendas de emergencia dañadas durante sistema frontal. Radio Biobio. https://www.biobiochile.cl/noticias/nacional/region-del-bio-bio/2023/04/29/gobierno-exigira-boleta-de-garantia-por-viviendas-de-emergencia-danadas-durante-sistema-frontal.shtml

Catalán L., J., Reyes Riquelme, C., González, I. (2021). Manual de diseño. Edificaciones en madera de 1 a 3 pisos. INFOR.

D. Thomas, G. Ding, Comparing the performance of brick and timber in residential buildings – The case of Australia, Energy and Buildings, Volume 159, 2018, Pages 136-147, ISSN 0378-7788.

D. Yeoh, M. Fragiacomo, M. De Franceschi, K. Heng Boon. (2011). State of the Art on Timber-Concrete Composite Structures: Literature Review.

DIN EN 392: Glued Laminated Timber - Shear Test Of Glue Lines, 1996.

Dias, A. & Schänzlin, Jörg & Dietsch, Philipp. (2018). Design of timber-concrete composite structures.

Díaz Tello, J. 2020. ANÁLISIS COMPARATIVO TÉCNICO ECONÓMICO ENTRE ENCOFRADOS DE MADERA Y ENCOFRADOS DE ALUMINIO, ACERO GALVANIZADO PARA LA CONSTRUCCIÓN": una revisión de la literatura científica 2010-2020". Lima, Perú.

E. Lukaszewska, H. Johnsson, L. Stehn. (2006). Connections for Prefabricated Timber-Concrete Composite Systems.

E. Lukaszewska, H. Johnsson, M. Fragiacomo. (2008). Performance of connections for prefabricated timber–concrete composite floors.

Ente Nazionale Italiano di Unificazione. (2016). UNI EN 338, Legno strutturale, Classi di resistenza.

F. Qiu, N. Yan, Ling, Ning, Ting, Wang, Bo, K. Bohumil. (2020). Behaviour of adhesively bonded engineered wood – Wood chip concrete composite decks. Construction and Building Materials.

Grant, D.J., Anton, A., & Lind, P. (1984). BENDING STRENGTH, STIFFNESS, AND STRESS-GRADE OF STRUCTURAL PINUS RADIATA: EFFECT OF KNOTS AND TIMBER DENSITY.

Gobierno de Chile. (2023): Plan de Reconstrucción Post Incendios 2023, Ñuble, Bíobío, Araucania.

González R., M., Hernández C., G., Vásquez V., L. (2011). Informe técnico 185. Buenas prácticas constructivas, diseño, costos y rendimientos. Publicación 1: Guía práctica para la construcción de viviendas de madera con sistema plataforma. Concepción, Chile: INFOR.

J. Skullestad, R. Bohne, J. Lohne. (2016). High-rise Timber Buildings as a Climate Change Mitigation Measure – A Comparative LCA of Structural System Alternatives, Energy Procedia, Volume 96.

J. Wacker, A. Dias, T. Hosteng. (2020). 100-Year Performance of Timber–Concrete Composite Bridges in the United States.

L. Núñez-Regueira, C.A. Gracia-Fernández, S. Gómez-Barreiro. (2005). Use of rheology, dielectric analysis, and differential scanning calorimetry for gel time determination of a thermoset, Polymer, Volume 46, Issue 16.

Lorca, J.(March 31st, 20213). Reconstrucción tras los incendios forestales: una lenta esperanza. La Tercera. https://www.latercera.com/la-tercera-sabado/noticia/reconstruccion-tras-los-incendios-forestales-una-lenta-esperanza/RINRHPKXVRBLVN3ABJOU7MGIXU/

M. Brunner Æ M. Romer Æ M. Schnuriger. (2007). Timber-concrete-composite with an adhesive connector (wet on wet process).

M. Hochella, D. Aruguete, B. Kim, A. Elwood Madden. (2012). Naturally Occurring Inorganic Nanoparticles: General Assessment and a Global Budget for One of Earth's Last Unexplored Major Geochemical Components.

M. Schiere. (2018). Moisture content of Timber Structures in Varying Ambient Climates.
Markus Petruch, Dominik Walcher. (2021).

Timber for future? Attitudes towards timber construction by young millennials in Austria - Marketing implications from a representative study, Journal of Cleaner Production, Volume 294.

Ministerio de vivienda y urbanismo. (2021): Plan de emergencia habitacional.

NCh1207, 2017: Pino radiata, Pino oregón, Pino ponderosa - Clasificación visual para uso estructural - Especificaciones de los grados de calidad.

Q. Fu, L. Yan, N. Thielker, B. Kasal. (2021). Effects of concrete type, concrete surface conditions, and wood species on interfacial properties of adhesively-bonded timber – Concrete composite joints, International Journal of Adhesion and Adhesives, Volume 107, 2021.

Qiuni Fu, Libo Yan, Bohumil Kasal. (2020). Testing methods for shear strength of bond line between concrete and different types of engineered wood, International Journal of Adhesion and Adhesives, Volume 102.

R. Andrew. (2017). Global CO2 emissions from cement production.

Simpson Strong Tie, 2021, Holdowns and Tensions Ties.

Trubiano, F. (Ed.). (2012). Design and Construction of High-Performance Homes: Building Envelopes, Renewable Energies and Integrated Practice (1st ed.). Routledge.

Weber, 2022. Ficha técnica Hormigón H-20.

APPENDIX 1.1 CONTRIBUTION TO THE SUSTAINABLE DEVELOPMENT GOALS

The Sustainable Development Goals (SDGs) are a universal call to action to end poverty, protect the planet and improve the lives and prospects of people around the world. Select which of the 17 SDGs your work contributes to:

☐ SDG-1 : No poverty.
☐ SDG -2 : Zero hunger.
☐ SDG -3 : Good health and well-being.
☐ SDG -4 : Quality education.
☐ SDG -5 : Gender equality.
☐ SDG -6 : Clear wáter and sanitation.
☐ SDG -7 : Affordable and clean energy.
☐ SDG -8 : Decent work and economic growth.
■ SDG -9 : Industry, innovation and infrastructure.
☐ SDG -10 : Reduced inequalities.
☐ SDG -11 : Sustainable cities and communities.
☐ SDG -12 : Producción y consumo responsables.
☐ SDG -13 : Climate Action.
☐ SDG -14 : Life below water.
☐ SDG -15 : Life on land.
☐ SDG -16 : Peace, justice and strong institutions.
☐ SDG -17 : Partnerships for the goals.

Linkage
This title report supports SDG 9, which aims to develop reliable and sustainable infrastructure in a formato of a faster system to build houses with the purpose of promote economic growth and human well-being, with a focus on accessible and equitable access for everyone.

APPENDIX 2.1. TYPES OF FOOTINGS

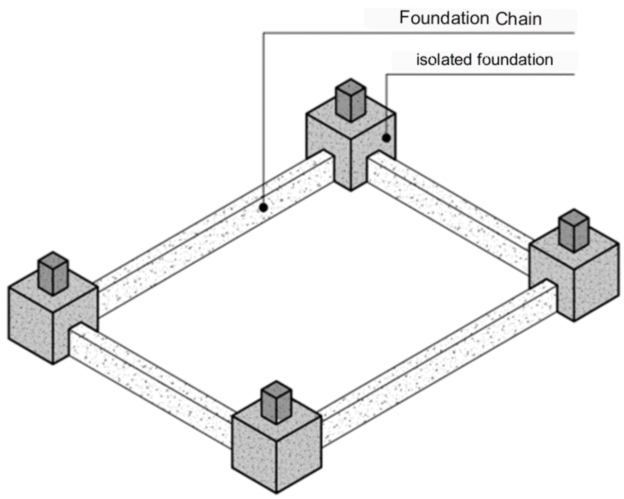

Figure A.2.1.1. Stripped footing.
Source: (Infor, 2011)

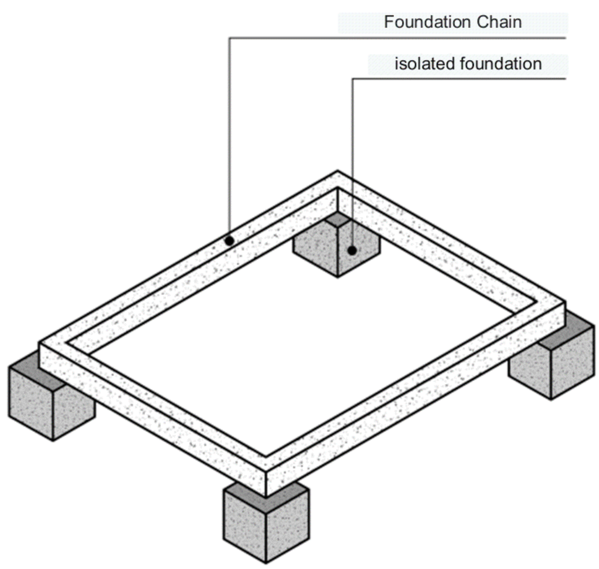

Figure A.2.1.2. Stripped footing at the ground level.
Source: (Infor, 2011)

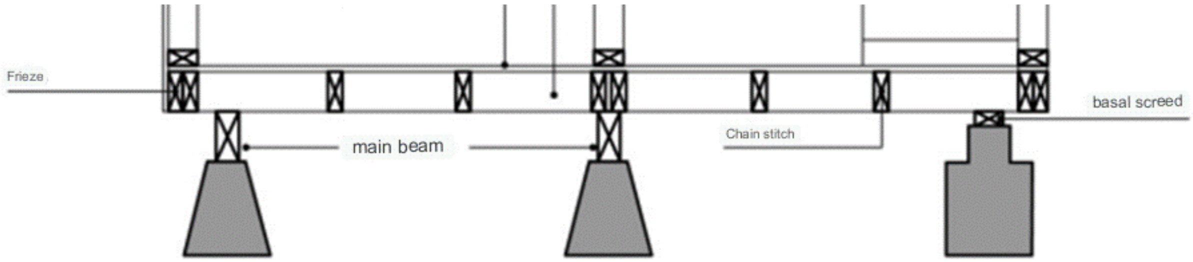

Figure A.2.1.3. Cross-section of foundation footings.
Source: (Infor, 2011)

APPENDIX 2.2. FINITE ELEMENT MODEL.

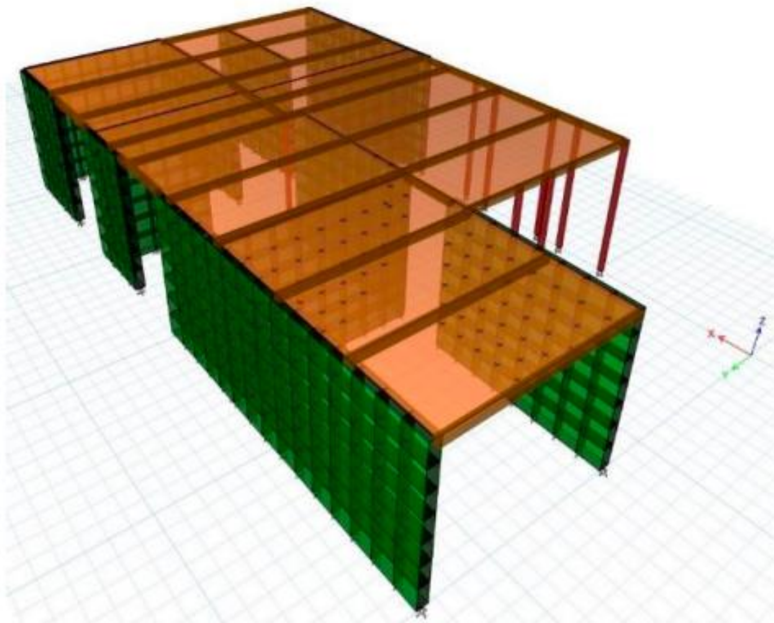

Figure A.2.2.1. Finite element model.
Source: (Infor, 2021)

APPENDIX 4.1. RESULTS OF SHEAR TESTS.

Table A.4.1.1. Results of compression-shear and double shear tests in MPa.

7D-40x40x160mm	28D-40x40x160mm	CWC-7D	CWC-28D	WCW-7D	WCW-28D
40x40x160	40x40x160	50x50x50	50x50x50	50x50x50	50x50x50
2.66	5.48	1.24	1.39	1.57	0.26
3.21	5.96	0.99	2.21	0.97	0.74
2.80	5.52	1.74	1.46	1.34	0.56
4.25	4.99	0.85	1.19	1.02	0.66
1.23	4.79	2.03	1.14	1.18	0.94
2.93	4.48	1.40	1.65	0.82	0.63
3.35	5.72	1.45	1.29	0.77	0.35
2.21	5.40	1.20	2.30		0.74
3.67	5.05		1.17		
2.60	5.76				
3.39	5.41				
3.24					
1.06					
2.49					
4.03					
2.72					
1.76					
1.62					
1.51					
2.32					
1.02					
2.72					
3.04					
1.43					

APPENDIX 4.2. STRAIN-FORCE CURVES.

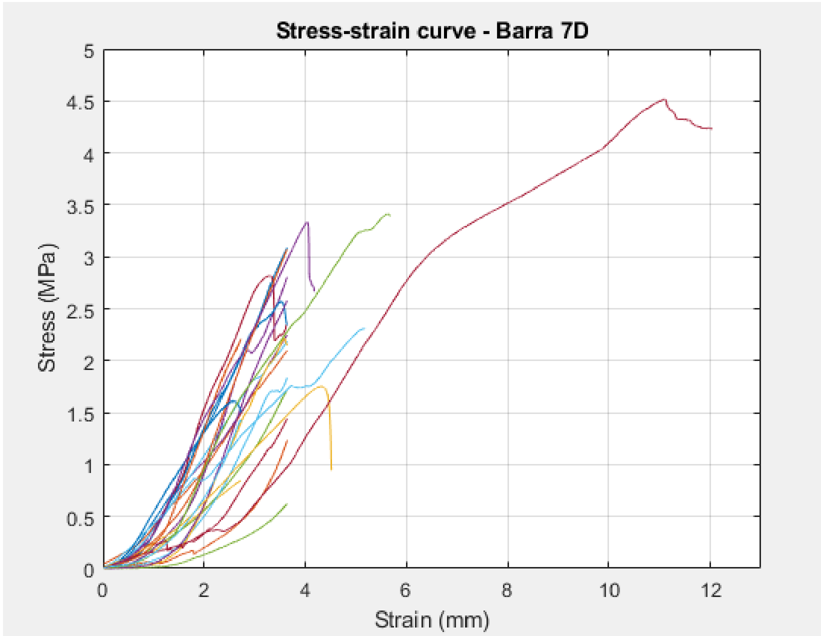

Figure A.4.2.1. Stress-strain curve for 7 day curing compression-shear test.

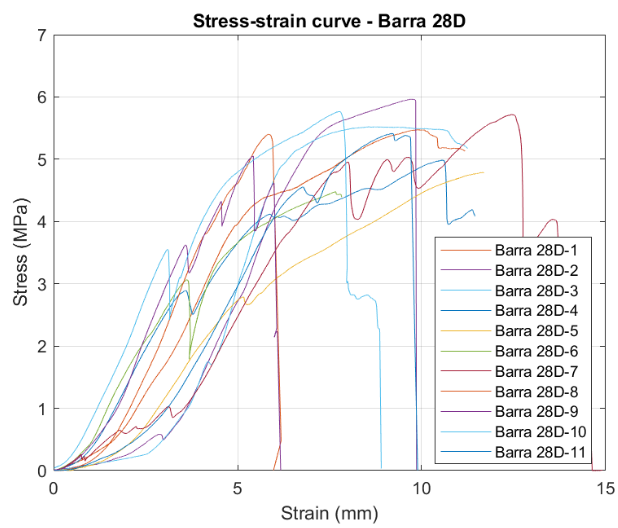

Figure A.4.2.2. Stress-strain curve for 28 day curing compression-shear test.

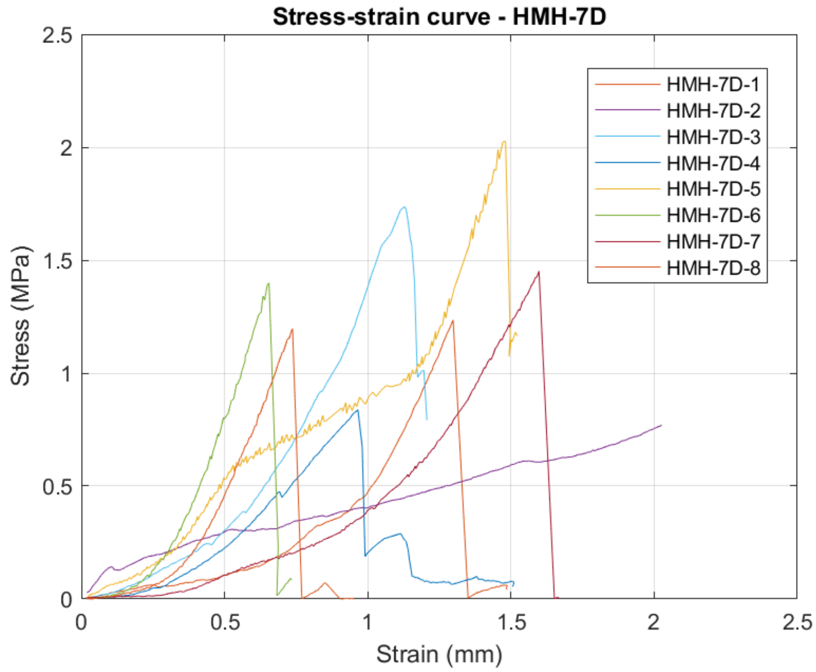

Figure A.4.2.3. Stress-strain curve for double lap shear test with 7 day casting for the Concrete-timber-concrete array.

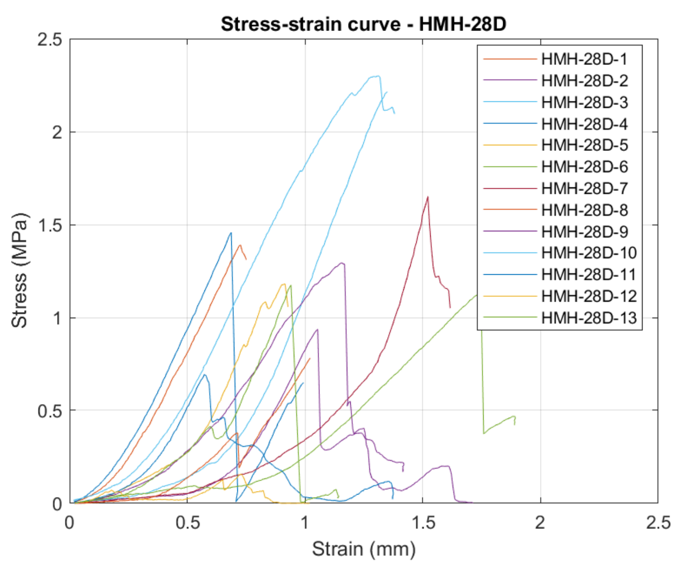

Figure A.4.2.4. Stress-strain curve for double lap shear test with 28 day casting for the Concrete-timber-concrete array.

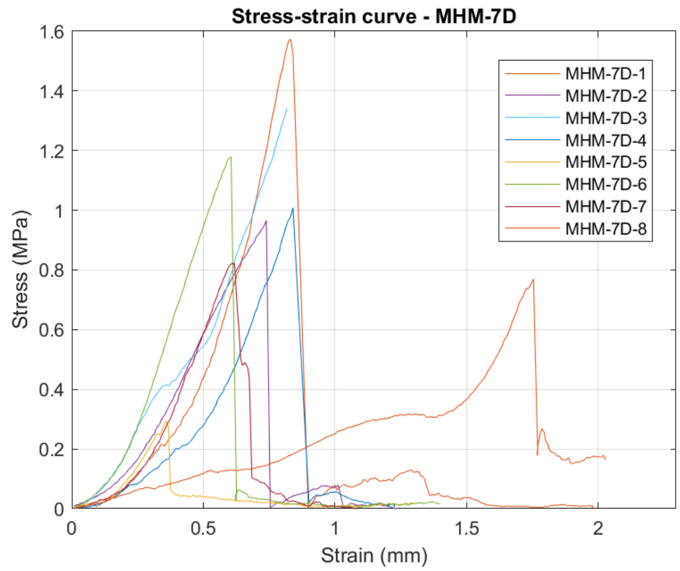

Figure A.4.2.5. Stress-strain curve for double lap shear test with 7 day casting for the timber-concrete-timber array.

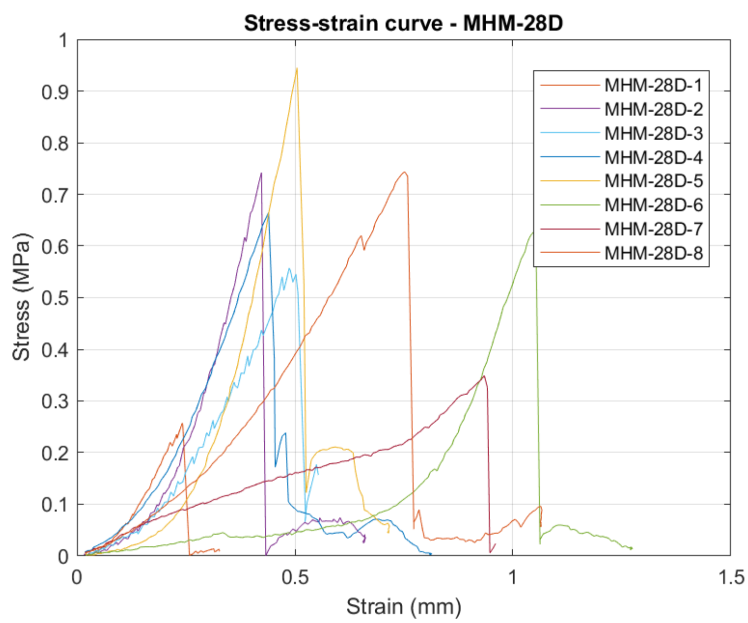

Figure A.4.2.6. Stress-strain curve for double lap shear test with 7 day casting for the timber-concrete-timber array.

APPENDIX 4.3 FLUENCY MODES OF A ½” BOLT

$$Ic:\ Pel,ad = \frac{d \cdot lc \cdot Rap,c}{FA} = \frac{12{,}7 \cdot 41 \cdot 34{,}74}{5} = 3.617{,}8N$$

$$Il:\ Pel,ad = \frac{2 \cdot d \cdot ll \cdot Rap,l}{FA} = \frac{2 \cdot 12{,}7 \cdot 41 \cdot 18{,}7}{5} = 3.894{,}8N$$

$$IIIl:\ Pel,ad = \frac{2 \cdot k3 \cdot D \cdot Rap,c}{(2 + Re) \cdot FA} = \frac{2 \cdot 1{,}4 \cdot 12{,}7 \cdot 41 \cdot 34{,}74}{(2 + 1{,}86) \cdot 4} = 3.280{,}4N$$

$$IV:\ Pel,ad = \frac{2 \cdot D^2}{FA}\sqrt{\frac{2 \cdot Rap,c \cdot F_{ff}}{3 \cdot (1 + Re)}} = \frac{2 \cdot 12{,}7^2}{4}\sqrt{\frac{2 \cdot 34{,}74 \cdot 310}{3 \cdot (1 + 1{,}86)}} = 4.040{,}6$$

APPENDIX 4.4. FLUENCY MODES OF A 4" NAIL.

$$Ic:\ Pel,ad = \frac{d \cdot lc \cdot Rap,c}{FA} = \frac{4{,}3 \cdot 59 \cdot 26{,}5}{2{,}2} = 3.051N$$

$$Il: Pel,ad = \frac{d \cdot ll \cdot Rap,l}{FA} = \frac{4{,}3 \cdot 41 \cdot 26{,}5}{2{,}2} = 2.121N$$

$$II: Pel,ad = \frac{k1 \cdot d \cdot ll \cdot Rap,l}{FA} = \frac{0{,}519 \cdot 4{,}3 \cdot 41 \cdot 26{,}5}{2{,}2} = 1.101N$$

$$IIIc: Pel,ad = \frac{k2 \cdot d \cdot ll \cdot Rap,c}{(1+2 \cdot Re) \cdot FA} = \frac{1{,}064 \cdot 4{,}3 \cdot 41 \cdot 26{,}5}{(1+2 \cdot 1) \cdot 2{,}2} = 1.082N$$

$$IIIl: Pel,ad = \frac{k3 \cdot d \cdot lc \cdot Rap,c}{(1+2 \cdot Re) \cdot FA} = \frac{1{,}13 \cdot 4{,}3 \cdot 59 \cdot 26{,}5}{(1+2 \cdot 1) \cdot 2{,}2} = 799N$$

$$IV:\ Pel,ad = \frac{d^2}{FA}\sqrt{\frac{2Ra,p \cdot F_{ff}}{3(1 + R_e)}} = \frac{4{,}3^2}{2{,}2}\sqrt{\frac{2 \cdot 26{,}5 \cdot 646{,}6}{3(1 + 1)}} = 635N$$

APPENDIX 4.5. COMPARATIVE TABLE FOR MECHANICAL FASTENERS.

Table A.4.5.1. Comparative between the resistance of the adhesive with 4" nails and ½" screw.

	7D-40x40x160 mm	28D-40x40x160 mm	CTC-7D	CTC-28D	TCT-7D	TCT-28D	
Av(kN)	18.34	34.07	3.02	2.03	2.13	1.22	Strength(kN)
4" Nail(%)	30.57	56.79	5.04	3.38	3.55	2.04	0.6
1/2" Screw(%)	5.59	10.39	0.92	0.62	0.65	0.37	3.28

UNIVERSIDAD DE CONCEPCIÓN – FACULTAD DE INGENIERÍA

RESUMEN DE MEMORIA DE TÍTULO

Departamento	**:** Departamento de Ingeniería Civil
Carrera	**:** Ingeniería Civil
Nombre del memorista	**:** Carlos José Soto Díaz
Título de la memoria	**:** Analysis of the mechanical behaviour of a new epoxy adhesive as a connector for concrete and timber
Fecha de la presentación oral	**:**
Profesor(es) Guía	**:** Dr. Siva Avudaiappan
Profesor(es) Revisor(es)	**:** Dr. Sebastián Calderón D.
Concepto	**:**
Calificación	**:**

Resumen

After forest fires ravaged the central-southern region of Chile in the summer of 2023, a substantial number of provisional emergency housing units were swiftly constructed. However, these efforts were hindered by slow progress, failing to meet initial production commitments. Subsequently, issues of water leakage within these houses became apparent during the rainy season, primarily at the joints between the concrete foundations and wooden structures.

In response to these problems, there was a motivation to explore new anchoring methods for emergency housing. Specifically, epoxy adhesive emerged as a potential solution due to its quicker application compared to mechanical fasteners, its water-resistant properties, and its ability to meet the necessary bonding requirements between concrete and wood.

Three tests were conducted for assessment: a bonding capacity test on a fiber cement plate, a compression-induced shear test involving wood and concrete bars, and a double-sided shear test on sandwich-style test specimens with varying compositions. Additionally, the performance of concrete with curing periods of 7 and 28 days was evaluated. Results were compared with seismic demands outlined in housing manual of the INFOR and with mechanical fastener resistance according to the Chilean standard NCh1198.

In conclusion, the adhesive shows potential as a new bonding method, though further testing is required to account for variables such as humidity and adhesive storage time, given the variability in results. Nonetheless, the adhesive exhibits good seismic performance per the Chilean standard, with resistance values akin to traditional mechanical fasteners like nails or bolts.