Insert testing for Boomeranger Boats Oy

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Degree Thesis

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EXAMENSARBETE	
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Sammandrag:
Detta slutarbete är beställt av företaget Boomeranger Boats Oy. Företaget bygger RIB båtar för professionell användning. Forskningen baserar sig på produktutveckling och testning. Företaget vill hitta en lösning för att kunna ändra däckutrustningens ordning i olika skeden av produktionen. Den nuvarande lösningen möjliggör inte ändringar. En förenklad standard måste planeras och skapas för att kunna tillfredsställa företagets behov av utrustningens monteringsmöjligheter. Boomeranger Boats har bråttom med sina beställningar av produkter och en lösning behövs snarast möjligt. De utförda testen bör simulera diverse krafter som uppkommer vid normal användning av båtarna. Den nuvarande lösningen består av att utrustningen fästs med bultar i aluminium lister i däcket. Listerna måste installeras i början av produktionen vilket definierar var utrustningen kan fästas under båtens livstid. Boomeranger Boats Oy vill få reda på om det är möjligt att använda sig av fogar för att fästa skenorna i däcket i ett senare skede at produktionen.

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Supervisor (Arcada):	Mirja Andersson
Commissioned by:	Boomeranger Boats Oy

Abstract:

This thesis is ordered by Boomeranger Boats Oy. The company builds custom RIB-boats for customers, mainly for professional use. This thesis is based on product development and the test findings indicate the most suitable solution for the research question. Boomeranger Boats Oy is interested in developing a new mechanism to fasten the deck utilities. This way should enable moving the utilities in any stage of the production if necessary. A test standard for the fastening mechanism has been designed and created in order to find out how much strength an insert can last inside a sandwich lamina. The tests simulate the forces that the boat is exposed to in real life. The problem with the current method is that the aluminum panels onto which rails are fastened are fixed to the deck. They need to be installed in an early stage of the production. Boomeranger Boats Oy is interested in knowing if it would be possible to use inserts to fasten the deck utilities which would enable changes in the positioning of the deck utilities even though the boat is fully constructed.

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Työn ohjaaja (Arcada):	Mirja Andersson
Toimeksiantaja:	Boomeranger Boats Oy

Tiivistelmä:
Tämä opinnäytetyö on tilaustyö yritykselle Boomeranger Boats Oy. Tarkoitus on löytää ratkaisu kansirakenteiden muunneltavuuteen. Yritys haluaa mahdollistaa kansirakenteiden vaihtamisen kohdasta toiseen tuotannon kaikissa vaiheissa. Työ perustuu tuotekehittelyyn sekä testaamiseen. Opinnäytetyössä on suunniteltu oma testimenetelmä jonka tarkoitus on simuloida voima jolle vene altistuu päivittäiskäytössä. Tällä hetkellä kansirakenteet kiinnitetään kiskoihin. Kiskot kiinnitetään alumiinilaattoihin jotka on asennettava samalla kun veneen kantta rakennetaan. Boomeranger Boats Oy haluaa saada selville onko mahdollista käyttää inserttejä laattojen sijaan. Tämä mahdollistaisi kansirakenteiden muunneltavuuden.

Avainsanat:	Komposiittirakenteiden inserttien testaus
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Hyväksymispäivämäärä:	

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FOREWORD

The first words of this thesis are dedicated as a thank you to the CEO, Miika Tammi and the Technology director, Jari Saari of Boomeranger Boats Oy, for making this project and opportunity possible.

This thesis is based on testing of product development ordered by Boomeranger Boats Oy in Loviisa, Finland. The company is interested in developing a new method for fastening the utilities on the deck. The current mechanism is based on rails that are fastened with screws to the deck and has some restrictions in mobility. In essence, the customer has to have the opportunity to wish for changes of location for seats or steering consoles even though the boat is almost ready for delivery.

Different types of tests are conducted and based on the results a decision will be made regarding which insert can last the highest loads. The solution will also be based on simplicity in construction.

I would like to thank all the persons that has helped me with this project:
Joonas Rautalin
Jari Saari
Erland Nyroth
Mirja Andersson
Björn Wiberg

1 INTRODUCTION

1.1 Boomeranger Boats Oy

Boomeranger Boats Oy is a company founded in Finland, Loviisa, 1991. The company produces RIB-boats (Rigid Inflatable Boat) for professional use. Customers consist of authorities like the Finnish military, the Coast Guard, Fire Brigade and the Police. Foreign customers consist of the Norwegian, German and the Swedish Navy to name but a few. Furthermore, most of the projects are secret and these orders can't be used as a reference.

The boats differ in size between 4 and 14 meters. Boats under nine meters are usually open with utilities for one to four persons. Boats over nine meters are tailored to the customers need and can either have cabin, a half cabin, closed cabin or no cabin. Boomeranger is not dependent on a certain manufacturer when it comes to engines. A customer can choose between an outboard engine and an inboard engine. The inboard engines are diesel engines and can installed in boats longer than six meters. All the boats are custom built in Loviisa based on the customer's order.

There are many boat manufacturers in Finland, however Boomeranger Boats Oy is the only company that manufacture RIB-boats for professional use in Finland. (www.boomeranger.fi)

1.2 Important Features in a RIB-Boat

The benefit of a RIB-boat is in its features. The boat is well balanced and with the help of its pontoons it is very stable while in water. Also the boat does swim in shallow water so it is possible to reach a variety of different shores. The big engines help the driver reach high speeds through fast acceleration. It easy to step onboard another boat from a RIB and the driver doesn't have to be too careful with damaging the other boat, or the RIB, because of the elasticity in the pontoons. With an inboard water jet engine, an engine without a propeller that blows water to go forward, the driver can perform tight 360 degree turns without moving forward. The most important feature is that the RIB-boats are extremely sea passable. (www.boomeranger.fi)

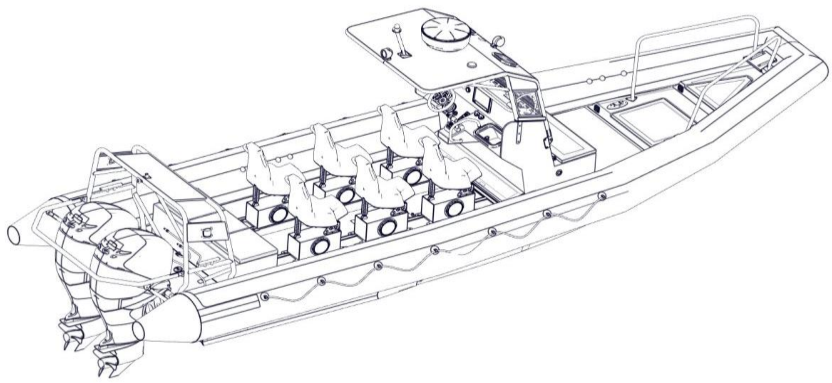

Figure 1-1 Typical RIB-boat. Drawn by design engineer intern Joonas Rautalin at Boomeranger Boats Oy

1.3 Previous testing

The tests performed in this thesis are specifically made in order to be able to answer the research question. Similar tests have been performed by the European Cooperation for Space Standardization (ECSS), and the basics and some point of views will be applied in the tests performed for Boomeranger Boats Oy. The idea with the tests in this thesis is the same as in ECSS, however one has to take into consideration the resources and the timetable and thus, construct a simplified test standard.

1.3.1 Limitations of methods

Boomeranger Boats Oy has requested that the tests should be performed on combinations of materials that have been used in previous testing and is used in current applications. Furthermore, the combinations and the inserts are given from the company and it is not an option to change the combinations. The results, discussion and conclusion have to be based on the materials given from the company.

2 LITERATURE REVIEW

2.1 Composite theory

A composite which is fiber reinforced can be defined as a polymer matrix. It is either a thermoset or a thermoplastic and is combined with a fiber or some other material, which is providing reinforcement in one or more directions. This is called the length to thickness ratio. Composites differ from other materials such as steel or aluminum in the following way: Composites are anisotropic, the properties of a composite is only apparent in the direction of an applied load. Steel and aluminum however, are isotropic, meaning that there are identical values in all directions of an applied load. This can be summed up by describing that the best mechanical properties of a composite is in the same direction as which the fibers are placed in.

In this study glass fiber reinforced polymers are used, also known as glass fiber. Other examples of reinforced fibers are: carbon fiber reinforced polymer and aramid fiber reinforced polymer.

Benefits with composites are: light weight, high strength to weight ratio, directional strength, corrosion resistance, weather resistance, low thermal conductivity, low coefficient of thermal expansion, non magnetic, low maintenance, easy to handcraft, tailored surface finish.

To reach a hard and strong material the glass fiber needs to be hardened. This happens by mixing resins, reinforcements, fillers and additives. The two basics needed are resin and hardener. All of these ingredients change the processing and the final performance of the finished product. The resin holds the composite together whilst the reinforcement supplies mechanical strength. Fillers and additives are used for process or performance help to reach special properties in the end product.

Properties wished for can be reached by tailoring the selection and combination of different components such as: Type of fiber reinforcement, fiber volume, directions of fibers (0, 90, +/- 45 or a combination), type of resin, the cost of the final product or manufacturing process (hand lamination or vacuum infusion).

The functions of the resins are to delegate stress between the reinforced fibers and act as glue. The resin does also protect the fibers from mechanical and environmental damage. There are two types of resins, thermosets and thermoplastics. Thermoplastic resins become soft when heat is applied and become rigid after cooling. Thermosets are usually liquid in their initial form. Once a thermoset resin is cured it can't be converted to liquid by heating any more. The most common types of thermosetting resins used are polyesters, epoxies and vinyl esters. Polyester is the most used resin in composites industry.

Composite parts can also be constructed with prepreg mats. A prepreg composite is impregnated with resin and heated to start the curing process. Usually smaller parts are produced in ovens specifically built for composite production. Prepregs can be stored in a refrigerator so that the curing process will not start by itself.

In a polyester resin the most important additives are catalysts or initiators. These additives makes the curing process faster and causing unsaturated resin to harden.

In this study a sandwich structure is used. A sandwich structure consists of two composite layers with a core material in between. The sandwich structure has been used in the industry for 45 years. The idea is to build strong, stiff, light and highly durable structures. This technology is used in boats, trucks and building panels. A weight increase of 3% could increase the flexural strength and stiffness by 3,5 times if the core and the composites are chosen correctly. The core material can be for example wood or a plastic foam.

In the experiments for this thesis a sandwich construction is used. A polyurethane foam with grooves in-between glass fiber layers. The polyurethane is a flexible, rather strong foam. The benefits of the grooves are that the resin will flow easier during the vacuum process and stiffen the foam even more. Boomeranger Boats Oy has requested for the tests to be performed with this specific foam. *(Holloway 1994)*

2.2 Three point bending

The basics of three point bending has to be discussed in order for the reader to get a better understanding of the results. However, the main focus in this thesis will be on a so called reversed three point pulling, where the test piece is fastened to a rack and then pulled upwards from the middle. The rack is specifically designed for this thesis

In a three point bending test the goal is to find out the modulus of elasticity in bending and flexural stress. The biggest factor wanted is the flexural stress-strain cycle to the material. A three point bending test is a rather easy to conduct taking into consideration that the test pieces have to be the size of a certain standard and the performance of the test is therefore rather simple. Disadvantages with this test are that the test pieces can be damaged which results in unreliable data. Also, the test pieces are sensitive to the rate of strain.

In a test the test pieces have their dimensions taken from a standard, for example, ISO 178. The distance between the bottom points and the test speed has to be the same in all the tests so that one can receive a reliable data.

The testing method itself involves test pieces of standard dimensions and a universal testing machine. The test piece is placed on two pins and the third pin lowers from above with a constant velocity until the test piece breaks. The fracture level when the machine has to stop, depending on the machine, can be adjusted to the smallest fracture or until it breaks completely.

The test pieces in this thesis will be of rectangular shape. For a rectangular cross section the formula will be:

$$\sigma_f = \frac{3FL}{2bd^2} \qquad (1)$$

- σ_f = The amount of stress in outer fibers at midpoint, (MPa)
- ε_f = The amount of strain in the outer surface, (mm/mm)
- E_f = The flexural Modulus of elasticity,(MPa)
- F = load at a given point on the load deflection curve, (N)
- L = Support span, (mm)
- b = Width of test beam, (mm)
- d = Depth of tested beam, (mm)
- D = maximum deflection of the center of the beam, (mm)
- m = The gradient (i.e., slope) of the initial straight-line portion of the load deflection

The formula for flexural strain is:

$$\varepsilon_f = \frac{6Dd}{L^2} \qquad (2)$$

The formula for flexural modulus is:

$$E_f = \frac{L^3 m}{4bd^3} \qquad (3)$$

(Pearson Prentice Hall Bioengineering 2008)

2.3 Four point bending

The principles for a four point bending tests are similar to three point bending tests. The main difference is that there is a second beam pushing downwards from above. This allows the stress to be over a bigger area of the test piece and brings a larger portion of the test piece to maximum stress. The outcome of the test provides values for modulus of elasticity in bending, flexural stress and flexural strain. The flexural stress-strain cycle to the material is also of interest.

This test is suitable for following applications:

- Advanced ceramics at ambient temperature
- Unreinforced and reinforced plastics
- Sandwich constructions by beam flexure (standard: ASTM D7249)
- Sandwich beam flexural and shear stiffness, which in this thesis is in interest (standard: ASTM D7250)

The formula for flexural stress in a four point bending test can be derived by doubling the amount of beams in the three point bending test formula:

$$\sigma_f = \frac{3FL}{2bd^2} \qquad (4)$$

The denominator is multiplied with two so it becomes:

$$\sigma_f = \frac{3FL}{4bd^2} \qquad (5)$$

The advantages with this test are that the geometries of the test pieces are simple and require little machining. The test is also fast to setup. The down side is that the stress distribution is more complex through the sample, meaning that similar test pieces can lead to variation in the results. *(Pais & Harvey (Eds) 2012)*

2.4 Tensile testing

Tensile testing can also be called tension testing. The results of interest are, when will a sample fail and in what tension. This test helps to decide which type of material could be used for production. With the help of the test results one can predict how the materials would react to other loads of forces. The results from a tensile test gives the value for ultimate tensile strength and maximum elongation. Also the reduction in area is given. These are results given directly from a universal testing machine. Furthermore, the results enable the determination of Young's modulus, Poisson's ratio, yield strength and the strain-hardening characteristics.

- Young's modulus can be defined as the linear elasticity of a material.
- Possion's ratio is the ratio of how much a material expands towards the two other directions from where it is compressed from.
- Yield strength, also known as yield point can be defined as how much stress is required so that the material starts to deform plastically. It is the point after the Young's modulus.

When it comes to composite materials a uniaxial tensile test is required. *(Davis 2004)*

3 METHOD

3.1 Purpose

The designers at Boomeranger Boats Oy wishes for an in new method for fastening equipment on the deck. For example: seats, control panels and racks for weapons. The problem with the current method is that the adjustability of the equipment is limited. The current mechanism is a rail fastened to aluminum panels in the deck. These panels are installed at the time of the production so that it can’t be moved later on in the production process. What is reached for is that the rail could be fastened late in the production process so that if a customer changes his or her mind about locations of the utilities it is possible to re-fasten the rails without breaking the deck. The fastening mechanism has to be resistance and fast to attach.

The tests that have to be performed are based on tensile testing. The main idea is to test how resistant the fastening mechanism is and how much force is required to break the rail from the lamina. Interesting questions are:

- What will the maximum lamina strength be? (maximum capacity of the universal testing machine in ARCADA laboratory)
- Will the lamina break where the insert is installed?
- How much force is required to break the lamina or the insert in which the rail is fastened in?

Different models of prototypes are constructed and tested in the same way to get a comparable result. All exact data is only provided for Boomeranger Boats Oy.

The test procedure will be following:

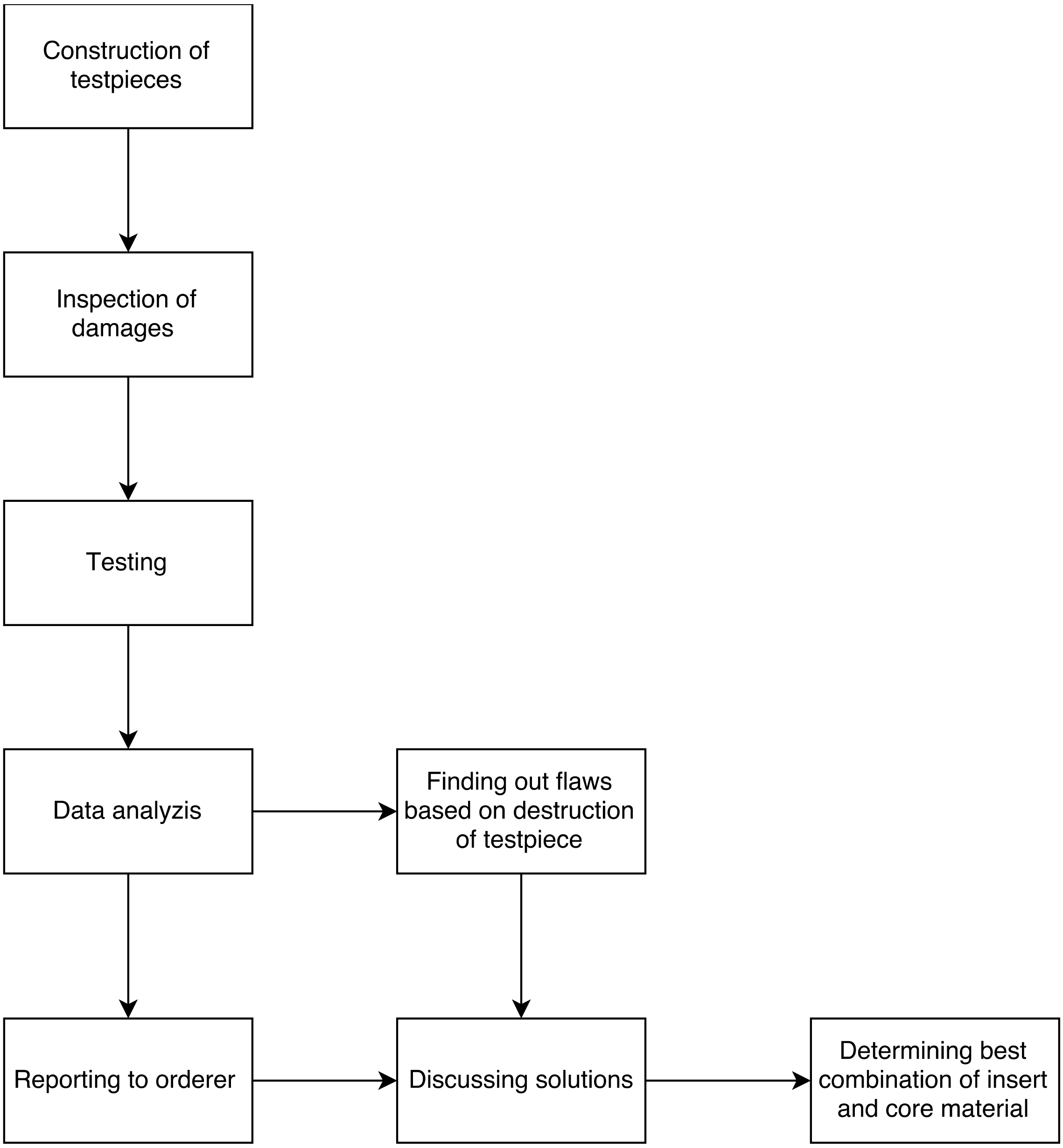

Figure 3-1 Process plan.

3.2 Tests and background

The idea is to make a sandwich laminate with an insert. A sandwich laminate consists of two face sheets, top and bottom, and a core material, therefore the name sandwich. An insert can be determined as a part of detachable fixation device. To construct an insert a cavity is produced, by drilling for example, and a nut like part is added in the cavity so that it is possible to fasten profiles or in this case rails to the composite.

Boomeranger Boats Oy could be interested in a method where the insert is potted and cured with a resin, epoxy for example. This allows them to fasten the rails to the deck even though the boat otherwise would be finished. However depending on the method, different types of tools are needed.

Table 1. Table of insert information (ECSS Secretariat 2011) P.73

Pottin Method	Device	Potting Level	Expected Filling	Comments
Casting	Resin funnel apparatus	Full	Very Good	Feasible but impracticable method. A resin reservoir is needed above each insert to complete filling due to resing shrinkage
		Partial	Bad	No longer in use. Sandwich plate has to be turned over before curing.
Injection	Compressed air cartridges (Semco cartridges)	Full Partial	Good (1)	Very economical method when a large number of inserts are fitted.
	Manual injection (by small medical squirter)	Full Partial	Good (1)	Usual for a small number of inserts, e.g. Repair. Injection methods enable handling of sandwich plate immediately after potting.
Foaming	No	Full	Good	Usual when inserts are potted during sandwich manufacture process.
Paste Application	Spatula	Full Partial	Bad	Not advicable for standard potting, i.e. Filling of honeycomb cells. Preferred method for CFRP tube inserts

Note (1) 100% filling is not possible because a small amount of air always remains trapped at the top of core cells.

(ECSS Secretariat 2011) P.73

3.2.1 Sandwich structure

A sandwich laminate consists of an upper face sheet, lower face sheet and a core material. The American Society for Testing and Materials (ASTM) defines the structure as following: "A structural sandwich is a special form of a laminated composite comprising of a combination of different materials that are bonded together so as to utilize the properties of each separate component to the structural advantage of the whole assembly." *(ECSS Secretariat 2011) p. 110*

These types of sandwich structures are used in modern construction applications. Different forms of structures are beams, plates or shells. Boomeranger Boats Oy is currently using sandwich structure on the deck of the boat. Benefits with working with sandwich structure is that is rather easy to drill in and easy to form in different shapes. Therefore it is possible to construct inserts in the decks of the boats.

3.2.2 Vacuum infusion process

The test pieces will be constructed with a process called vacuum infusion. The process is suitable for sheet laminating and it guarantees an even spread of resin. Equipment needed for the process are: A smooth surface (glass for example), vacuum pump, vacuum tape, composites, resin, pieces of tube, buckets, gloves and extinguisher.

The surface the vacuum lamination is performed on needs to be clean of all dried resin from earlier work. Even if the surface is slippery it is recommended to apply release agent so that when it is time to remove the part it is just to lift it up. The amount of fiber mat and foam, if needed, is cut to the wished size and placed on the lamination surface. There needs to be a flow mat on the lamina, so that the resin will spread easily and evenly. A vacuum bag is cut from plastic sheet. Note, that the bag has to be notably bigger than the composite mat. The vacuum tape, which is a double-sided soft tape, is applied on the bag, and then taped onto the laminating surface. It is considered easier to first apply the tape to the plastic sheet because of the folds that has to be made (for slack), than to tape directly onto the lamination surface and then applying the plastic sheet. One can think it in the following way: if there are many areas where there has been added tape, the risk of it not being airtight grows.

Before preparing the vacuum bag it is recommendable to determine, depending on the size, how many inlets and where their inlet point is going to be and where the outlet is going to be. If the part is large, over four square meters, it is recommended to use more than one inlet. However there is another way to make the resin spread easier. By taping spiral tube rolled in cotton weave around the piece, and inserting the outlet in to the spiral there will be suction around the piece and the resin will cover the whole area. The cotton is applied to reduce the efficiency of the suction of the resin so that the composite piece will not dry of resin.

Once the part is covered and sealed it is time to test for leakage by simply sucking out all the air and following the pressure meter if it is reducing pressure after that the pump is switched of. It is nearly impossible to produce a completely air tight seal, however it would be optimal. If there appears to be holes they can be plugged by simply pressing the inside of the soft tape under the plastic sheet.

The resin is infused by suction from a bucket at the inlet point. The suction is produced by a pump and which is connected to another bucket to where the extra resin can flow into. The bucket is connected to the vacuum-sealed construction and by under pressure the resin is distributed over the whole area. *(Hon David 2011)*

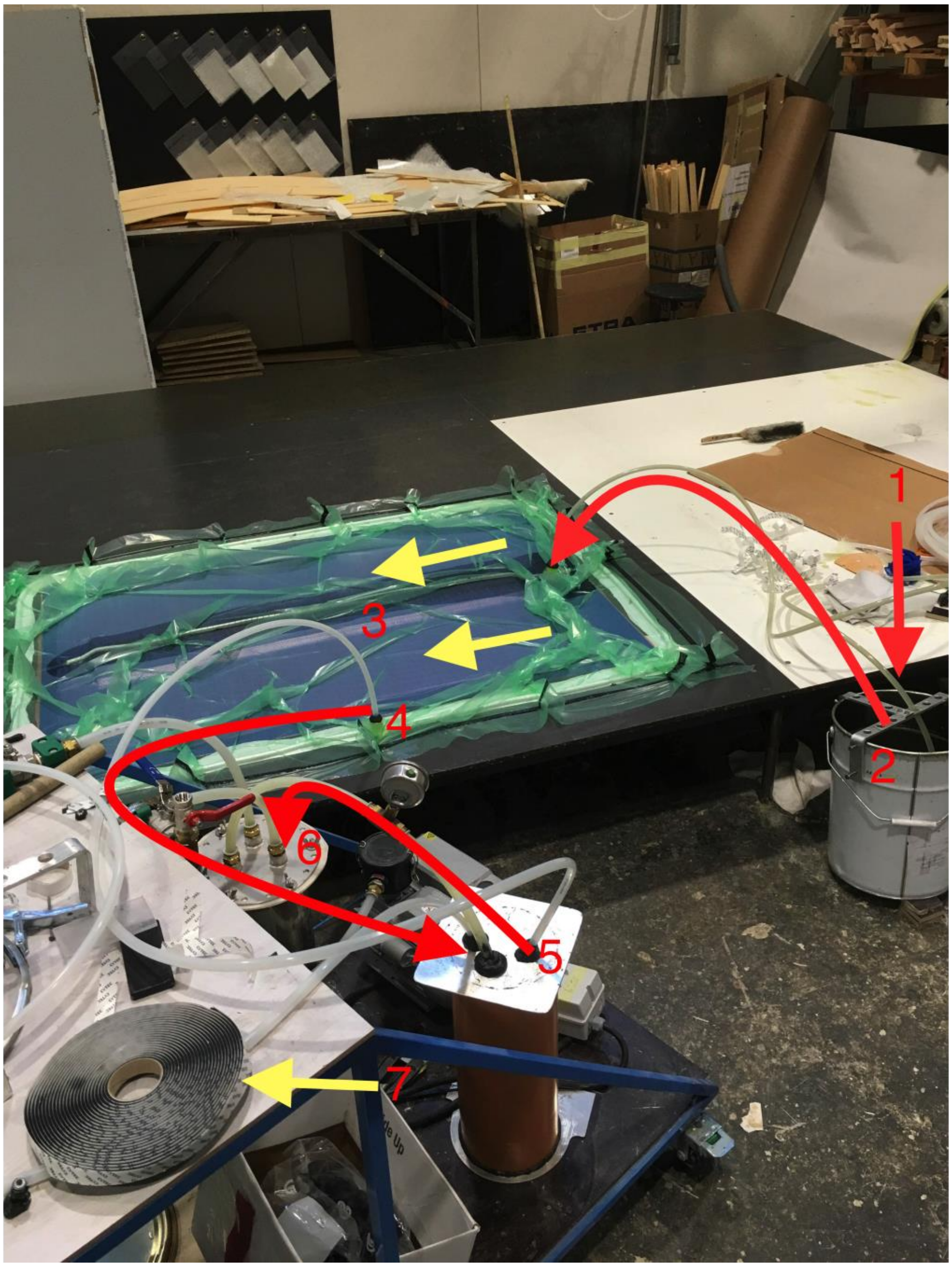

Figure 3-2 Vacuum infusion process

1. Resin bucket, resin mixed with hardener.
2. From the bucket it is sucked to the vacuum-sealed construction to the inlet point.
3. The resin is spread evenly over the whole blue area. The blue texture is the flow mat and the composite is under it.
4. The outlet point, from where the overlapped resin is sucked away.
5. The bucket to where the overlapped resin is gathered in.
6. The under pressure pump
7. The double sided tape

3.2.3 Improving bending and shear resistance

When the insert is installed in the lamina it is assumable that the material will have a lower capacity of resisting bending stress and shear stress. Furthermore there is a way to reinforce the material and improve the resistance. Such methods would be reinforcing the face sheets in the area where the insert is mounted. The reinforcement could consist of additional of multidirectional prepregs, fiber reinforced plastic sheets that need heat to cure, to increase the bending stiffness locally.

From a manufacturing point of view one has to remember that this adds one more step to the manufacturing process. The procedure requires a lot of work and time. Also it would be optimal if once the deck is ready it simply would be possible to fasten the deck utilities without any extra work. If prepregs where to be added it would require heat at the certain area and it would slow down the manufacturing process because of the curing time. The question, if it is necessary to add reinforcements will be answered in the test results section.

3.3 Inserts

Boomeranger Boats Oy is interested in testing different types of inserts that are in some way installed between the sandwich structures. The inserts are ordered from different companies or custom made for Boomeranger Boats Oy.

The first insert is rather small and the design is simple. The idea is that a hole is drilled in the laminate and the insert is screwed inside. In this study the insert is glued in its place because the foam between the glass fiber is soft and the teeth’s will not bite hard enough. Benefits with this insert is that it is fast to install and easy to handle. The idea of simply drilling a hole and inserting this part is fast and smooth. Problems while installing this can be that the insert doesn’t attach to the core material. The test results will show how it differs from other inserts.

The second insert requires more preparation and something to fill up the gap between the core material and the insert. This requires milling with a special tool. Once the cavity is created and the insert is in its place the top is covered with a plastic piece with two holes so that the epoxy adhesive can be inserted in the cavity. The epoxy is inserted from one hole and the other hole is for the epoxy to come out, in this way it is certain for the cavity to be filled.

The third insert also requires a lot of preparation. The top of the laminate is drilled with one tool and the cavity is milled. Other ways the installation is the same as in the second insert.

3.4 Sandwich Structure for the Test Pieces

Table 2. Table of designed pressure for different parts of a boat

Design Preassure		
Definition (Unit)	Symbol	Value
Loaded displacement (kg)	m_{LDC}	7275
Waterline length (m)	L_{WL}	8,38
Hull length (m)	L_H	11,00
Beam between chines (m)	B_C	2,65
Long side of panel from drawing (mm)	l	2200
Short side of panell from drawing (mm)	b	450
Panel aspect ratio	l/b	4,89
Long. pressure distr. Factor	k_L	1,000
Design area (m^2)	A_d	0,506
Area reduction factor, displacement	k_{ARD}	0,635
Area reduction factor, planing	k_{ARP}	0,466
Design category factor	K_{DC}	0,8
Cargo t/m^2	Q	0,2
	$P_{DMCARGO}$	6,0
	P_{DMBASE}	17,5
Motor craft deck pressure, design	P_{DM}	8,9

Table 3. Stack analysis

Sandwich laminate stack analysis ISO 12215-5 Annex H			
Design pressure	Panel short dimension	Design shear force	Design bending Mt
P	b	F_d /mm	M_d
kN/m^2	mm	N/mm	Nmm/mm
9,0	450	0,0	0

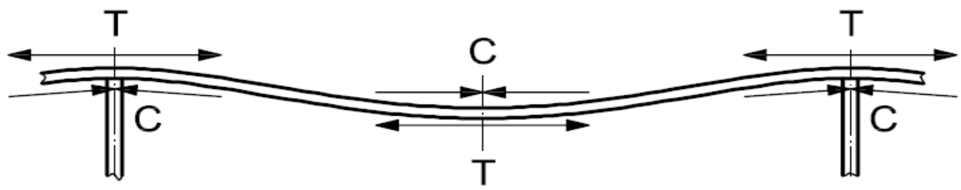

Figure 3-3 How forces bends a sandwich beam

Table 4. Core material features

Features	Unit	Value
Divinycell PVC I (kg/m^3)	r_c	130
Shear strength (N/mm^2)	τ_u	0,00
Shear modulus (N/mm^2)	G_c	0,0
Ultimate compressive strenght (N/mm^2)	s_{uc}	0,00
Compressive modulus (N/mm^2)	E_{co}	0,0
Design shear strength (N/mm^2)	τ_{dc}	0,00

Table 5. Table with information about the test pieces

Ply	Definition	Fibre		
		Dry mass kg/m2	Type	Content y
No.		input	G,C,A	C.1
1 outer	Rov 600	0,60	G	0,58
2,00	Rov 600	0,60	G	0,58
3,00	-	0,00	G	0,58
4,00	Divinycell H130	0,00		0,50
5,00	-	0,00	G	0,58
6,00	Rov 600	0,60	G	0,58
7,00	Rov 600	0,60	G	0,58
Total	Fiber	2,40		0,58
	Resin (kg)	1,74		Average
	Core	2,08		0,58
	Total weigth	6,22		

Table 6. Test piece lamination information

Sandwich number	1	2	3
Date	31.3.2016	1.4.2016	5.4.2016
Temperature °C	19,8	19,9	20,0
Relative Humidity %	27 %	28 %	26 %
Resin	Dion Impact 9102	Dion Impact 9102	Dion Impact 9102
Inhibitor	9854	9854	9854
Inhibitor %	0,05 %	0,05 %	0,05 %
Accelerator	9802	9802	9802
	1 %	1 %	1 %
Hardener	No 24	No 24	No 24
	2 %	2 %	2 %
Glass fiber	4 x Roving 600 g/m^2	4 x Roving 600 g/m^2	4 x Roving 600 g/m^2
Length (m)	1,65	1,65	1,65
Width (m)	1,30	1,30	1,30
Weight of glass fiber when dry (kg)	1,29	1,29	1,29
Harts required for the glass fiber (kg)	3,7	3,7	3,7
Corematerial	Divinycell H130	Divinycell H130	Divinycell H130
Length (m)	1,65	1,65	1,65
Width (m)	0,97	0,97	0,97
Amount of harts mixed (kg)	7,0	7,4	7,0
Time in bucket before infusion (min)	5	10	20
Geltime in Bucket (min)	75	90	70
Overlap Harts (Kg)	1,5	1,4	0,7
Pressure During Infusion (Bar)	0,88	0,88	0,86
Pressure At The End (Bar)	0,70	0,88	0,65
Infusion Time (min)	6,5	7,5	11

3.5 Testing method

The test pieces are tested in three ways. A horizontal pulling, a stress test where the force is applied from the side, and rotation to test how tight the bolts can be fastened. A rack is constructed for the horizontal and vertical testing. The rack is used in the Testometric machine in Arcada’s plastic lab.

The rotation is tested with a torque wrench until the lamina breaks. The tests seem rather simple, however they are supposed to simulate the same forces that the deck equipment on the boats are exposed to.

F = Force

Figure 3-4Pulling force. Drawn by author

Figure 3-5 Perpendicular force. Drawn by author

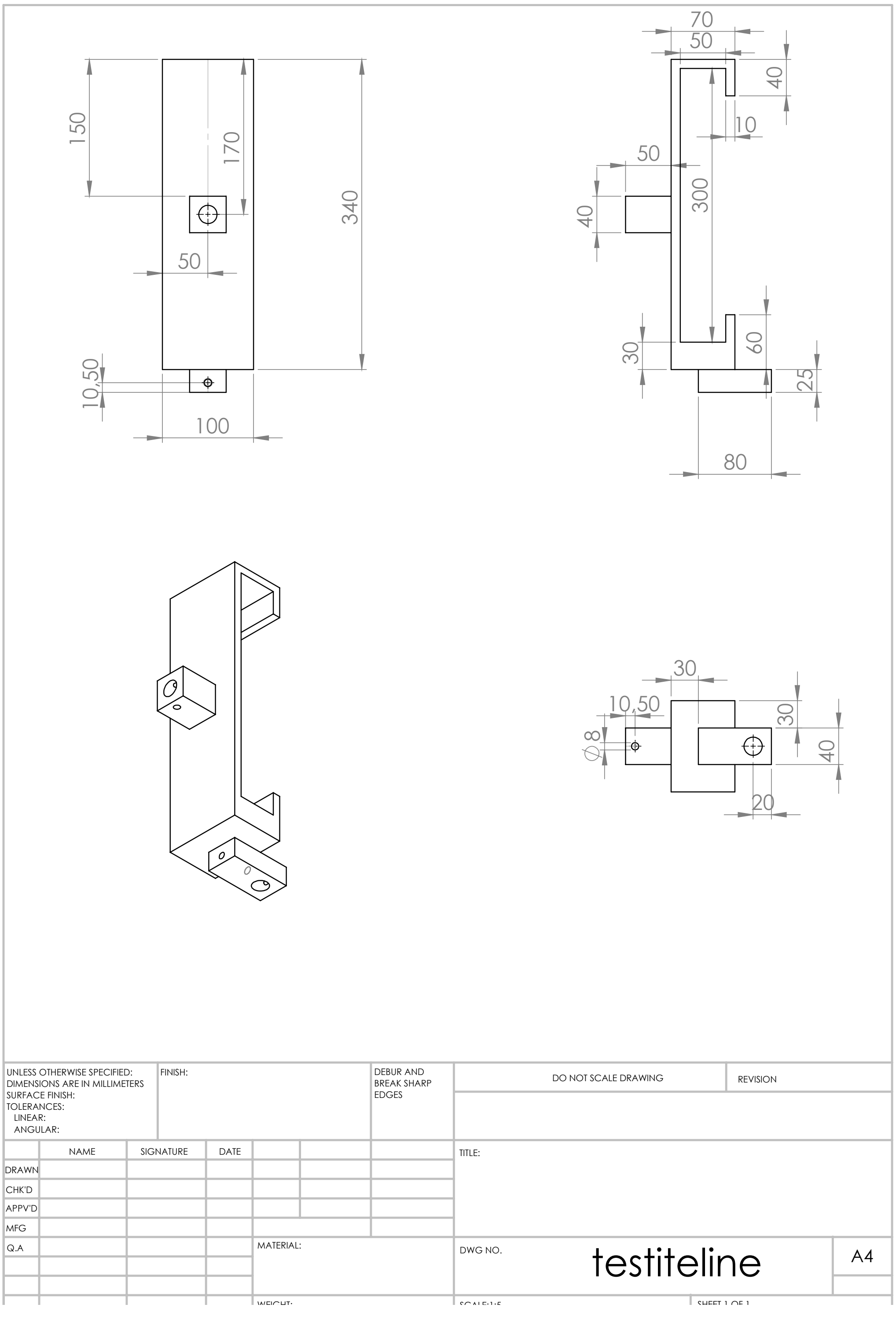

Figure 3-6Test rack design

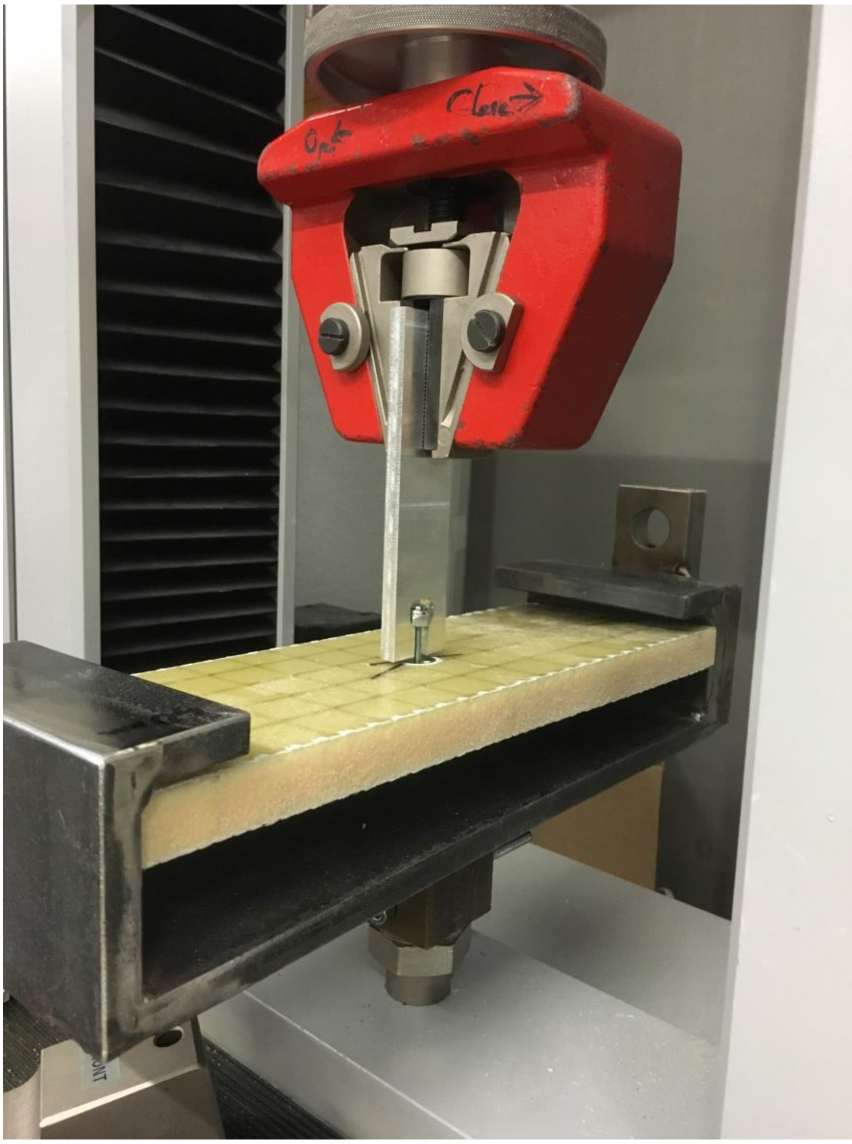

Figure 3-7 The pulling process

4 RESULTS

The results for the inserts differs from each other significantly. 6 mm bolts were used in insert number one and two, 3 mm in the third insert. The results wanted are high tolerances of stress in at least one of the inserts. It is preferable to receive results that have large varieties because it makes the outcome clearer. If the results turned up similar one would have to weigh the pros and cons to find the optimal solution. However, in this case the data from the tests and the incidents during the tests speaks for themselves. In one case there was no damage appearing to the lamina or the insert, only the test equipment. Surprisingly, those are the types of results that makes it easier to determine which insert is the best.

In total 54 test pieces were constructed. In all of the test pieces an insert was installed. To reach a reliable result and conclusion, six test pieces are tested per test type. One test piece per test is reserved for errors.

Repeatedly failed test pieces and their results are narrowed down to an average chart. The appendices shows all the tests performed.

The foam has grooves in it so that the resin will flow easily trough the whole sheet in the manufacturing process. Boomeranger Boats Oy have tested different combinations of materials at VTT Technical Research Centre of Finland Ltd and decided to use a specific combination for the deck.

Installation time for insert number one is two minutes while insert number two and three take 15 and 12 minutes respectively. The epoxy adhesive used in all the installation processes has a curing time of 12 hours.

4.1 Testing insert number one

Testometric
materials testing machines

winTest™ Analysis

Sample ref : test

Test Name : Thesis_Martin_nuutinen_20.4
Test Type : Tensile
Test Date : 20.4.2016 11:58
Test Speed : 10,000 mm/min
Pretension : Off
Sample Length : 100,000 mm

Test No	Force @ Peak (N)	Elong. @ Peak (mm)
1	1681,000	10,393
2	1535,300	9,969
3	1408,400	8,767
4	1812,000	11,146
5	1740,800	10,615
6	1714,500	10,577
Min	1408,400	8,767
Mean	1648,667	10,244
Max	1812,000	11,146
S.D.	149,081	0,817
C. of V.	9,043	7,980
L.C.L.	1492,215	9,387
U.C.L.	1805,119	11,102

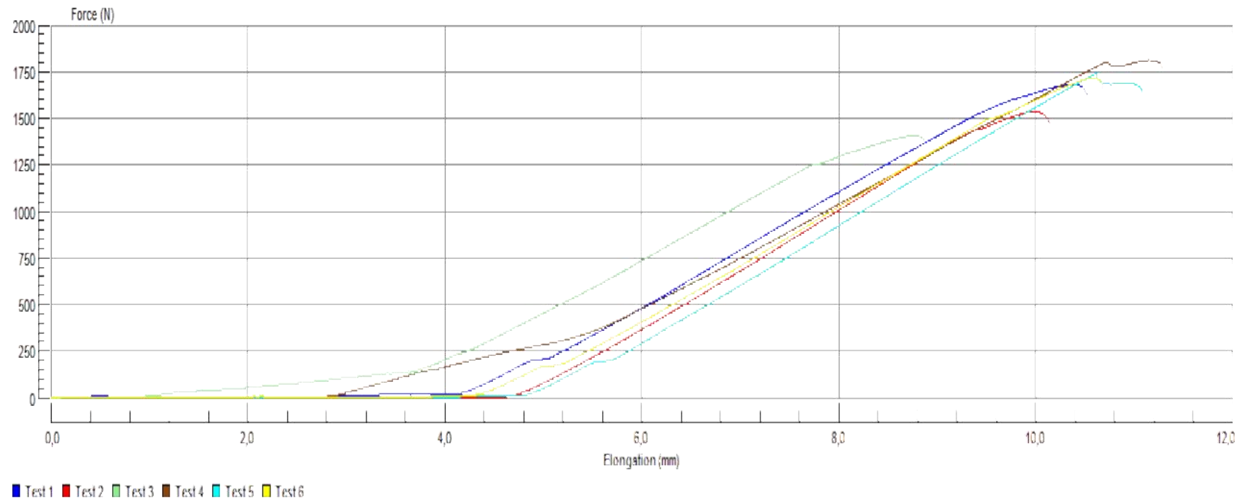

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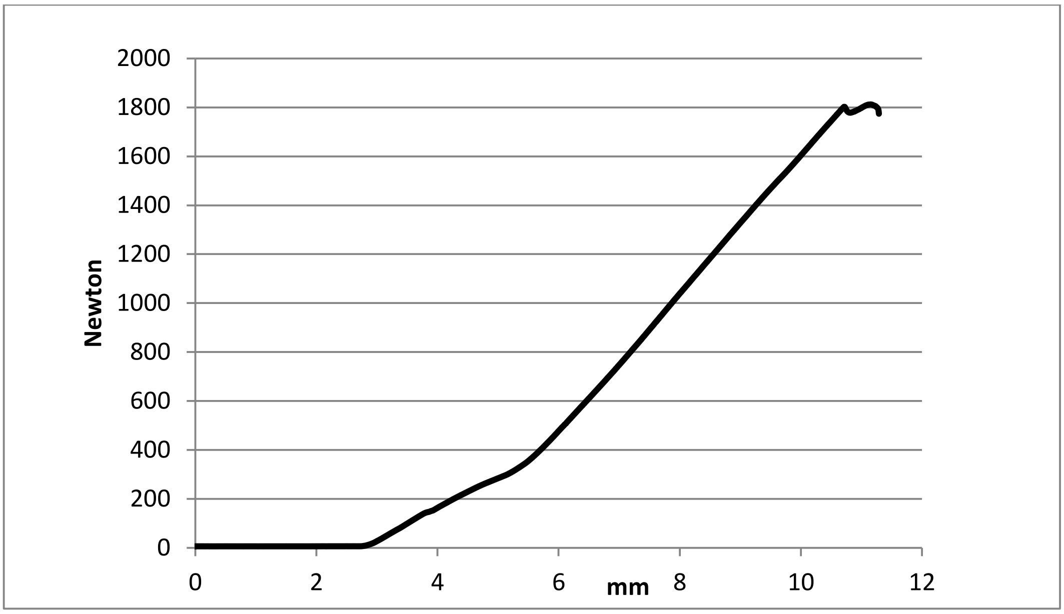
Figure 4-1 Pulling test, insert number one

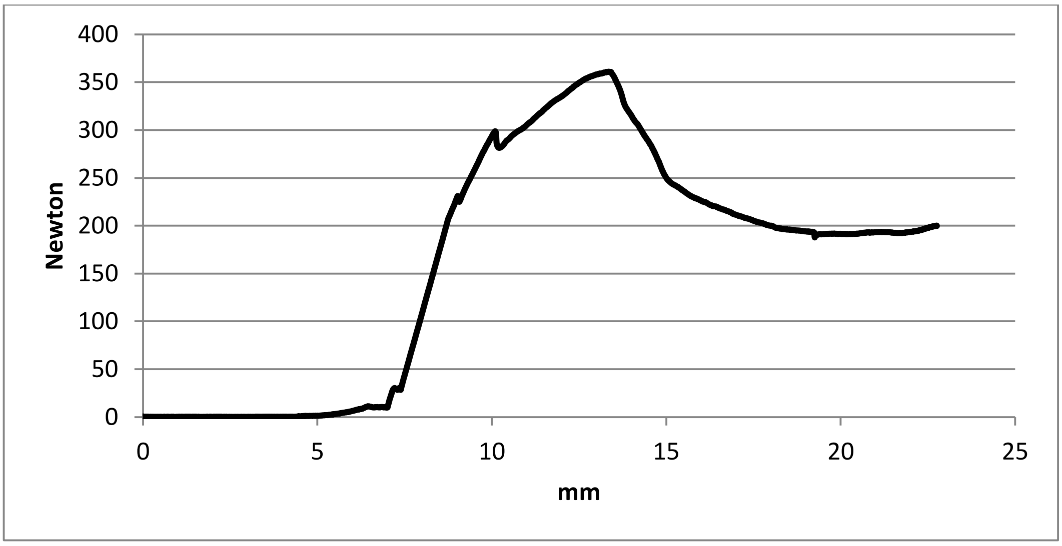
Chart 1 – Pulling test, insert number one (an average of six tests)



The raw data of one test piece is studied and formatted to a graph it is possible to see that the force peak is at 1812 N. At that point the lamina in the test piece delaminates from the core material and the machine stops the test. This is comparable with about 184 kg of pulling force. This force describes how much is required for the insert to delaminate.

The results of the second test provide a value for the stress in the perpendicular direction.

Chart 2 – Perpendicular test, insert number one (an average of six tests)



It is possible to see that the values for the vertical stress is low, 350 Newton is roughly converted into 35 kg, which is not nearly enough. The problem is that the insert is so small and the core material is soft that it doesn't compress the foam. The insert breaks it instead. The insert is very fast to install but it can't be used because of its low resistance.

If a soldier for example, who ways 80 kg and has 50 kg of gear, falls on the bench when the boat is in full speed or making quick turns it has to last more than 35 kg per insert.

In the torque test the insert failed completely. It is possible to wrench the bolt until it breaks the laminate on the bottom. This has to be prohibited in some way so that this kind of mistakes will not happen on the deck.

Figure 4-2 Delamination on the bottom

Figure 4-3 Torque test failure

Testometric materials testing machines

winTest™ Analysis

Test Name : Thesis2 martin nuutinen 20..4
Test Type : 3 Point Flexural
Test Date : 20.4.2016 13:11
Test Speed : 10,000 mm/min
Preload : Off
Width : 10,000 mm
Thickness : 1,000 mm
Span : 100,000 mm

Test No	Force @ Peak (N)	Strain @ Break (%)
1	361,040	1,365
2	115,380	1,251
3	110,910	1,698
4	251,320	0,905
5	192,390	1,491
Min	110,910	0,905
Mean	206,208	1,342
Max	361,040	1,698
S.D.	104,320	0,295
C. of V.	50,590	22,006
L.C.L.	76,680	0,975
U.C.L.	335,736	1,709

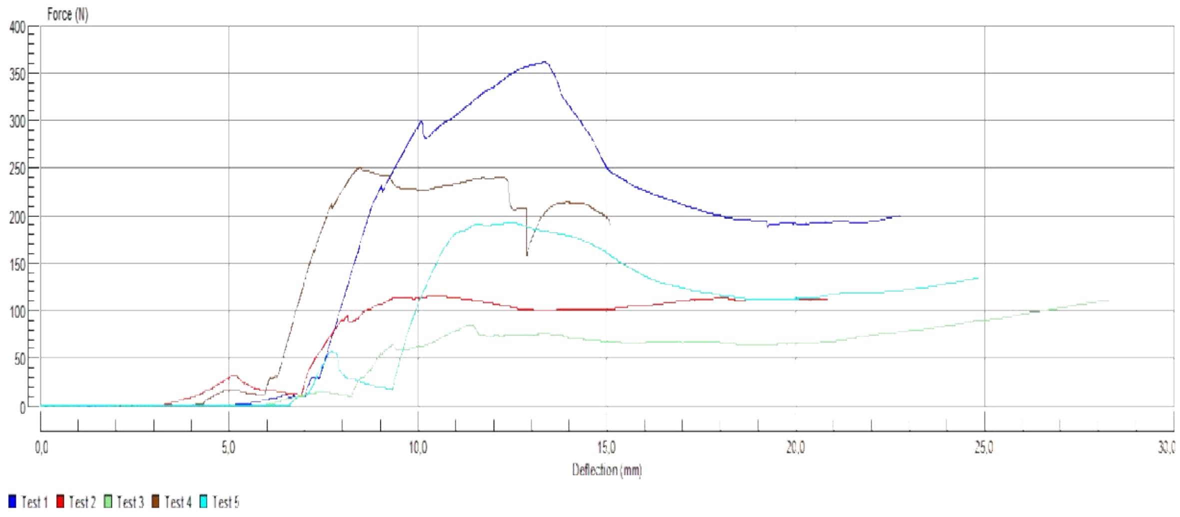


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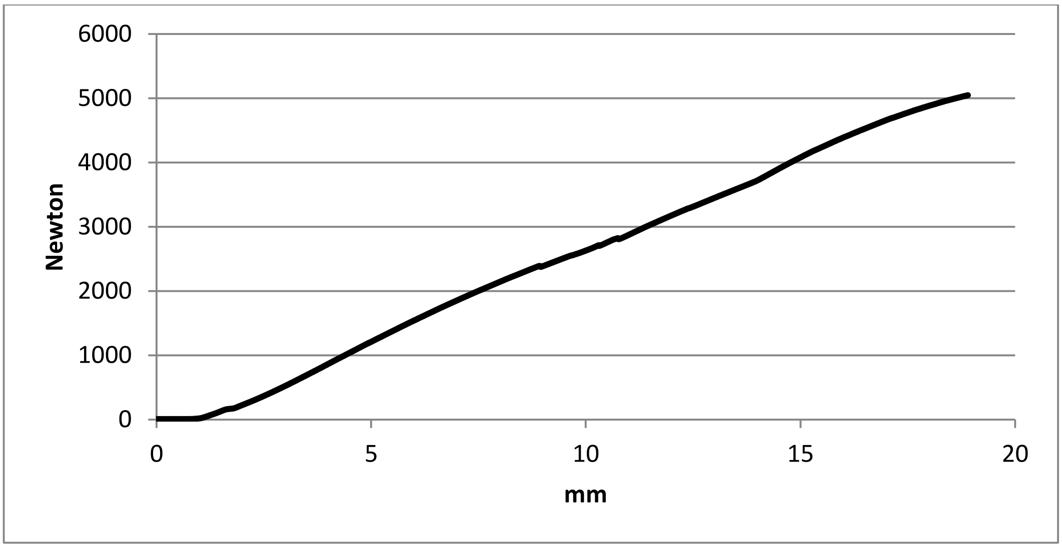
Figure 4-4 Perpendicular test, insert number one

4.2 Testing insert number two

Chart 3- pulling test, insert number two (an average of six tests)



The force peaks at 5000 Newton, which can roughly be converted to 500 kg. The test machine stops when the test piece delaminates from the core material. This result is very impressive and unexpected. The insert in itself is not damaged in any way, the sandwich structure is however destroyed. This result assures that the insert will keep the deck utilities attached to the deck in a horizontal direction.

Testometric
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winTest™
Analysis

Sample ref : test

Test Name : Thesis_Martin_nuutinen_20.4
Test Type : Tensile
Test Date : 20.4.2016 11:33
Test Speed : 10,000 mm/min
Pretension : Off
Sample Length : 100,000 mm

Test No	Force @ Peak (N)	Elong. @ Peak (mm)
1	4361,500	17,101
2	4494,700	16,517
3	4742,700	16,781
4	4779,600	17,757
5	4674,000	17,050
6	5049,700	18,901
Min	4361,500	16,517
Mean	4683,700	17,351
Max	5049,700	18,901
S.D.	239,275	0,865
C. of V.	5,109	4,985
L.C.L.	4432,595	16,443
U.C.L.	4934,805	18,259

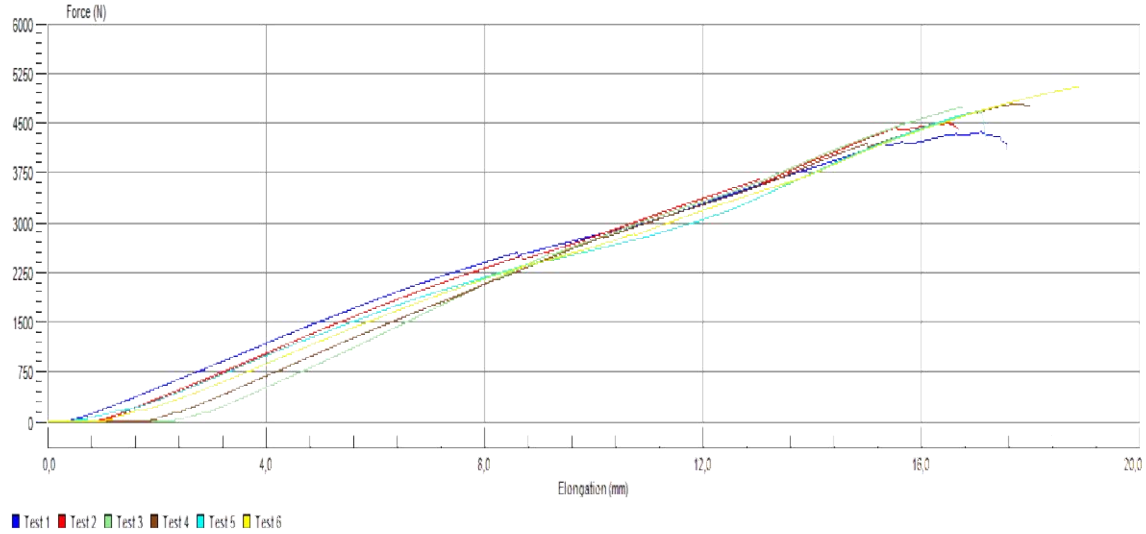

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Figure 4-5 Pulling test, insert number two

The results of the perpendicular stress test is interesting and surprising. One would think that the top layer of glass fiber would break or that the core material would break. However that is not the case. In this test the bolt, that simulates the deck utility, fails. It bends the insert and the lamina has no marks of cracks or failure. All the bolts used in the test can be bought from regular hardware stores. Therefore, the conclusion is that the insert and the materials are very resistant and the bolts the weakest link.

Chart 4 – Perpendicular test, insert number two (an average of six tests)

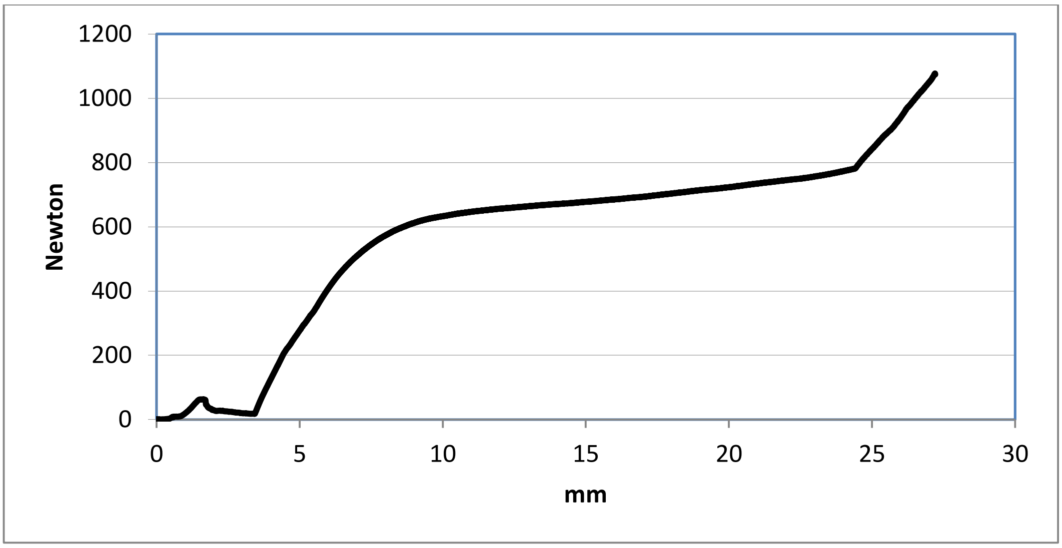
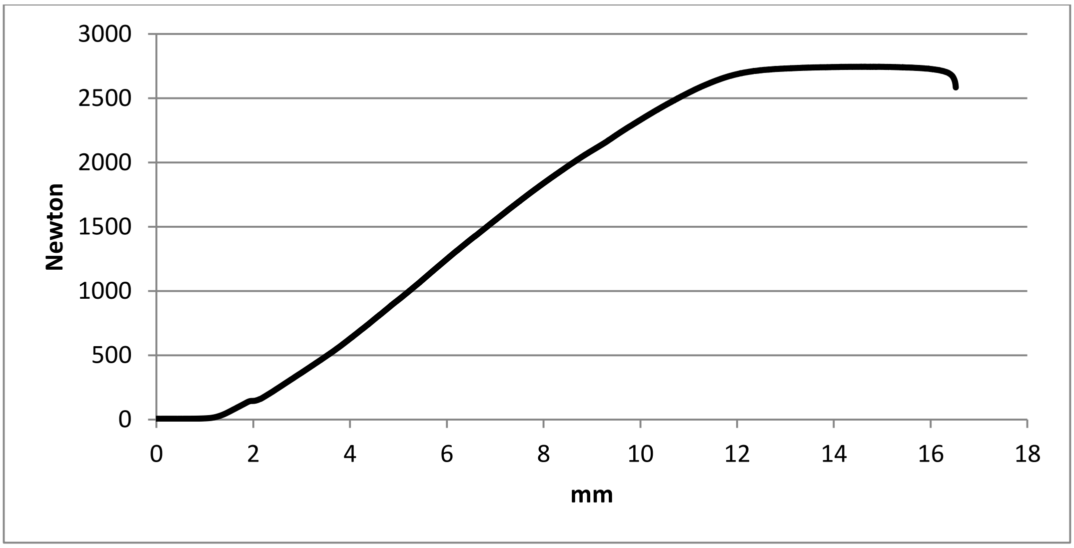


Figure 4-6 Torque test failure

In the torque test the insert was magnificent. However, the bolt wasn't. It can be seen in *Figure 4-6* that the bolt has snapped. The torque wrench was limited to 60 nm. No damage could be found on the other side of the test piece.

The problem with the third insert is that in the tests 3 mm bolts have to be used. It is a problem because it is not strong enough. However the pulling tests has been performed and every time the bolt snaps of or the teeth's of the bolts breaks.

Chart 5 – Pulling test, insert number three (an average of six tests)



4.3 Testing insert number three

The bending test couldn't be performed on the small insert because of the small diameter of the bolt. A conclusion was made that if a 6 mm bolt bends, a 3 mm will also bend. Same assumptions were made for the torque test, also the bolts are actually screws so it is hard to find a suitable tool.

To reach higher resistance in the pulling direction in all the inserts one could try to add layers of glass fiber to the bottom of the construction. This makes the construction stiffer and more tolerant to strain. The failure of the bolts is an abnormal result. An unexpected fact was that metal breaks before polyurethane foam and glass fiber. It could be possible to strengthen the structure in the perpendicular direction. However this would require new tests to reach a new durable combination of core material and fibers. The tests are relevant for the application to know if inserts could be used in manufacturing of the boats at all.

5 DISCUSSION

With such a big difference in the results it is rather easy to determine the most suitable solution for Boomeranger Boats Oy: Insert number two. Even though it is a bit more complicated to install it is worth the effort. With a drill and hand mill the cavity is easy to produce, the epoxy can be applied quickly and can be chosen based on curing time if the manufacturers are in a hurry. Once the epoxy has dried and the wished amount of inserts are installed the rails can easily be attached. If the deck utilities need to be moved it is easy to just cover the overlap insert with epoxy and finish the surface with sandpaper.

It is clear that the inserts have a high resistance and can handle a lot of stress and strain. The use of inserts would allow the company to move the deck utilities at any time of production.

Adding glass fiber layers on the bottom side of the construction can strengthen the deck. This will give a higher resistance in the pulling direction. One has to remember that the weight also increases. A harder core material could increase the strength in the perpendicular force. The Divinucell Foam is however a light weight, high performance foam and could be suitable for the deck.

These results are not compared to other similar researches because there are no results available. The combination of core materials and their fastening mechanisms are business secret in competitive companies.

The outcome is surprising as it does not match the expectations expressed in this thesis. The fact that the bolt broke and the core delaminated from the composite layers was not expected. The insert itself was in one piece and no signs of damages were visible. It was possible to fasten a new bolt to the insert after the tests were performed.

In reality insert number two would work well compared to the other inserts. Insert number two would assure a durable fastening mechanism for the rail. A rail could be fastened to ten inserts without the risk of damaging the foam or the laminate. The rails need to be attached with stronger bolts that are used in this test, bolts that cannot be bought from a basic hardware store. The problem is not in the insert, it is in the bolts which is a problem that easily can be solved. A 130 kg solider wouldn’t have to worry about breaking the boat while in action, which is a very important factor, if the bolts are strong enough.

During the test process the custom made rack worked well, it suits the test machine even though small adjustments have been made (drilling straight holes for example). The software for the machine worked without problems. During the installation of the inserts some problems appeared. The resin has a longer curing time than expected. Instead of one-hour gel time it took over 4 hours for it to harden. Otherwise all the tests were executed as planned except insert number three. The insert is precluded as an option.

In the future the exact same types of bolts could be used in the tests as in the fastening of the deck utilities. Also if the company decides to use inserts and then fasten the rails to them, it would be recommendable to test how much the rail can tolerate stress and strain. Also some type of adhesive could be added between the rails and the laminate. This would allow higher resistance to forces from different angles.

6 CONCLUSION

This research has successfully proven that it is possible to fasten rails to the deck of a RIB-boat with inserts. The construction presented and tested in this thesis provides one possibility for such a solution. The tests conducted simulate forces in real-world scenarios. The result is that the manufacturers can fasten the rails to the deck with inserts at any time of production.

The conclusion is that if the insert has a cavity with a larger area the compression of the core material, in this case polyurethane foam, it is more tolerant to stresses than smaller inserts. Boomeranger Boats Oy should use insert number two of the three options. Insert number two is by far the most stress tolerant option. The tolerance is highest to all exposed directions of force. The procedure for installing the insert requires more time but the construction can stand a force of 5000 Newton. Insert number one and three on the other hand are not considerable options as their constructions have not proven to last the tests.

In order to measure the robustness of the inserts that are faster to install the constructions of insert one and three need to be revised. As a result of weak components the construction failed therefore, stronger bolts have to be used. The bolts turned out to be a critical weak point in the construction. This fact made it impossible to determine the exact tolerance of the theoretical construction. In order for the tolerance to be measured exactly specialized bolts needs to be used.

REFERENCES

Davis, J.R. 2004, ***Tensile Testing***, 2nd edn, ASM International.

ECSS Secretariat 2011, "Space engineering Insert design handbook", , pp. 73-110.

Hollaway, Leonard (Editor), 1994, Handbook of Polymer Composites for Engineers, Woodhead Publishing, Cambridge, England.

Hon David, S.N. 2011, "Wood and cellulose chemistry, 2nd ed. **Jum** " in , ed. New York: Dekker Marcel, pp. 5.

Kaw, Autar K., 1997, Mechanics of Composites Materials, CRC Press, New York, NY.

Miller, Tara, 1998, Introduction to Composites, 4th Edition, Composites Institute,

Society of the Plastics Industry, New York, NY.

Pais & Harvey (Eds) 2012, *Four Point Bending,* Taylor & Francis Group.

Pearson Prentice Hall Bioengineering 2008, "Chapter 4 Mechanical Properties of Biomaterials". Biomaterials -The intersection of Biology and Material Science" in , pp. 152.

Rosato, Dominick V., 1997, Designing with Reinforced Plastics, Hanser/Gardner, Cincinnati, Ohio.

Electronic Sources

http://boomeranger.fi/company

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