Product development of A-frame

Ville Mikael Törnebladh

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Författare:	Ville Törnebladh
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Handledare (Arcada):	Rene Hermann
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Agility är en hundsport där målet är att genomföra en bana med hinder. Hunden skall tillsammand med föraren springa banan så fort som möjligt. Av hindrena är A-hindret det största hindret som simulerar ett uppförskliv. Det är ett hinder som i många fall är stort och klumpigt. Målet är att utveckla ett A-hinder, genom att göra produkten mera flexibel främst genom viktminskning men också priset spelar en stor roll. På marknaden existerar olika slag av hinder av olika material, design och storlek. Det kan dock vara svårt att finna hinder som är både billiga och praktiska. Produkter som har endera eller den andra kan finnas men inte både och. Strukturen bör tåla relativt stora krafter tack vare de stötkrafter som uppstår. För att analysera och få ett realistiskt värde på stötkraften har en fallande kropp beaktats. Rekordet för en högthoppande hund är 1.72 m, hunden har också landat från denna höjd. Om det antas att inbromsningen är ~20 cm, detta innebär att stötkraften skulle vara 3796 N. Tillsammans med en säkerhetsfaktor på 3 skulle detta innebära att strukturen kan tillfälligt bära vikten av en liten personbil. Fiberförstärkta plaster verkar som en nish på marknaden. De har goda mekaniska egenskaper i förhållande med låg vikt. Fortsatt undersökning visar att materialet är billigt och hållbart. A-hindret består av två större klättringsytor. Tack vare relativt låga materialkostnader förblir utgifterna låga. Produktion av stavsegment som har formen av ihåliga kvadrater kommer att integreras till en yta, med sådan design kommer strukturen att ha goda mekaniska egenskaper i förhållande till vikt. Prodktionen av dessa kvadratiska stavsegment genom laminering kan vara krävande och kommer att göras i flera steg. Först lamineras halva kvadrater och integreras sedan till hela kvadrater. Produktionen behöver inte vara effektiv på grund av den begränsade marknaden för denna produkt. Små kvantiteter producerade med låga kostnader kan föra in god vinst.

Nyckelord:	Agility, hund, A-hinder, produkt utveckling, fiberförstärkta plaster, komposit, glasfiber, hinder.
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Commissioned by:	

Abstract:

Agility is a competitive dog sport where the dog is to complete a course of obstacles. Together with his handler the course is to be completed as fast as possible. Of the obstacles the largest is the A-frame which simulates a climbing scenario. It is a rather large obstacle that in many cases is heavy and uncomfortable to move around. There is a vast selection on different product on the market, different materials, shapes and sizes. However finding a product that is both cheap and practical seems hard. The goal is to do a product development of an A-frame by making it more flexible, mainly by weight reduction but also cost is an important factor. The structure will need to withstand a significant load due to impact forces, created by a dog weighing 45 kg. To analyze the force a falling scenario has been considered to get a reasonable value that also the dog can withstand. The record for a high jumping dog is 1.72 m meaning it also has to land from this height. Assuming deflection is ~20 cm, this will create a force of 3796 N. With a safety factor of 3 this means that the structure could temporary carry the weight of a small car. Fiber reinforced plastics seems like a niche on the market. They possess good mechanical properties in correlation to weight. Further investigation shows that this low cost material can be used to produce a product that would be both cheap and strong. The A-frame comprises of two larger sheets that work as climbing walls. By manufacturing beam segments of a box shape and integrating them into a sheet, outstanding mechanical properties to weight can be achieved. Creating an actual box beam by laminating can be challenging, the process would need to be divided into steps. First laminating half boxes that would then be integrated into complete boxes in a second step. The market for an A-frame is rather small and there for manufacturing would not need to be efficient. A small quantity of products to a reasonable production cost, turning good profit with low sales quantities.

Keywords:	Agility, dog, A-frame, product development, fiber reinforced plastic, composite, fiberglass, obstacle.
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1 INTRODUCTION

What is dog agility? Dog agility is a dog sport that you can compete in as high as on an international level. The main idea of agility is to lead the dog through a course of different obstacles that the dog needs to complete in a specific order, in the right way and as fast as possible. There are three different main groups of obstacles; jumps, contact and others (see table 1). In this thesis the A-frame is going to be the subject for of research. It is the largest of the obstacles and the study will give us sufficient data that can be applied for the other contact obstacles.

Table 1: Different agility obstacles [1].

Jumping obstacles	Contact obstacles	Other obstacles
Bar jump (1-3 jumps)	A-frame	Open tunnel
Broad (long) jump	Dog walk	Closed tunnel (chute)
Tire jump	See-Saw	Pause table
Wall jump		Weave poles
Spread jump		

The basic idea of this thesis is to do a product development research, there are two different way to do this, first developing a completely new product and second taking an already existing product and improving it. In this case the idea is to try to improve an existing product by using new materials and improving design.

1.1 The A-frame

A-frames can be categorized into two standards depending on what they will be used for. The first and most demanding ones are for competition use. Second is the ones used by trainers demanding flexibility in order to train dogs with different skill sets. The so called training category is quite broad and ranges from small obstacles to full sized ones that differ in some way from the actual standards.

Common materials today are aluminum, plywood, wood, steel and even in some cases plastics. Products are made in singularly one material or then combinations of two or more, for example; an aluminum frame with plywood sheets as surface material.

1.1.1 Official measures

There are three different categories in competitions. They are defined by the size of the dog and equipment is adjusted accordingly. The A-frame consists of two parts that when erected form the shape of an A, the frame needs to be adjustable in such a manner that the angel and height can be altered. At full height with the 90 degree angle the A-frames stand 190 cm high. The width needs to be within the limits of 90-115 cm. Also there needs to be profiles on the surfaces of the A-frame to help the climbing, they are placed approximately 25 cm from each other along the whole surface. The profiles are to be 20 mm vide and 5-10 mm high, there should not be any sharp corners on them. The contact surface should be painted 106 cm from the lower corners in such a way that the contact and the frame are different colors (see figure 1) [2].

The A-frame is a product that, because of the way it is constructed, usually consists of at least two large sheets of walking surface that when erected stand in the form of an A. The sheets width is 90-115 cm and the length is 270 cm. When bought from retailer the prices range from 500-2000 € depending on what kind of material and design is used (see appendices 6.1).

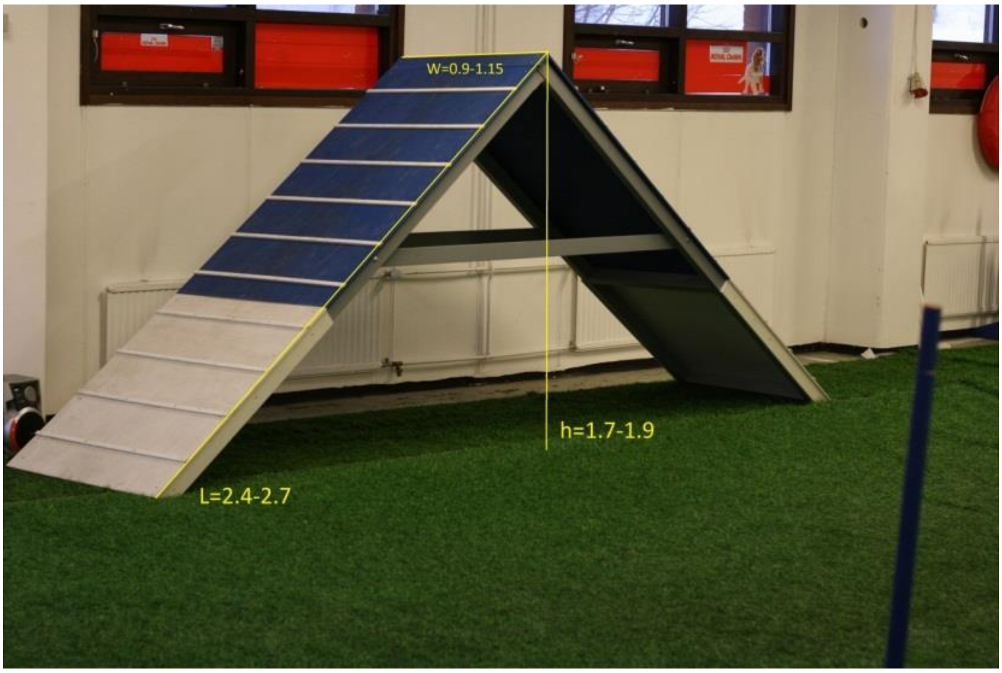

Figure 1: A- frame with measurements.

1.1.2 How to use

When climbing the A-frame the dog needs to touch the contact area at least with one paw, both when going up and coming down the frame (the area can be seen in picture 1 painted in white). The contact surfaces main objective is to assure that the dog does not jump off and on the obstacle to early, preventing injuries. Speed and agility are advantages.

1.2 Issue/hypothesis

The product to be developed is meant for the training of dogs in the sport of agility. Training locations change and to be able to offer services on a larger scale. It would be optimal to transport the equipment from one location to another. This is something that is restricted in some scale because of the size and weight of the parts that the obstacle comprises of.

Another thing that has to be taken into consideration, because dogs are the ones using the equipment, is the surfacing. Several of the materials mentioned and used need to be applied with a non-slip surface to improve the grip. The same will be taken into account in this project.

Assumptions at this stage are that by using a polymer composite layered as a sandwich, together with my own design. I could reach the goal of making the product more flexible, lighter, cheaper and thus easier to transport.

1.3 Agility population

According to an article by Helsingin sanomat [3], there was 10 000 persons in Finland that were active with dog agility in 2012 and it was assumed that the number is increasing. The article also states that there is a considerable demand for trainers and facilities around all of Finland.

2 A-FRAMES ON THE MARKET

There are numerous different options considering product on the market today either of one material or combinations of several materials. In this chapter the scale of the market and the existing products on the market are going to be looked at.

2.1 Hypothetical market and demand for A-frame in Finland

There are around 10 000 persons that are more or less active with the sport of agility in Finland [3]. As our study of companies that produce A-frames, with certainty there are 6 companies in Finland, but the number used for calculation will be assumed somewhat higher. Assuming 10 companies produce and sell products on a constant basis in Finland. This assumption is based on the fact that some companies might not be found with the help of the internet also some foreign companies compete for the market. When dividing 10 000 with the 10 companies this means that each company produces on average frames for 1000 users. This would be a great number if each one of these 1000 persons would own an A-frame however this is not the case. People who do agility usually go to an inside arena or an outside field where all the equipment are available paying an amount of money for the use. This means that the market shrunk and a new assumption must be made. A reasonable estimate for the best case scenario would be 10 person use one frame and worst case 45 persons. These numbers are hypothetical numbers that in some cases are correct; the idea is to have a somewhat reasonable average numbers.

Also to consider is that A-frames have a life span which needs to be calculated in to the long-term sales. Depending on the material, conditions, how much moved and used. 2 years of minimum use and maximum of 30 years usage for on frame, is a good estimation. In the best case a 100 units per year would be produced. In the worst case the yearly demand would be 0.666667 units, which would mean that one frame, would be sold each 1.5 years.

10 000/10=1000 => 1000/5=200 => 200/2=100 best case
10 000/10=1000 => 1000/50=20 => 20/30=0.666667 worst case

This is a hypothetical calculation for the market and demand of the product both for a best case and a worst case scenario. In reality the number for how many units sold would be found somewhere in between these values. Ultimately depending on how good the product would be [4].

2.2 Wooden frame

Anyone with decent carpentry skills can with the help of right dimensions, go buy the material and with some tools assemble some kind of A-frame. Most of the wooden constructions compose of plywood sheet as the surface material and a frame constructed of wooden beams, for example two by four. Wooden frames are the cheapest ones to come by, not only if you have the possibility to build one but also on the market (see appendices 6.1).

2.3 Metals in an A-frame

The great property with metals is that they are easily and constantly recycled. Recycling has become a major issue today, consumers are aware of the effects on the environment. Thus giving metals an advantage they have a long life span if maintained, also they are easy to recycle.

Metals do in some grade deteriorate with time due to oxidation this chemical deterioration that is easy to prevent by surface treatment. Due to this the only real destructive force is structural collapse. Metals are affected by use and constant loads in such a way that eventually the metals become so to say tiered. This means that due to load, the structure will slowly lose its rigidity and shape. A good example is the spring, a spring that has been under load for a long period of time, either negative or positive, will eventually lose its original parameters and become longer or shorter. Not only shape and size is a factor when this happens but also structural integrity. With more rigid designs and structures cracking is the effect of the structure failing.

Aluminum is the favored material on the market today; it can be used to produce light weight structures that are easy to assemble and alter. There are numerous product on the market today not only purely aluminum but structures used in combination with other materials, like plywood. Aluminum is expensive and so are the frames, well designed products are of low weight (see appendices 6.1).

2.4 Plastic A-frame

A-frames produced of a polymer material is not that common but there are some manufacturers that have taken on the challenge of plastics. Doggy Jumps® are producing an A-frame of a polymer material however they do not announce what material [5]. Other scenarios where you can find polymer materials are in combinations of more than one material. An example is the company, Action K9 sports that produce an A-frame with a steel frame and glass fiber surfacing [6].

In general A-frames produced in polymer are scares it is hard to say an exact reason. A good estimate would be the fact that this is a product that is not sold in such a large scale and cost in proportion to mechanical property is not great. Products are made on the basis of demand and the demand for A-frames is hard to estimate, thus many company produce frames based on customer orders. This fact gives the polymer a clear disadvantage because polymer materials are a good option for mass production. Not for small markets, machines for polymer production are expensive thus demanding a larger production scale.

3 DESIGN

An A-frame consists of two sheets that are combined at the top forming the shape of an A. Each sheet will have the dimensions of 2.7 m long and 0.9 m wide, if needed we can widen the bottom of the sheet to 1.15 m for increased stability. The design and calculations will be concentrated on a uniform width [2].

The sheets will be of equal size and are going to be connected to each other at the top. Beyond this some kind of rod or beam will be produced to connect the sheets on the middle making sure the structure stays erected (see figure 2).

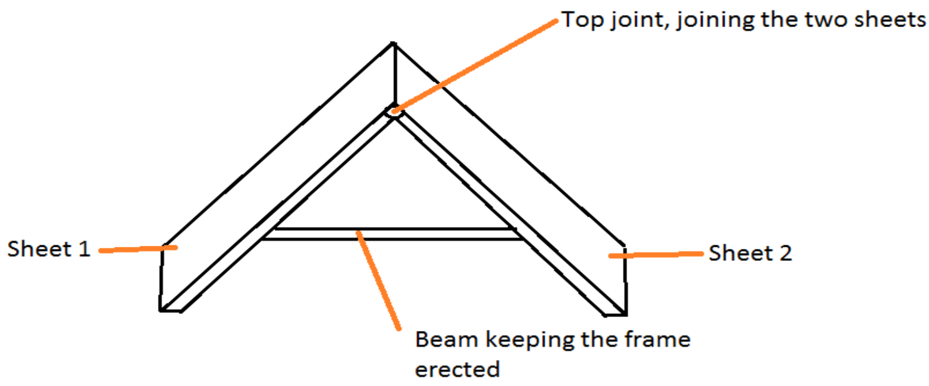

Figure 2: Parts of an A-frame.

3.1 Material properties

In this chapter calculation are going to be made for the product so that parameters can be determined. To begin with forces acting on the structure must be determined. To give a clear picture a couple of alternatives will be calculated so that comparison of different materials can be made. The materials will be aluminum, wood, steel, glass fiber and sandwich (glass fiber + core). Also the option of using more than one material for our structure needs to be considered in such a manner that optimal properties can be achieved.

3.1.1 Fiber reinforced plastic (FRP)

Fiber reinforced materials are more complex to calculate compared to solids thus it is harder to estimate how they will behave in different situations. If considering a solid, for example steel, tensile and strength modules are constant in all directions. Fiber constructions however these constants vary depending on the direction of the fibers. The strengths in composites are always strongest along the fibers and week where there is only resin as binder. However with careful consideration you can use this as an advantage by designing the product in the right way. Using fiber directions optimally a reduction in weight can be made and still have a strong enough construction.

Assuming that the weight percentage of resin is 30 and fibers 70, first this needs to be re-calculated into volume fractions. Then young´s modulus (E) needs to be consider for different coordinates and directions. Because strength is most relevant along the plane of the sheet, properties will be good along the length and width of the sheet.

Volume fraction

Wf = weight fraction of fiberglass = 0.7

Wr = weight fraction of resin = 0.3

ϱf= density of fiberglass = 2.54 g/cm3

ϱr = density of resin = 1.1 g/cm3

n = krenchel factor = 0.5

(1) Vf = volume fraction of fiberglass = (Wf/ϱf)/(Wf/ϱf+Wr/ϱr) = 0.5026 [7].

Young´s modulus (E)

(2) E = n * Ef * Vf + (1-Vf) * Er ⇔ E = 19.78 GPa [7].

n = 0.5

Ef= young´s modulus for fiberglass = 72 GPa

Vf = 0.5026 = 50.26 %

Er = young´s modulus for resin (polyester) = 3.4 GPa

This value is achieved using E-glass and the resin to fiber ratio is 70% fiber by weight fraction. The fiber considered is with a plain (0°,90°) alignment and young´s modulus is measured along the fiber (see values in tables 2-4).

Young´s modulus (45°)

$1/E = 0.25 / 19.78 + 0.25 / 19.78 + (1 / 2.55 - 0.56 / 19.78) \times 0.25$

E (45°) = 8.60 GPa

Poisson´s ratio (v)

(3) v = vf * Vf + vr (1 – Vf) [7].

vf = poisson´s ratio of fiberglass, vr = poisson´s ratio of resin

One source states that poisons ratio for fiber 0.22 respectively 0.34 for polyester [8]. Now with this formula it would give us that poisson´s ratio for our composite would be 0.28.

Shear modulus (G)

(4) 1/G = Vf / Gf + (1-Vf)/Gr [7].

Gf = shear modulus of fiber glass, Gr = shear modulus of resin

The shear modulus for the fiber and resin is calculated using a formula that uses young´s modulus as a guide line for calculating the modulus.

(5) $G = E / (2(1+\nu))$ [7].

Thus giving that the shear modulus for our composite is 2.55 GPa.

Strain (ε)

The strain for a composite structure needs to be considered on the basis of material strains for glass fiber and resin. The strain needs to be considered based on the material with a lower strain value, because it is going to be the one failing first. Strain determines how much a material will deflect and is given with a percent value. For E-glass the strain is 4.7 % and for polyester 3.3 %, thus polyester needs to be used in the calculations (see tables 3-4). The strain for polyester is 3.3 % when the material fails thus a safety factor needs to be considered. For the structure a safety factor of 3 has been used to assure structural integrity. In other words the allowable stain will be 1.1 %.

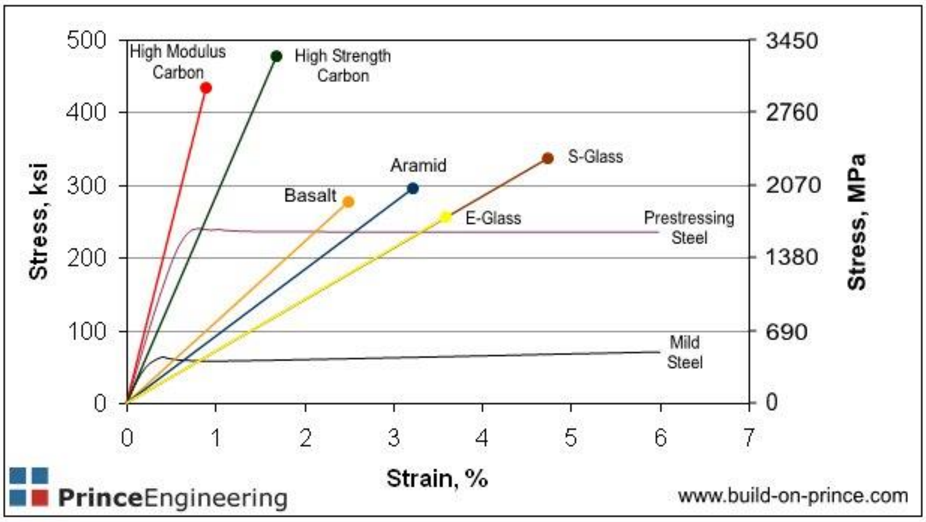

Figure 3: stress-strain comparison FRP (FRP Reinforcements for Structure, Price Engineering Building on Prince, Inclusive Engineering, Accessed 4.9.2013. Published 2011.) [11].

Figure 3 shows a stress-strain diagram of different composites in comparison with a few common steels. Here can be seen a big difference in properties between composites and steel. Steel is a ductile material thus having a yield point where the material starts to deform until it finally breaks. Composites are stiff materials that reach their tensile maximum and break.

Shear strength

Shear strength can be calculated with the help of the shear modulus (G) and shear strain (γ), according to hooks law.

(6) $\tau = G*\gamma$ [9].

The shear strain is calculated on the basis of strain, yielding $\gamma = 2\varepsilon$ (ε= allowable strain). Resulting in an allowable shear strength = 56.1 MPa [10].

Allowable tensile strength of fiber glass composite

According to hook´s law; using young´s modulus for the laminate and the allowable strain.

(7) $\sigma = E\epsilon$ ⇔ σ= 19.78 GPa * 0,011 ⇔ σ = 218.57 MPa

The tensile strength is measured along the fibers (0°,90°) (see table 2-4).

3.1.2 Properties of glass fiber and resin

Fiber reinforced plastics or composites compose of two different materials, cooperating together giving wanted properties. Fibers work as the bases for the mechanical properties, enhancing them. While the matrix or resin works as binding factor adhering the mix. The fibers on their own have good mechanical properties but without the matrix they bear resemblance to a carpet being flexible. The matrixes most commonly used are thermosets; liquid in its unprocessed form but whit a hardener takes a solid form. Together the materials form a solid and hard material that has a vast area of uses.

Table 2: Prices of glass fiber and resin [12].

Fiber mat/Resin	Mass/Area (g/m2)	Amount	Price (€)
Shopped strand	300	35 kg (116 m2)	151,19
Roving (0,90)	800	50 kg (62 m2)	221,79
Combi (mat)	600 + 300	80 kg	423,41
Polyester (hand)	-	10 kg	58,47
Polyester (hand)	-	1 kg	9,07
Polyester (infu-sion)	-	1 kg	20,87
Hardener	-	1 kg	21,00
Gelcoat (white)	-	3 kg	37,30

There are different types of fiber mat the two most common ones are shopped strand and roving (0,90). Also considering resins there are alternatives but polyester will be the resin choice due to its low cost. Looking at the price of polyester it obvious that infusion resin is more expensive, it is a specialized resin that is lower in viscosity it flows better meeting the demands for infusion (see table 2).

Table 3: Mechanical properties of different glass fibers (FRP Reinforcements for Structure, Price Engineering Building on Prince, Inclusive Engineering, Glass Fiber Types, Accessed 4.9.2013. Published 2011.) [11].

Fiber type	Density (g/cm3)	Tensile strength, MPa	Young´s Modulus, GPa	Elongation (%)
A-glass	2.44	3300	72	4.8
AR-glass	2.7	1700	72	2.3
C-glass	2.56	3300	69	4.8
D-glass	2.11	2500	55	4.5
E-glass	2.54	3400	72	4.7
ECR-glass	2.72	3400	80	4.3
R-glass	2.52	4400	86	5.1
S-glass	2.53	4600	89	5.2

Table 4: Mechanical properties of polymer resins [13].

Resin type	Density (g/cm3)	Tensile strength, MPa	Shear strength, MPA	Young´s Modulus, GPa	Elongation (%)
Polyester (Or-thopthalic)	1.1-1.2	55	80	3.45	2.1
Polyester (Isophthalic)	1.1-1.2	75	130	3.38	3.3
Epoxy	1.15	85	120	10.5	0.8
Vinylester	1.1-1.2	80	140	3.59	4.0

3.1.3 Aluminum

For the purpose of comparison an aluminum alloy 6061-T6 will be used, it is one of the more common and widely used alloys. The number 6061 represents the mixture of the alloy, 6061contains magnesium and silicon as major elements. With different mixtures of alloys there is a goal to achieve different properties within the alloy, depending on use. T6 stands for a specific tempering grade (solution heat-treated and artificially aged). The 6061-T6 alloy is known for its good strength but also for being easy to work with, or being good for welding (see appendices 6.2).

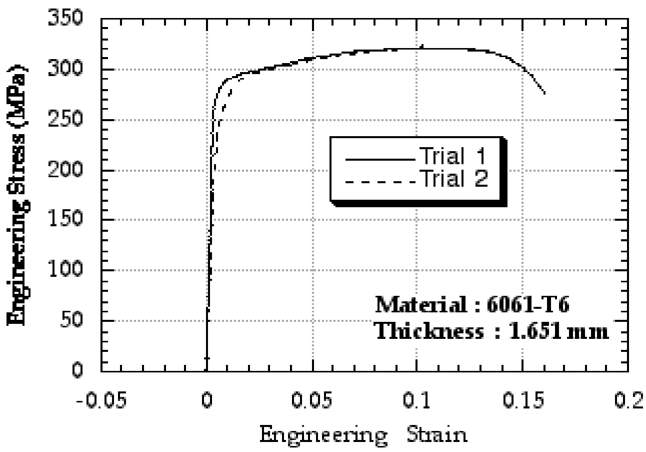

Figure 4: Stress-strain diagram of aluminum 6061-T6 (The Ohio State University, Ring compression studies, Chapter 4, Accessed 3.9.2013) [14].

A stress-strain diagram of aluminum 6061-T6 can help understand material properties. The curve starts off going almost straight up, stress increases without significant elongation (see figure 4). The alloy reaches its yield point and the curve takes a change in direction, now increasing in length until reaching its maximum tensile strength. The curve takes a dive and eventually the material breaks. Yield point is at about 276 MPa and maximum tensile strength about 310-325 MPa. The density of the aluminum alloy is 2700 kg/m³ (see appendices 2). The price of aluminum today is 2 038 dollar per metric ton and this is the price for unprocessed material [15].

3.1.4 Steel

Steel is a term used for an alloy that is based on iron and carbon. However due to the vast usage of steel many different mixtures are available. Carbon is the main definer of the hardness and mechanical properties within the steel. Also other additives determine the quality and properties of the steel (see table 5). Steel is produced as an alloy and forged, for example; into billets, then further processed into a finished product.

Steel needs to be coated to prevent deteriorations caused by oxidation. Examples of coating are painting, galvanizing or a special process of coating creating stainless steel. This is something that would be demanded from a product used outside, where oxidation is more aggressive.

For this product steel could be a good option for joints, screws or inserts.

Table 5: Properties of different steel alloys (see appendices 6.3)

Metal	Cost (US$)	Density Mg/m3	Young´s Modulus (GPa)	Yield strength (MPa)	Tensile strength (MPa)	Ductility
Iron	~150 (ore)	7.9	211	50	200	0.3
Mildsteel	~600	7.9	210	220	430	0.21
High-carbonsteel	600->	7.8	210	350-1600	650-2000	0.1-0.2
Low-alloysteel	600->	7.8	203	290-1600	420-2000	0.1-0.2
High-alloysteel	600->	7.8	215	170-1600	460-1700	0.1-0.2
Cast iron		7.4	152	50-400	10-800	0-0.18

3.1.5 Wood

Wood is a naturally occurring fiber structure; it is today and has been for ages a popular construction material for different uses. Cheap, easy to work with, versatile and even beautiful these makes wood a pleasant material to work with. Wood has a considerably lower density than metals but since it does not have as good strength properties, the effect will be a larger volume of wood is needed to make up in strength. Thus the wooden structure will in many cases be heavier than for example an aluminum structure.

When using wood in constructions you always consider building in such a manner that stress is applied along the grains (fibers). There are many different species of wood and each with some differences in properties. Mechanical properties range, young´s modulus 7-25 GPa and stress 4-14 MPa along the grain. Two species of wood found in Finland that reaches high strength values is birch and oak. They are solid and heavy woods [16]. The density of wood that can be found in the Finnish forest ranges between 300-740 kg/m³. The number is dependent on what kind of wood, where it has grown and moisture.

However there is an alternative to solid wood and that is plywood, sandwich laminated wood sheet. By creating a sandwich laminate there is an increase in mechanical properties that make them more versatile. Plywood is a common material used when demanding sheet constructions with high strength, for example in A-frames (see appendices 6.1). Density of plywood is dependent on how it is produced and from what kinds of wood, density ranges between 460-680 kg/m³ [17].

3.2 Strength analysis and theory

When looking at the A-frame as a structure, it is easy to determine that beam deflection theory is the way to analyze the structure. Beam is the key word, what shape and material dose the beam need to be in order to optimize wanted properties. The shape of the beam is directly comparable with the moment of inertia or (I). This will help determine the best possible shape in such a way that strength in comparison to weight will be optimal. The material could be a composite material or a uniform material, to determine this materials need to be analyzed. Elastic modules or young´s modules need to be investigated in cooperation with strength properties.

3.2.1 Speed and weight of a dog

The fastest dog in the world can reach speeds of up to 70 km/h this would however be achieved running in a straight line and only for small periods of time [18]. There are numerous dog breeds, ranging in weight from just a few kilograms to excess of 80 kg [19]. However these both values are extreme and will not be found within one dog. Furthermore a dog will not be able to achieve maximum speed during an agility course. Some research on dogs and speed to weight ratio conclude that a reasonable maximum in agility conditions would be a 45 kg combined with a speed of 45 km/h. These would be the maximum values that the structure would need to withstand.

3.2.2 Impact force

The deflection of both the structure and the dog´s legs will together with the kinetic energy of a moving dog determine to impact force. Earlier was estimated a maximum speed of 45 km/h and weight to 45 kg. These values will work as guidelines to insure a strong enough structure. The deflection of the structure can easily be determined by calculations; later values can be altered if needed. However a more flexible structure would assure for a softer landing. Also the dog´s body will allow for some deflection and in a real situation this will be the most significant one. Basically a dog can allow movement from the length of their front legs to the chest, this is seldom needed but in case of a high jump might be a possibility.

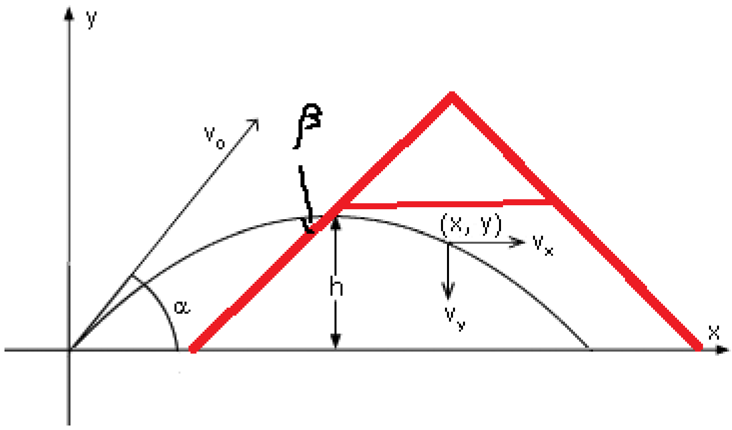

Figure 5: illustrates how a jumping dog would move during a jump, (Wikibooks, feb 2013. formelsamling/fysik/mekanik) [20].

Table 6: Calculations that illustrates take off angle in correlation to impact angle and speed, calculated using formulas (9) and (11) (also see figure 5). The cells in red the dog is already on the structure when jumping.

angle take off (α)	speed x take off	speed y take off	position x	angle of impact (β)
5	12,45243373		insufficient α	
10	12,31009691		insufficient α	
15	12,07407283		insufficient α	
21	11,66975533		3,90739229	39,2
25	11,32884734		2,58490975	30
30	10,82531755		1,90989427	22,35
35	10,23940055		1,50884968	15,8
40	9,575555539		1,22836013	9,7
45	8,838834765		1,01463515	3,9
50	8,034845121		0,84238416	-1,8
55	7,169705454		0,69772306	-7,3
60	6,25		0,57222084	-12,8
65	5,282728272		0,46036204	-18,2
70	4,275251792		0,35831191	-23,6
75	3,235238064		0,26325393	-29
80	2,170602221		0,17300496	-34,3
85	1,089446784		0,0857743	-39,7
90	0		0	

After doing calculations to compare different take off angels the results show that the highest force obtained at impact will be when the take of angel is 21° degrees (see table 6). This would require the dog to leap from 3 meters away from the frame. As mentioned this is a contact obstacle the idea is to teach the dog to touch the contact surface when going on and off. However there is always the possibility that a dog over shoots it ending up on the mid-section where deflection and stress reaches maximum values. The kinetic energy for the moving dog would become 2888 J, the impact force would then be decreased due to the angle of impact with 38.8 % (see table 6 & figure 5). However this is a high energy and without a sufficient deflection would harm the dog. World record attempts for dogs jumping heights on solid ground is as high as 172 cm, this can be used as a base line to determine a maximum comfortable impact force a dog can withstand [21]. This would generate energy of 760 J. A dog of this size has a leg length of 35-55 cm depending on breed; it will be assume the dog can use 20 cm of this for deflection. A free fall from 1.72 m would then give an impact force of 3796 N. This will be used as maximum force for the calculations.

(8) Kinetic energy $= \frac{1}{2} * mv^2 * \sin \beta°$

(9) Work = W = F * d

(10) $x = vt + \frac{1}{2} at^2$

(11) Impact force $= F = (\frac{1}{2} mv^2) / d$

v = speed = 12.5 m/s^2 d = deflection = 0.1 m

L = 2.7 m t = time (sec.)

m = mass = 45 kg

3.2.3 Strength of materials

Stress equals the force divided with the cross sectional area. There are two main stress elements to consider tensile (σ) and shear (τ). The formulas are the same but the planes that they function in are different. Tensile is when a material is under pulling force while shear is under a breaking force.

(12) $\sigma = F / A$ $\tau = F / A$

Strain (ε) is defined by dividing the original length (L) with deformation (d).

(13) $\varepsilon = d / L$

Young´s modulus or the modulus of elasticity is a value that expresses the stiffness of a material. Hooks law states that: (8) $E = \sigma/\varepsilon$. In other words young´s modulus is proportional to the stress and strain. Stress-strain can in proportion to each other be used to determine material behavior under different kind of loads.

σ = tensile stress τ = shear stress F = force

A = cross sectional area E = young´s modulus ε = strain

d = change in length (deformation) L = length

h = thickness

3.2.4 Material analysis

Young´s modulus (E) and the ultimate stress (σ) of a material are key factors when it comes to analyzing material properties. When looking at the A-frame structure it becomes apparent that when simulating a dog jumping onto the frame a bending scenario will occur. The structure needs to be analyzed from a bending point of view. The two sheets that construction consists of are 2.7 m in length and 0.9 m in width. Imagine supporting the sheet in both ends and applying a force on the middle. The optimal material needs to be determined, with the help of E and σ. The moment of inertia will be a key factor to help improve the ratio of stress-strain. The moment of inertia determines the materials resistance to bending.

By analyzing the materials being possible contenders, uniform materials to a possible sandwich structures. For sandwich the price of materials will become a key factor.

Formulas

(14) $\sigma = (F / A) = E * \varepsilon$

(15) I = moment of inertia (rectangle) = $(w * t^3) / 12$

(16) $c = t / 2$

(17) $\sigma = (F*L*c) / (4* I) \Leftrightarrow h^2 = (F*L*3) / (2*w*\sigma)$

(18) $d = (F*L) / (48*E*I)$

Table 7: Material comparison considering tensile strength, young´s modulus and density (see chapter 3.1.1) (see appendices 6.2-6.3) [16]-[17], [22].

Material properties	Aluminum	Glass fiber	Steel	Plywood	Wood
E	69.8 GPa	19.78 GPa	210 GPa	~6 GPa	10.9 GPa
σ	276 MPa	218.57 MPa	220 MPa	~14 MPa	95 MPa
Density (kg/m3)	2700	2108	7800	300-740	460-680

The impact force produced by a jumping dog was determined to be 3796.4 N. With the help of this material comparison, thickness can be determined. The thickness (t) is defined by material properties E and σ.

Table 8: Comparison to determine best material based on E, calculation using formulas (18)-(19) (see table 7, chapter3.2.2) [23].

Material	Young´s (GPa)	Stress (Mpa)	yield (MPa)	Force (N)	L (m)	w (m)	Minimun-t (mm)	Max. deflection (cm)
Aluminum	68.9	310	276	3796	2,7	0,9	7.9	5.2
Fiber glass	19.78	218.6		3796	2,7	0,9	8.8	12.7
Steel	220	430	220	3796	2,7	0,9	8.8	1.2
wood (pine)	10.9	95		3796	2,7	0,9	13.4	6.5
Plywood	6.0	14		3796	2,7	0,9	34.9	0.7

Calculations are based on a uniform material shaped as a solid rectangle. The calculations have been made to determine a good material on the basis of young´s modulus (E). Also to get an idea of how thick the material in question needs to be. Two materials become interesting options those are aluminum and fiberglass, due to the fact that they perform well while having a low density (see table 8).

However this is only half of the truth, now also the flexural rigidity needs to be determined. This is determined not only by E but also by the moment of inertia (I). Together these two values will become the guideline for material selection. The moment of inertia is determined by the cross sectional shape of the beam, or by the combination of two materials as a sandwich construction.

3.2.5 Moment of Inertia (I)

To get an idea of how to start designing our product it is viable to compare different beam shapes considering the moment of inertia (I). The comparison is mainly based on comparison to a solid rectangular with; box, I, Chanell, T and round beams.

Table 9: Moment of inertia for different beam shapes calculated using Excel, aluminum has been used as material for the sake of weight comparison [23].

	Rectangular beam	Box-beam	Tube	I-beam	chanell-beam	T-beam
Moment of inertia (m4)	5,5E-02	3,2E-02	6,3E-03	3,2E-02	2,0E-02	2,0E-02
Area (m2)	0,81	0,29	0,29	0,29	0,29	0,29
Volume (m3)	2,2	0,79	0,79	0,79	0,79	0,79
Density (kg/m3)	2700	2700	2700	2700	2700	2700
Weight (kg)	5905	2126	2126	2126	2126	2126
y (m)	t/2	t/2	D/2	t/2	0,61	0,61

Due to the fact that weight is a key factor for our structure also weight and volume has been taken into consideration for the different beams. This helps us determine the best value for (I) and thus giving us optimal values for our structure. This values are calculated using rather large beam dimensions and do not correspond to actual values. However with this table a reasonable design option or options can be chosen.

Values for moment of inertia, a good way to compare these values is to look at the value for I and compare them to the weight. For example; comparing a box beam where the value for (I) is 3:5 ratio for that of a solid beam, while the weight is 1:3 ratio (see table 9). This means that with a box beam the same rigidity and strength can be achieved with a lighter weight. Comparing the other values it can be seen that Chanell-beam has a smaller moment of inertia compared to that of a box beam. This means that a Chanell will be more flexible but also allows for a higher stress. A circular beam or a half tube could also be sufficient options; the half tube needs to be considered because it might simplify production.

3.2.6 Shear force

Shear is an internal force that strives to pull parallel plains apart from each other. Shear force can also be seen as a dividing, breaking or cutting force. When a beam is subjected to a bending force the top will compress and the bottom will extend. The beam has a thickness; it will affect the magnitude of the tensile and compressive forces. Thus also effecting shear, shear will affect perpendicular to tensile and compressive forces. The further the distance from the bending force/load the greater the shear (see figure 6). Especially when it comes to more rigid structures, like sandwich and beams with a high moment of inertia, it will be important to consider shear forces. The beams are optimized to maximize the tensile capabilities of the material and thus there might be a weaker section that has to withstanding the shear.

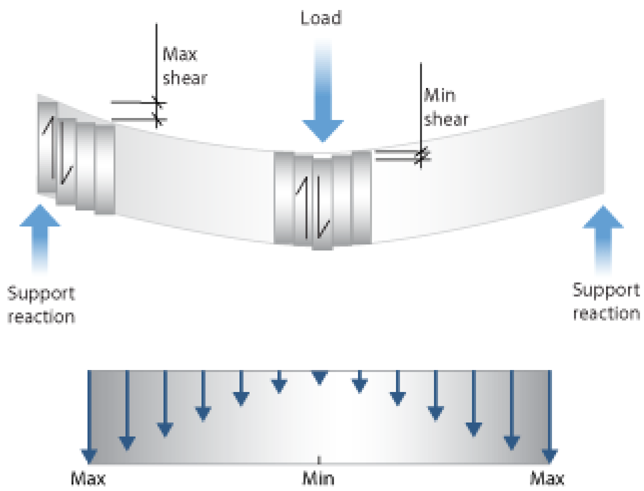

Figure 6: Illustration of shear forces acting on beam (Build right, shear force, Beams) [24].

3.2.7 Sandwich

A sandwich construction is when two or several materials are layered on top of each other. The main idea is to layer it such a way that the face material is strong considering mechanical properties and the core is light weight material. When adding distance between the faces a transformation in forces acting on the material is achieved. The first and foremost property by doing this is that an increase in moment of inertia is achieved. In other words the structure becomes stiffer, also an increase in strength compared to weight.

When analyzing the forces acting on a material in three-point bending it will become apparent that tensile forces are greatest on the surfaces and in the middle non-existing. Shear force also need to be considered in three point bending the shear will be greatest at the ends of the beam. When a beam is placed under load it will deflect this causes the top and bottom of the beam to move in different direction causing a shear force. In a sandwich structure this force will mainly affect the core and the adhesive holding the sandwich together. If shear force is too great between skin and core, where it is held to getter by an adhesive the result will be delamination.

Sandwich was discussed as a solution however further research show that this is not a reasonable alternative. The key issue lies with the price of the core material, a cheap core might be affordable but this would add so little considering structural properties. In other words it would only work as a matrix bringing distance to the face materials. This is a quality that can be achieved with the right beam design for a lower price.

D = E * I = flexural rigidity, b,h,e,c= dimensions,
Ec= young´s modulus for core

(19) $$D = (E_f * (bh^3-ec^3)/12) + \boxed{(E_c * (ec^3/12))}$$

This is the formula that decides flexural rigidity for a boxed-sandwich beam; if the E-modulus for the core is low this will make the core insignificant. However there is a chance that sandwich might make production easier and thus will be considered [25].

3.3 Price

Table 10: Prices of different material; structural materials, core materials and resins [12] ,[26]-[28].

Materials	Size	Area (m2)	thick-ness (mm)	Price/unit (€)	Needed (at least)	Total cost
Aluminum sheet	1m * 2m	2	0.5	37,3	6	223,8
Aluminum sheet	1m * 2m	2	1	74,6	6	447,6
Glassfiber com-posite	1 m * 1m	1	1.6	3,56	10	35,6
Plywood sheet	1,2 m * 2,7 m	3,24	15	39,8	2	79,6
Film plywood sheet	1,25 m * 2,5 m	3,125	15	63,9	2	127,8
Wood	0,123 m * 6 m	0,738	48	2,25	8	18
PET core 3D	1m * 1m	1	5	25	6	150
PUR core 3D	1m * 1m	1	5	27	6	162
Balsa core	1,22 m * 0,61 m	1	6	17,85	7	124,95
Balsa core	1,22 m * 0,61 m	1	12.5	23,25	7	162,75
PU foam (low density)	(1,2 m * 1,2 m)*6	8,64	12	41	1	41
Nidaplast (poly-mer honeycomb)	1,2 m * 1,2 m	1,44	5	19,9	6	119,4
Nidaplast (poly-mer honeycomb)	1,2 m * 1,2 m	1,44	10	25,77	6	154,62
PVC foam	2 m * 1m	2	5	46,89	3	140,67
PVC foam	2,15 m * 1m	2,15	10	70,35	3	211,05
Polyester (infusi-on)				20,87	2	41,74
Polyester (hand)				9,07	4	36,28
hardener				21	1	21
Gelcoat				37,3	1	37,3

The product needs to be manufactured at a low cost even though production volumes are low. Hence our material selections will be based on optimal material properties light weight, durable and low cost. Looking at the table for prices and the table for material properties a primary conclusion can be made (see table 10).

3.4 Design inputs

Beyond material and price there are some other factors that needs to be considered before doing a final design for the product. Inputs are factors that in some way help achieve the properties wanted from the product.

3.4.1 Number of joints

The first issue concerning design is how many joint to plan for the product. One joint is with certainty needed and it is the one combining the two sheets at the top. Possibly also some kind of joint to connect the support beam to the sheets, keeping the frame upright. In the beginning there was an idea of dividing the sheets into smaller segments to help transportation; this idea was disregarded due to conflict with competition standards.

For the sake of discussion the original idea for the product will be looked at, dividing the structure into more than two parts thus decreasing the size of the individual parts. The benefits of smaller parts would become apparent for the end user in the form of easier transportation from one location to another. Negative factors with this would be a more complicated process for the production and design steps. The fact is that joints and joining are most commonly the weaknesses in structure, the more of them present the less durable the product will be in the long run. Joints allow for some movement and this automatically increases the factor of wear, the more it moves the higher the wear. Also if considering lamination the more parts the more separate laminations needed, making the production less sufficient.

The other option is to develop a product that would consist of two main parts, with that production would be more sufficient but also competition standards could be met. This would be a benefit especially when dealing with composites it would enable the lamination to be done in one or two faces, thus making production sufficient and also insuring maximum strength. Negative is the size of individual parts would be larger, making transporting less sufficient.

Different kinds of joints

The first and most relevant joint will be the one combining the two main sheets at the top of the frame. The joint needs to make assembling easy and be incorporated into the lamination process. A common design for this joint is a tube structure that is divided into segment on both sheets. The segments fall in between each other and are held in place with a road going through the tube holes.

3.4.2 Surfacing and hygiene

Surfacing of the product is also something to be considered, climbing a structure of this shape demands some friction. A plain laminate surface does not provide sufficient grip for a dogs paw. Depending on what kind of surfacing wanted options on how to apply or change the surface will become relevant. Also hygiene is an aspect to be consider in such a way that the cleaning will be possible.

Rubber

The preferred product for a surfacing to improve grip is a rubber surface with a rough finish. It can be seen on several of the product on the market [34]. This would be a more expensive solution since the surface would need to be purchased. The price ranges between 100-250 euros depending on the retailer. Rubber will deteriorate with time thus changing the surface needs to be possible.

Sand

Sand is also a common solution used for materials like wood and ply wood to further enhance grip. It is either applied as sandpaper with a sticky surface or optionally it could be applied by gluing sand particles on the surface. In the case where composites would be used the sand particles would be glued either in the coating step or prior to it.

Topcoat

It is possible to blend the topcoat with talc powder making the topcoat more viscose, this enables the surface to be manipulated in such manner that it becomes rougher.

Wood

A wooden surface could possibly be used for surfacing due to the fact that it is the only material that does not need to be treated for grip enhancement. Products on the market today are in many cases further treated even though they are made of wood.

3.4.3 Support

The parts produced for the construction of the A-frame will be sheet like parts, because of this they need to be supported somehow. The supporting structure mainly works as strength and stiffness enhancing.

Sandwich

A sandwich laminate enhances structural rigidity and strength, with that also weight reduction is achieved. Sandwich when considering composites, consists of two laminated skins around a core material, for example; glass fiber/Pet-foam/glass fiber. Because there is core between the two layers of laminate this will cause the bending force to be transformed into a tensile stress on the skin.

Beams

Beams are a common way to support all sorts of structures, by carefully choosing and placing the beams strength can be enhanced. Different beams have been investigated and the values will determine the shape of beam (see chapter 3.2.4).

Lamination technic

As a third option a new way of producing a laminate could be investigated. Integrating beams into sheets making them structurally more rigid. A good guideline for this thought process is looking at a cardboard. Structurally weak material where mechanical properties have been enhanced with design.

3.4.4 Design ideas

To use one material for the entire structure is always a possibility if using metals or fiber glass. Wooden structures are going to demand at least some inserts consisting of joint, nails, screws, rivets or other materials to hold the structure together. There is also the option of combining different materials, the sheet comprising of one material and the frame support possibly the other.

Ideas:

-Plywood sheet with composite beams laminated to the bottom of it
-FRP beam segments laminated into a sheet
-Sandwich sheet with aluminum frame
-Sandwich beam segments (box) laminated into sheet
-Aluminum sheet bent into beam segments and put together into sheet
-Aluminum sandwich, aluminum faces adhered with core
-FRP
-FRP sandwich

3.5 Conclusion of materials

Fiber glass is going to be the material of choice but to get a better picture of properties aluminum will be used for comparison. Fiber glass is a flexible material; it has a high tensile strength and is easy to form into different shapes. Chanell-beam, half tube and box-beam are going to be possibilities for beam designs. They have the best characteristics for this kind of structure providing significant support when considering bending of a beam, also with some regards for manufacturing. These beams can then be either used as the supporting structure or by integrating several into one rigid sheet. The down side with FRP laminates is the common issue of them needing to be coated, with a topcoat to protect them from UV-light. It will bring some extra expenses but thus far calculations stat that it is cheaper than an aluminum structure.

Aluminum can by itself provide for a good structure and with the right kind of design can be made light weight. Aluminum is more rigid than fiber glass but has a lower maximum tensile strength. Now it is important to take into consideration that aluminum has uniform material properties in all planes of the material. Compared to fiber glass that has good properties in direction of the fibers, this can however be used to direct wanted maximum properties in the needed plane (see tables 8-10).

Table 11: Material strengths for comparison of beam stresses in table 13 (see appendices 6.2 and chapter 3.1.1).

Properties	Aluminum	Fiberglass
Tensile strength (yield)	276 MPa	218.6 MPa
Shear strength	207 MPa	56.1 MPa
Shear modulus	26 GPa	2.55 Gpa

Table 12: Calculations on deflection for an individual sheet which comprises of 18 smaller beam sections (10 half tube), the sheet makes up for one side of the frame (see formula (19), chapter 3.2.4) [23].

F = 11389,41 N **Max. Deflection (cm)**	**Rectangular beam**	**Box-beam**	**chanell-beam**	**Half tube**
Aluminum	0.72	4.8	9.34	8.00
FRP	2.52	16.7	32.5	27.9

Table 13: Shear and tensile stresses has been calculated for an individual sheet comprising of different beam segments, when comparing values to material properties it will show the measures are sufficient (see table 11) [9], [23].

F = 11389,41	**Box-beam**	**chanell-beam**	**Half tube**	**Rektangular beam**
Shear stress on beam (MPa)	9.9	19.1	7.0	0.76
Tensile stress on beam (MPa)	136.0	349.1	250.3	20.5
Total weight				
Aluminum	25.7	19.4	34.7	328
Fiber glass	20.0	15.2	27.1	256
Density FRP	2108	2108	2108	2108

First and fore most it needs to be stated that one sheet comprises of 18 (half tube 10) smaller beam sections within the structure. These two tables are the main information in the form of calculations to determine material selection. It is important to take all the significant data into consideration to get the optimal results for the study; deflection, tensile stress, shear stress, weight, price then the values need to be compared to each other and material properties. These values state how the individual frame sheets will act under a load; taking into consideration an impact force and a safety factor of 3. Hence aluminum and fiber glass are the main contenders when it comes to mechanical properties compared to weight. Considering the fact that aluminum is more than 10 times more expensive than fiberglass. These dimensions have been optimized for the use of fiberglass, aluminum could be used but with these values the structure would become too rigid and expensive (see tables 10-13). Comparing values in table 11, 13 for tensile- and shear strength to stress it can be concluded that beam properties are sufficient.

Sandwich was excluded as a material due to the fact that it would make the structure significantly more expensive compared to using only fiberglass. If a core would have been used, a weaker and softer core, thus difference in mechanical properties would have been insignificant (see chapter 3.2.7).

3.5.1 Fatigue

Fatigue is something that you want to consider when designing a structure. Mechanical fatigue affects a structure when a repeated load is applied and creating a stress that is close to the maximum material strength. The structure is forced to deflect close to its maximum or yield, this will fatigue the structure. Creating microscopic cracks in the material and structure, over time the material will tier, eventually deforming or breaking. Fatigue is considered on the basis of tensile strength and stress. The ratio for maximum material tensile strength and beam stress, with these values the difference is significant and will provide for a long life. Chemical deterioration will also affect, the material properties will decrease, resulting in the mechanical fatigue becoming more significant. For fiber glass UV-light is the factor creating chemical deterioration.

3.6 Structural design

In the next step design will become relevant using knowledge from earlier a couple of options will be drawn. They will be made in such a way that just one side of the structure will be drawn, due to the sheet being structurally the same. Focus point will be how the sheet has been reinforced and made more rigid. Also joint will be a focal point. Development of an idea for the product has already been formed, but for comparison purpose a few options will be made.

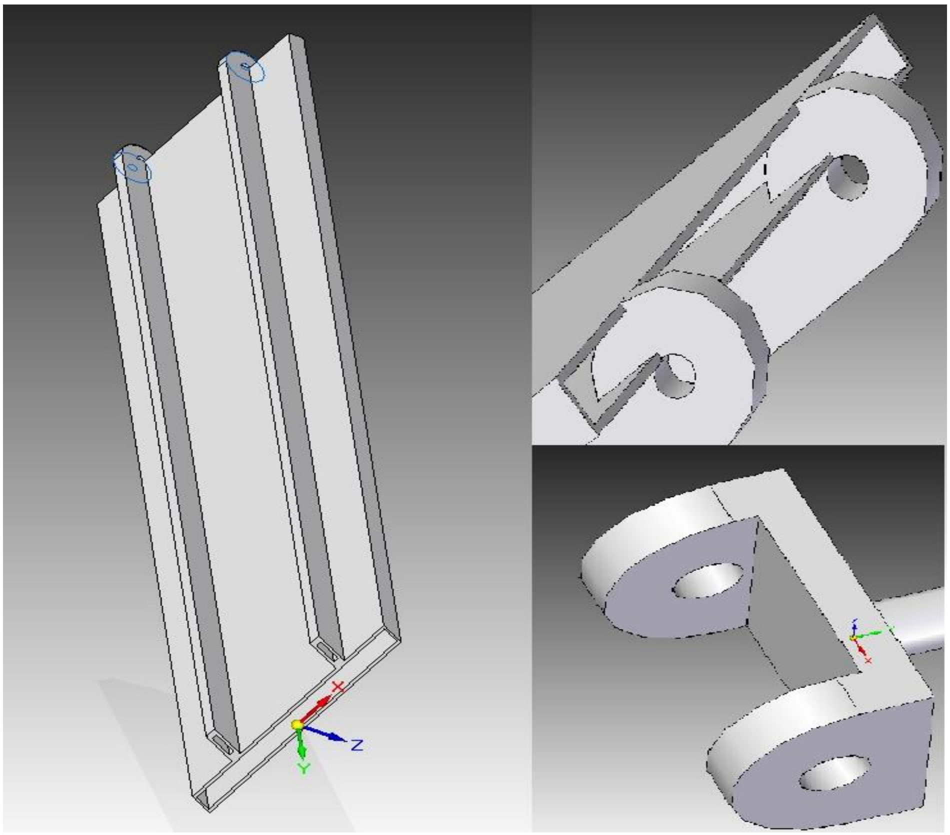

Figure 7: Design 1, possible design for sandwich, software Solid edge.

Design 1 is a simple design that could be considered in the case of a sandwich structure or wooden A-frame (see figure 7). Sandwich sheet that is supported with thin walled sandwich beams, in corporation with the supporting beams there are joint that would then be combined with counter parts. In case of wood the structure would be solid and also joints out of a different material would be incorporated into the design.

3.6.1 Structural support

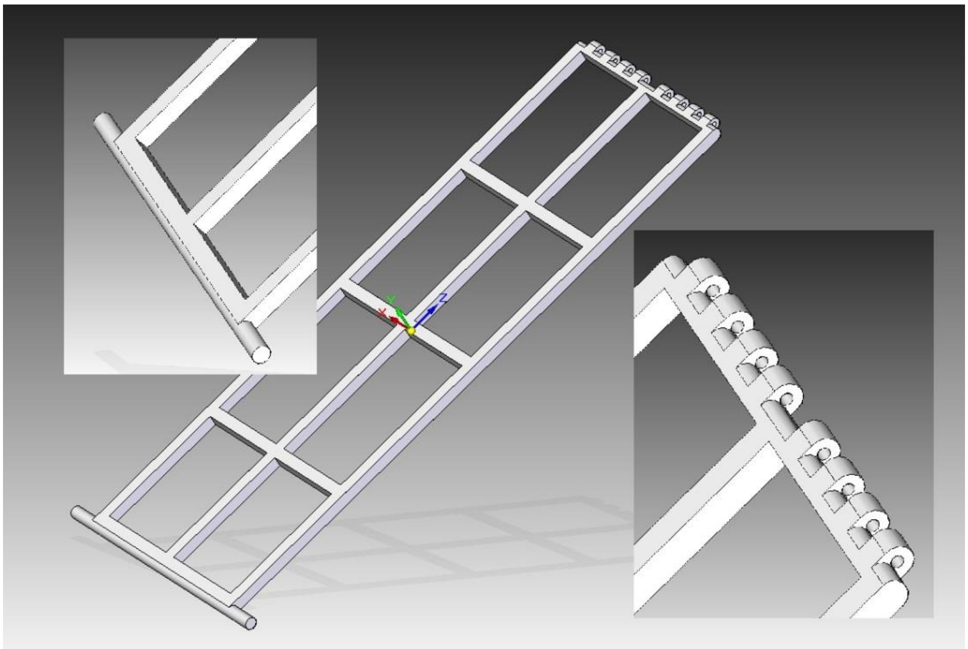

Figure 8: Design 2, this represents the structural support of a side of an A-frame.

Design 2 is made as an example; to show how to, with the help of beam construction add sufficient support to structures (see figure 8). It can be seen that the support has been divided into smaller segments thus dividing the force directed to the sheet, the sheet would be added on top. In other words with this kind of support the load will mostly be directed to the underling beam structure, that can be seen in this picture, demanding less physical properties from the actual sheet.

The top joint in the picture is a bit different from that in design 1, here teeth like design. Two similar sides where flanges on top of the sheet fall in between each other, they would be joined with a road going through the holes. Also the structure has added support on the bottom making it more stable, a simple widening at the bottom giving more contact surface to the ground.

3.6.2 Two part sheet

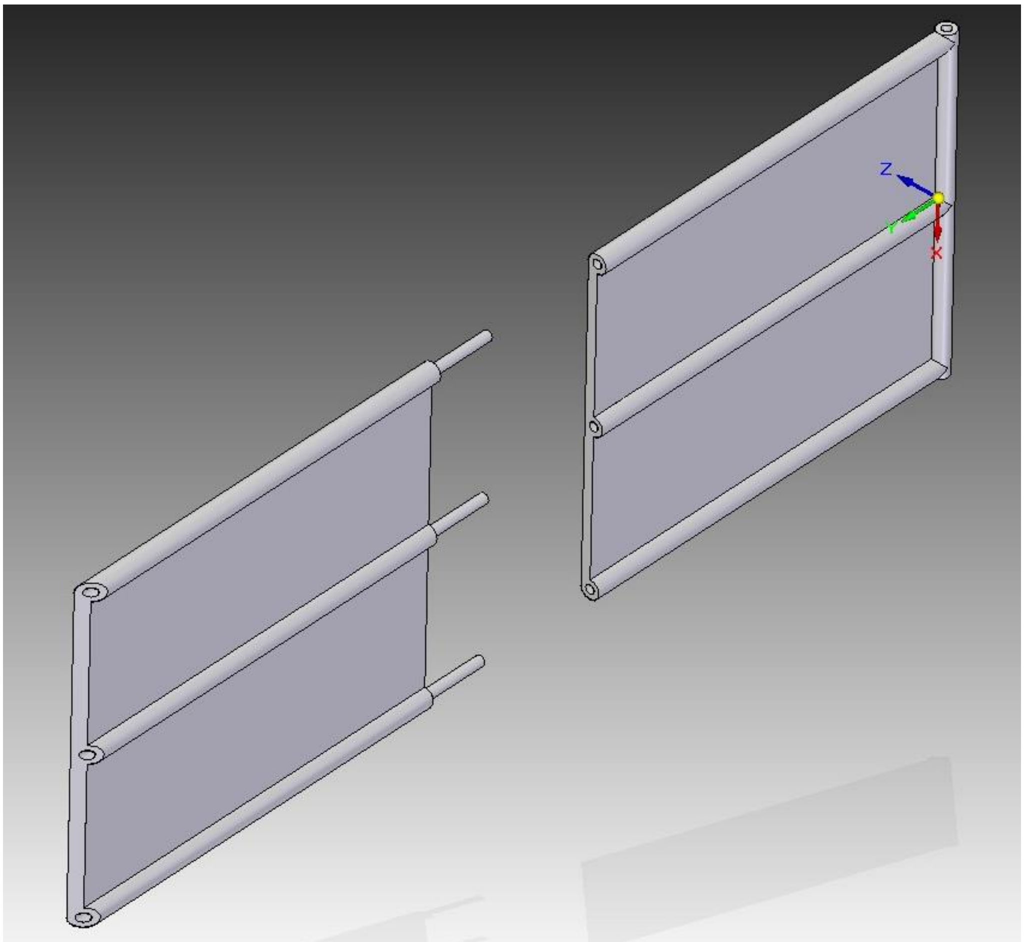

Figure 9: Design 3 a sheet divided into two parts with the help of joints.

Design 3 illustrates an option on how a large sheet can with the help of joints be divided into more than one part (see figure 9). The original idea was to make an easy to move and light weight structure, in such a manner that it is easy to move the structure from one place to another. This design would conflicts with competition standards and decreases the already small market. As a movable obstacle this is a good idea but the market would be more restricted.

3.6.3 Design option, rigid material

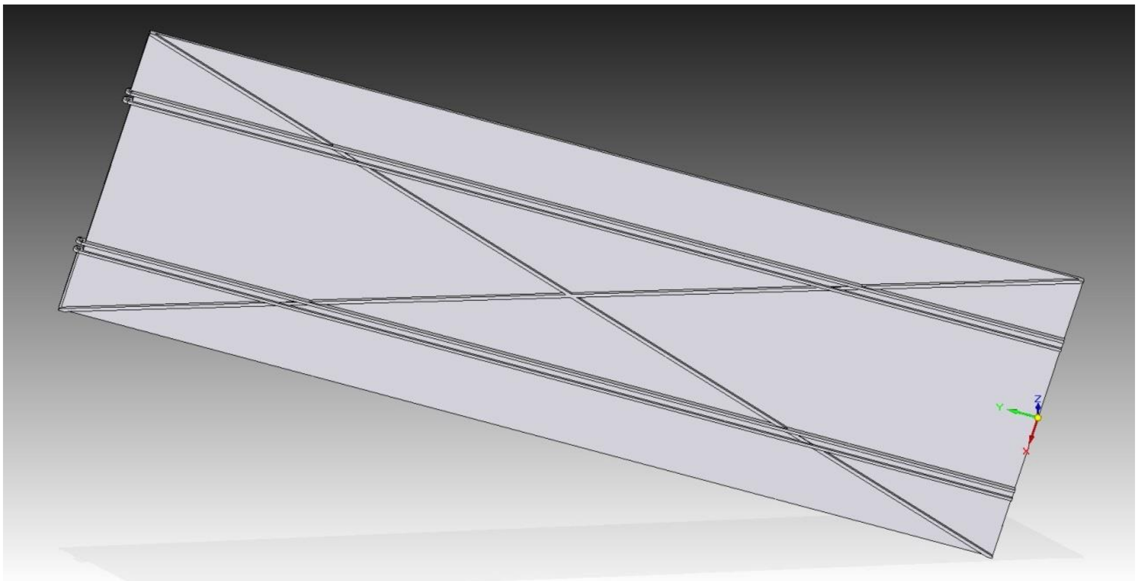

Figure 10: Design 4, design option for a more rigid material.

Design 4 shows an option that could be incorporated with uniform more rigid materials like aluminum or steel (see figure 10). The supporting beams are Chanell-beams and the crossing support is a rectangular beam. In the top end of the sheet joints incorporated to the Chanells will work as joints for the second sheet, similar solution as in design 1 (see figure 9).

3.6.4 Chanell

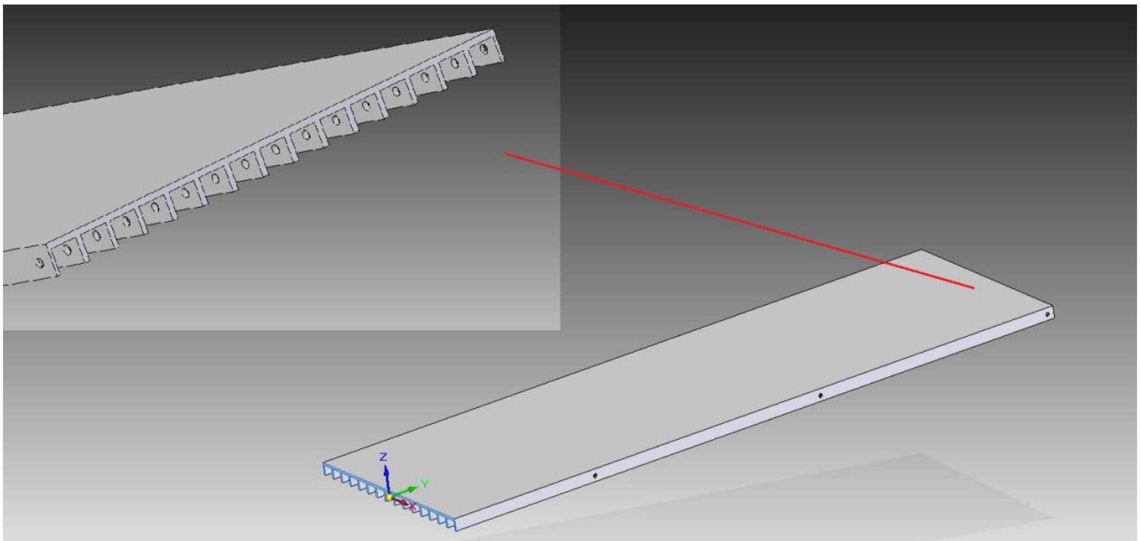

Figure 11: Design 5, multiple Chanell sections combined into rigid sheet.

Design 5 illustrates a sheet that composes of multiple Chanell sections combined into a structurally rigid sheet. The holes going through the sections are to insure that the sections stay together but also to give support perpendicular to the beams. The hole at the top end of the sheet would also work to join the two sheets together with a rod of some sort. This kind of design could possibly be used with aluminum or with a fiber structure. With fiberglass the problem lies with the flexural modulus. Fiber glass is flexible, with sufficient measures and material thickness this design can be used with FRP. Design 5 is mainly to illustrate the option of using Chanell, it is an option to be considered (see figure 11).

3.6.5 Final design

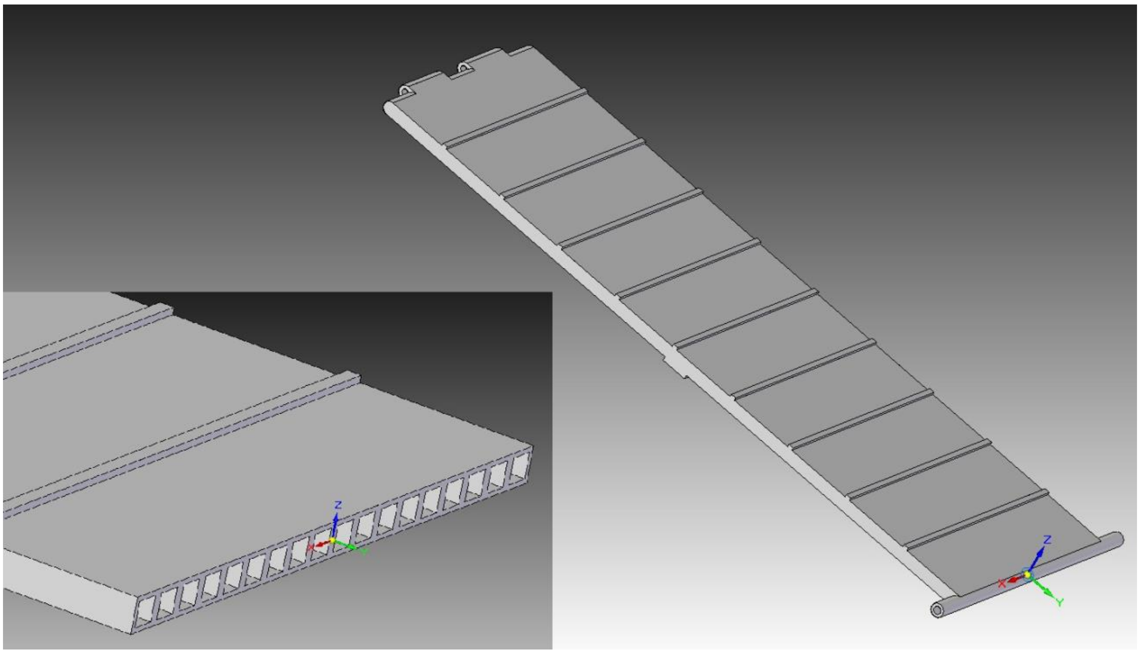

Figure 12: Design 6, multiple box-beams comprising of a structural sheet.

Design 6 is the final design for our product and is optimized for the use of fiber glass in such a way that a light weight and rigid enough structure is achieved (see figure 12-13). Beyond the box-beams also perpendicular beams have been added to assure mechanical strength perpendicular to the box-beams. They are positioned at the bottom (round), in the middle on the bottom side, at the top integrated into the sheet and joint. The small lists on the surface are for climbing, improving grip. The box beam could also be used in combination with a foam core (sandwich) this would not be necessary but could simplify production.

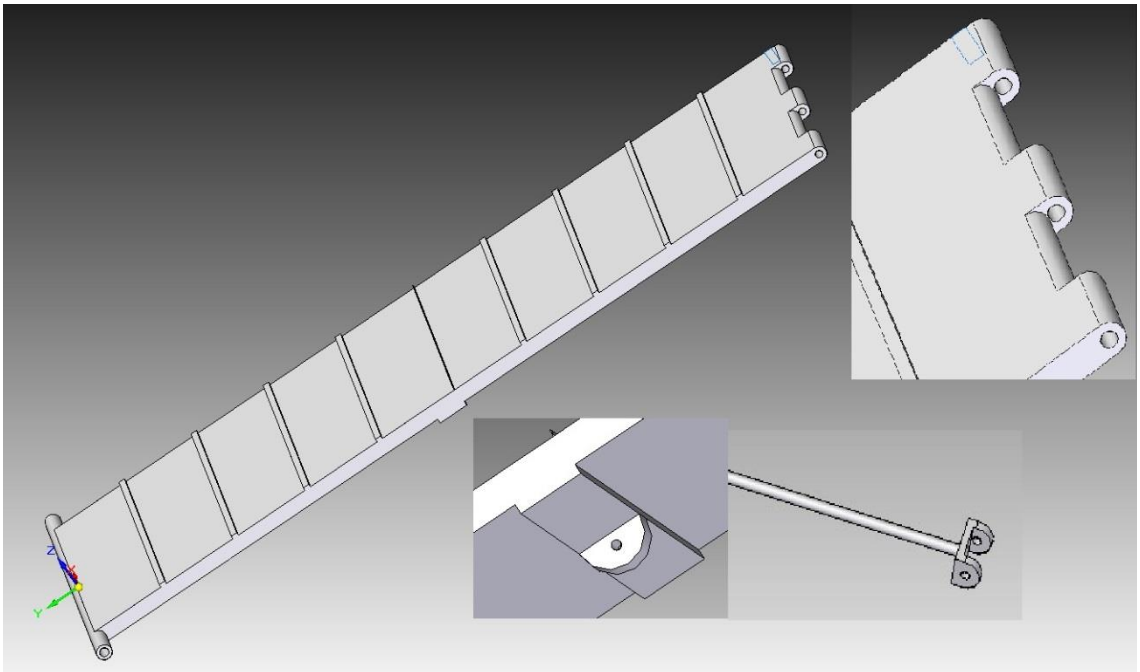

Figure 13: Design 6, second sheet and joints.

The second sheet of design 6, with some features that allow for assembly of the frame, staff connecting the two sheets together and keeping them upright (see figure 13). The flanges on the sheet will fit together with those on sheet one, together with a road going through the holes the joints will become complete.

The primary choice for this project is to use a box beam construction, where several beams are combined to produce a rigid sheet structure. Each of the box segments would have outer dimensions of 50*50 mm, with a material thickness of 1 mm. Calculations have been made on a beam of this size but hence 18 beams are combined to build up the sheet, all acting forces must be divided by the number of beams. Since fiber glass is a rather flexible material the dimensions have mainly been chosen on the basis of material deflection, tensile and shear force of the material are sufficient. It might be possible to alter values to some extent to reduce weight even further, this is not necessary because the weight is already low. The individual sheets have a weight of ~20 kg, to this there will be weight addition in the form of joints, supports and surfacing.

4 MANUFACTURING

Planning a manufacturing process for the product is an important step before it will be introduced to the market. A key factor when it comes to planning is demand and market. How vast is the demand in other words how many products need to be produced on a yearly bases.

4.1 Magnitude of production

When looking at the possible market it becomes clear that this kind of product has a quite small target market (see chapter 2.1). In other words the amount of product sold each year would be quite small. To be able to make a reasonable income with the product the production cost need to be kept low. Low production cost can be ensured by simple methods of manufacturing. Usually this means that the production rate is slow, needs more human presence and less advanced production methods.

4.2 Lamination

Thus far it has been concluded that a box beam combined with fiber glass would be the wanted structure. The question now, how to produce this with simple and low cost methods. There are several ways to do lamination processes, mainly for individual parts in separate molds but also some automated processes have been developed for simple shapes. The most likely in this case is going to be vacuum lamination due to the fact that calculations are based on a high fiber to resin ratio. Vacuum infusion is the cheapest and easiest way to achieve a good laminate. Hand layup is also an alternative but would require altered dimensions due to the fiber to resin ratio would be different, more resin compared to vacuum.

4.2.1 Manual labor

Requirements for this kind of product, is that it needs to be cheap to produce and thus requires some manual labor. The product will most likely be produced on the basis of demand, an ordered products is produced. A small supply could be good in case of sudden orders but mainly production on demand.

4.2.2 Mold

When producing something out of fiberglass there needs to be some kind of form to give the material its desired shape. Depending on the actual manufacturing method some differences in mold design and price. The mold will be adapted for vacuum infusion also being usable with hand layup. The mold will be constructed out of fiberglass or wood to keep costs low; if the right equipment were available also milling the mold would be an option.

4.2.3 Shape

A box beam is in practice hard to laminate without special equipment especially with dimension of this magnitude. Thus the production needs to be divided into more steps, demanding more than just one lamination. Laminating multiple Chanell sections into a sheet structure and then integrating the sheet with flat surfaces, resulting in box sections. Another way that might allow for a single lamination could be the use of core materials, each box section with its own core. There might how ever be a slight issue with resin flow in the case of doing a single laminate, in that case lamination could be divided into two steps.

Another option would be to use of a half tube shape this would have the advantage of making lamination a bit easier. The half tubes would be integrated into a sheet, looking similar to roofing sheets. Could be made into a one step process with the right mold design, this would require that the bottom part of the sheet would stay waved. However for the sake of cheaper tools a two-step lamination process might be more cost efficient especially in the beginning. A tube shape is not as rigid in bending as a box beam and there for more material would be required to make up for properties (see chapter 3.2.5).

4.2.4 Estimated material costs

The price of glass fiber would be about ~20 m^2 * 3.5 € = 70 €. And the laminate would require ~10 kg of resin. For infusion the cost would be 150-200 €. To the price would then be added the cost of gel coat, with a 3 mm layer the price would be ~40 €. Resulting in a total cost of 260-310 €, additional cost would be materials needed for the infusion process.

5 CONCLUSION AND RESULTS

Issues that was set to be solved; developing a product, light weight, possibly modular, material selection, design options, stiffness, surfacing, cheaper and flexible. The goal was to improve an already existing product.

5.1 Steps

This project is a purely theoretical study into the development of an agility A-frame. Information has been sought from different sources, together with calculation and research the information has been used to yield sought answers.

5.1.1 Market

The process began with doing research into already existing product and alongside beginning to understanding the market. When looking on an international scale the market seems quite vast. If an international level could be reached this would result in success for the product. However when studying the quantity of the market within country borders it become apparent that production needs to be kept low cost. The problem with bringing a new product onto the market is that it needs to be tested, people do not buy product they know nothing about. Without regarding the future of the product, it needs to be considered that the beginning of the products life span sales will be minor. Production methods need to be designed accordingly and made as simple as possible.

5.1.2 Design and material selection

To find the best material for this use a study on material properties was done. The original thought was to produce an improved structure with the help of introducing alternative materials to those common on the market today. Fiber glass, possibly as a sandwich structure, was the original material that was to be the focus of the study.

It yields that fiberglass would be a good option for producing this kind of structure and to a low cost. Fiber glass is a flexible material and thus some consideration on rigidity needed to be made. The moment on inertia needed to be altered and the best option was to form a box-beam, or to be more specific multiple beams. To optimize the rigidity and strength, the structure was divided into multiple smaller beams then integrated into one sheet. Each beam having the dimensions; of 50*50*2700 mm outer and 48*48*2700 mm inner, 18 of them put together forming a sheet making up for one side in the A-frame (see figure 12-13).

5.1.3 Manufacturing

Due to the fact that the market is small, requires that the production is as simple and cheap as possible. Material costs are more or less the same regardless of production methods. The production needs to be simple thus less advanced tools results in lower manufacturing costs. Never the less there are always something that will affect the budget, composite lamination requires a mold to give the material its shape. The mold would be produced out of fiberglass on a wooden core, laminated by hand and then surfaced to prevent the actual product sticking to the mold. Because a high quality laminate is required vacuum infusion is the method to be used. This would require cost of a vacuum pump and some extra material; like flow mats, plastic film, resin, vacuum tape and hoses.

REFERENCES

[1] Suomen Agilityliito, 2008. *A kilpailusääntö*, p. 6, Accessed 28.01.2013, [ONLINE] Available:
http://tango-109.srv.hosting.fi/wordpress/wp-content/uploads/2009/11/agilityliitto_kilpailusaanto_a4.pdf

[2] Suomen Agilityliitto, 2008. *B1 Agilitytuomarin ohje*, p. 9, Accessed 28.11.2013, [ONLINE] Available:
http://tango-109.srv.hosting.fi/wordpress/wp-content/uploads/2009/11/agilityliitto_agilitytuomarinohje_a4.pdf

[3] Helsinging Sanomat, Jorma Palovaara, 21.1.2012. *Agilityn harrastajilla on pula tiloista*, , Uutiset, Acessed 08.02.2013, [ONLINE] Available:
http://www.hs.fi/juttusarja/penaali/artikkeli/Agilityn+harrastajilla+on+pula+tiloista/1135270232506

[4] NC State University, 2009. *Estimating market potential: Is there a market?*, The Bussiness Development Files, Accessed 14.3.2013, [ONLINE] Available:
http://plantsforhumanhealth.ncsu.edu/extension/marketready/pdfs-ppt/business_development_files/PDF/estimating_market_potential.pdf

[5] Doggy Jumps®, 2010. *Dog Agility Equipment*, Products, Accessed 07.02.2013, [ONLINE] Available:
http://www.doggyjumps.com/catalog/index.php?CG_ID=11

[6] Action K9 Sports Equipment Company, 2008. *A-frames*, Contacts, Accessed 22.02.2013, [ONLINE] Available:
http://actionk9.com/aframe.html

[7] Richardso, David. 2011. *The Fundamental Principal of Composite Material Stiffness Predictions*. Bristol: University of the West of England, pp. 6-28.

[8] Larry Peel & Adarsh Jagannath & Naveen Kumar Ramaiah. 2012, *Laminated composite plates*, 11 pp. Accessed 27.9.2013, [ONLINE] Available:
http://www.engineer.tamuk.edu/departments/ieen/faculty/drlpeel/courses/Composites/Composites_properties_spr12_mod.pdf

[9] Mathew Vihtonen, 2005. *Strength of Materials*, Chapter 1-2, pp. 1-39, Chapter 4, pp. 1-30, Accessed 28.11.2013, [ONLINE] Restricted access (Arcada): https://people.arcada.fi/~mathew/intern/Strength%20of%20Materials/Notes/Chapter%201-2.pdf

[10] Nc State University, 2004. *Strain and Strain Tensors (elastic)*, p. 2, Accessed 25.11.2013, [ONLINE] Available: http://www4.ncsu.edu/~murty/MAT450/NOTES/straintensor.pdf

[11] Price Engineering Building on Prince, 2011. *FRP Reinforcements for Structure*, Inclusive Engineering, Accessed 4.9.2013, [ONLINE] Available: http://www.build-on-prince.com/frp-reinforcement.html#sthash.SJtjDDcD.iISVsUxn.dpbs

[12] KN Composite, *Matot (lujitteet)*, Accessed 17.9.2013, [ONLINE] Available: http://kuitunik.shop.sigmatic.fi/category/3/matot-lujitteet

[13] Prof. Hansmann, H. 2003. *Composites, polyester resins*, ASM Handbook/extraction, Hochschule Wismar, p. 6, Accessed 4.9.2013, [ONLINE] Available: http://solidsurfacealliance.org/files/ASM_20Handbook_20Vol_2021_Composites_12_polyester_resins.pdf

[14] The Ohio State University, *Ring compression studies*, Chapter 4, Accessed 3.9.2013, [ONLINE] Available: http://www.matsceng.ohio-state.edu/~daehn/mahadevanthesis/tabofcont/ch4/index.html

[15] Index mundi, 2008. *aluminum monthly price*, Accessed 20.02.2013, [ONLINE] Available: http://www.indexmundi.com/commodities/?commodity=aluminum&months=60

[16] Green, David, W. & Winandy, Jerrold, E. & Kretschmann, David, E. 1999. *Mechanical properties of wood*, chapter 4, pp. 4-24 Accessed 12.9.2013, [ONLINE] Available: http://www.conradfp.com/pdf/ch4-Mechanical-Properties-of-Wood.pdf

[17] PuuInfo, *Lujuusteknisiä ominaisuuksia*, Puu materiaalina , Acessed 19.02.2013, [ONLINE] Available: http://www.puuinfo.fi/puun-lujuusteknisia-ominaisuuksia

[18] VetStreet, Kim Campbell Thornton, 24.9. 2012. *meet eight of the fastest dogs on the planet*, accessed 28.8.2013, [ONLINE] Available: http://www.vetstreet.com/our-pet-experts/meet-eight-of-the-fastest-dogs-on-the-planet

[19] Most extream.org, 2012. *Biggest dog in the world*, Accessed 28.8.2013, [ONLINE] Available: http://mostextreme.org/biggest_dog.php

[20] Wikibooks, feb 2013. *formelsamling/fysik/mekanik*, accessed 14.11.2013, [ONLINE] Available: http://sv.wikibooks.org/wiki/Formelsamling/Fysik/Mekanik

[21] Guinness world record, 2006. *Highest Jump by Dog*, accessed 17.10.2013, [ONLINE] Available: http://www.guinnessworldrecords.com/world-records/dedication/highest-jump-by-a-dog

[22] UPM, 2007. *Handbook of Finish plywood*, pp. 18-20, Accessed 6.11.2013, [ONLINE] Available: http://www.upm.com/cn/products/plywood/Documents/Handbook_EN.pdf

[23] Engineers edge, 2000. *Strength/Mechanics of Material Basics, General Equations and Definitions*, Accessed 28.8.2013, [ONLINE] Available: http://www.engineersedge.com/mechanics_material_menu.shtml

[24] Build right, *shear force*, Beams, Accessed 18.11.2013, [ONLINE] Available: http://toolboxes.flexiblelearning.net.au/demosites/series10/10_01/content/bcgbc4010a/04_struct_members/01_beams/page_007.htm

[25] DIAB AB, 2003. *Sandwich Handbook*, Sandwich Concept, pp. 1-15, Laholm, Sweeden. Published 10.1.2003.

[26] Kosken Metalli Oy, 2013. *Alumiinilevyt*, Luoettelo, accessed 18.10.2013, [ONLINE] Available: http://www.koskenmetalli.net/index.php/component/virtuemart/?page=shop.browse&category_id=43

[27] Taloon.com, 2004. V*anerit*, Tuoteet, accessed 21.10.2013, [ONLINE] Available: http://www.taloon.com/vanerit/4057/dg?gclid=COy2punJp7oCFcF4cAodJR0ATw

[28] East coast fiberglass supplies, *Composite Laminating Core Materials*, accessed 25.10.2013, [ONLINE] Available:
http://www.ecfibreglasssupplies.co.uk/c-454-core-materials.aspx

[29] Sm@rt®-99, *A-frame-99*, Accessed 07.02.2013, [ONLINE] Available: http://www.agility-geraete.de/en/Agility/Contacts/A-Frame-99.html

[30] DogAntti, *A-este*, accessed 07.02.2013, [ONLINE] Available: http://www.dogantti.fi/tuotteet.html?id=1/23

[31] Pet world industry, *Agility*, A-frame, Accessed 22.02.2013, [ONLINE] Available: http://www.petworldindustry.com/category/29/agility

[32] Things4YouDog.com, 2006. *Aluminum Agility A-frame*, Accessed 22.02.2013, [ONLINE] Available: http://www.things4yourdog.com/aluminum%20agility%20a-frame

[33] Circles Agility, *Practice grade A-frame* , Accessed 22.02.2013, [ONLINE] Available: http://www.circlesagility.com/Agility_A_frames_2.htm

[34] Stone mountain pet products, 2009. *A-frames-Standing Up to the Competition*, accessed 22.02.2013, [ONLINE] Available: http://www.stonemountainpetproducts.com/products/agility/a-frames/index.php,

[35] Easy AGI, *A-este*, agilityesteet, acessed 22.02.2013, [ONLINE] Available: http://www.estekalusteet.fi/easywood.php

[36] Koirakoulu heiluhännät, *A-este*, Agilityesteiden Myynti, acessed 22.02.2013, [ONLINE] Available: http://www.anittakerminen.fi/agi-aa.html

[37] Agimet, *A-este*, Accessed 26.02.2013, [ONLINE] Available : http://www.agimet.fi/

[38] T:mi A-este, 2012. *Esteet ja Hinnat*, Accessed 26.02.2013, [ONLINE] Available : https://sites.google.com/site/tmiaeste/benefits

[39] North Coast Pets, 1996. *Agility Equipment*, Accessed 26.02.2013, [ONLINE] Available : http://www.northcoastpets.com/agility_equipment.htm

[40] Agility warehouse, *Agility Equipment> A-frame*, Accessed 26.02.2013, [ONLINE] Available: http://www.agilitywarehouse.com/productsl3.cfm?id=292

[41] Agility A Go Go, 2013. *A-frames- 9 Foot Competition*, Accessed 26.02.2013, [ONLINE] Available: http://agilityagogo.com/esales/catalog/product_info.php?products_id=31

[42] Agilityshop.no, *Agility Utstyr*, Accessed 12.3.2013, [ONLINE] Available: http://agilityshop.mamutweb.com/Shop/List/Agilityutstyr/1/1

[43] Allsportcenter, 2010. *agilityhinder*, Accessed 12.3.2013, [ONLINE] Available: http://www.allasporter.se/agilityhinder.html

APPENDICES

Prices of A-frames

Company	size of elements (length*width)	weight	price (euro)	material frame	material surface	surface (gripp)	Elements (pieces)
Aginy (fin)	240 cm*100 cm		440	wood	plywood	sand	2
dogAntti (fin)	comp. Standards	90 kg	1680	aluminum	aluminum	rubber	2
Easy AGI, piantek Oy ltd (fin)	270 cm * 90 cm			aluminum	plywood	rubber	2
Easy AGI, piantek Oy ltd (fin)	270 cm * 90 cm			wood	plywood	rubber	2
Koirakoulu Heiluhännät (fin)		72 kg	650-900	wood	plywood	sand	2
Agimet (fin)	comp. Standards	60 kg	1685	aluminum	aluminum	rubber	2
Agimet (fin)	comp. Standards	70 kg	1984	aluminum	aluminum	rubber	2
T:mi A-este (fin)			340	wood	plywood		2
Sm@rt®-99	comp. Standards	64 kg	1388	aluminum	aluminum	rubber	2
Doggy Jumps®	comp. Standards		1100	aluminum	aluminum	rubber	2
Doggy Jumps®	comp. Standards	80 kg	926	polymer	polymer	rubber	2
Agility-equipment.com	9 ft * 3 ft	68.5 kg	910	aluminum	aluminum	paint additiv	2
Agility-equipment.com	6 ft * 3 ft		512	aluminum	aluminum	paint additiv	2
Affordableagility.com	9 ft * 3 ft	63.5 kg	720	aluminum	plywood	traction treated	2
Affordableagility.com	46 inch * 32 inch	13.6 kg	353	aluminum	plywood	traction treated	2
Action K9	9 ft * 3 ft		1054	steel	glassfiber	non skid treat-	2

Sports						ment on fiber-glass	
Action K9 Sports	9 ft * 3 ft		1461	stain-less steel	glassfiber	non skid treat-ment on fiber-glass	2
Things4YourDog.com	9 ft * 3 ft	38 kg	930	alu-minum	plywood	non slipp surfa-ce	6
Stone Moun-tain Pet Pro-ducts	9 ft * 36 inch	68 kg		alu-minum	aluminum or ply-wood	rubber	2
Circles Agility	9 ft * 3 ft		619	steel	plywood	poly metal skin	2
North coast pets	9 ft * 3 ft		665	alu-minum	plywood	boat deck	4
North coast pets	7 ft * 30 inch		490	alu-minum	plywood	boat deck	4
Agility ware-house	274 cm * 91.4 cm		1135	alu-minum	aluminum	rubber	2
Agility ware-house	9 ft * 3-4 ft	60 kg	625	wood	plywood	rubber or sand	2
Agility A Go Go	9 ft * 3 ft	95 kg	608	steel	plywood	rubber	2
Agility A Go Go	6 ft 8 inch * 30 inch	38.5 kg	325	steel	plywood	rubber	2
Agility A Go Go	5 ft * 3 ft	38.5 kg	294	steel	plywood	rubber	2
Agilityshop.no			1546	gal-viniced steel		kvartssand	2
AllSportCenter			948	gal-viniced steel	plywood		2

Convertions	3 ft= 91.44 cm
1 inch=2.54 cm	30 inch=76.2 cm
1 ft=30.48 cm	32 inch=81.28 cm
6 ft 8 inch=203.2 cm	46 inch=116.84 cm
9 ft=274.32 cm	(fin)= com-panies in fin-land

[5]-[6],[29]-[43]

Properties of 6061-T6 aluminum

Aluminum 6061-T6; 6061-T651

Composition Notes:
Aluminum content reported is calculated as remainder.
Composition information provided by the Aluminum Association and is not for design.

Key Words: al6061, UNS A96061; ISO AlMg1SiCu; Aluminium 6061-T6, AD-33 (Russia); AA6061-T6;
6061T6, UNS A96061; ISO AlMg1SiCu; Aluminium 6061-T651, AD-33 (Russia); AA6061-T651

Component Wt. % Component Wt. % Component Wt. %

Al 95.8 - 98.6 Mg 0.8 - 1.2 Si 0.4 - 0.8
Cr 0.04 - 0.35 Mn Max 0.15 Ti Max 0.15
Cu 0.15 - 0.4 Other, each Max 0.05 Zn Max 0.25
Fe Max 0.7 Other, total Max 0.15

Material Notes:

Information provided by Alcoa, Starmet and the references. General 6061 characteristics and uses: Excellent joining characteristics, good acceptance of applied coatings. Combines relatively high strength, good workability, and high resistance to corrosion; widely available. The T8 and T9 tempers offer better chipping characteristics over the T6 temper.

Applications: Aircraft fittings, camera lens mounts, couplings, marines fittings and hardware, electrical fittings and connectors, decorative or misc. hardware, hinge pins, magneto parts, brake pistons, hydraulic pistons, appliance fittings, valves and valve parts; bike frames.

Data points with the AA note have been provided by the Aluminum Association, Inc. and are NOT FOR DESIGN.

Physical Properties Metric English Comments

Density 2.7 g/cc 0.0975 lb/in^3 AA; Typical

Mechanical Properties

Hardness, Brinell 95 95 AA; Typical; 500 g load; 10 mm ball
Hardness, Knoop 120 120 Converted from Brinell Hardness Value
Hardness, Rockwell A 40 40 Converted from Brinell Hardness Value
Hardness, Rockwell B 60 60 Converted from Brinell Hardness Value
Hardness, Vickers 107 107 Converted from Brinell Hardness Value
Ultimate Tensile Strength 310 MPa 45000 psi AA; Typical
Tensile Yield Strength 276 MPa 40000 psi AA; Typical
Elongation at Break 12 % 12 % AA; Typical; 1/16 in. (1.6 mm) Thickness
Elongation at Break 17 % 17 % AA; Typical; 1/2 in. (12.7 mm) Diameter
Modulus of Elasticity 68.9 GPa 10000 ksi AA; Typical; Average of tension and compression.

Compression modulus is about 2% greater than tensile
modulus.
Notched Tensile Strength 324 MPa 47000 psi 2.5 cm width x 0.16 cm thick side-notched specimen, Kt
=

17.
Ultimate Bearing Strength 607 MPa 88000 psi Edge distance/pin diameter = 2.0
Bearing Yield Strength 386 MPa 56000 psi Edge distance/pin diameter = 2.0
Poisson's Ratio 0.33 0.33 Estimated from trends in similar Al alloys.
Fatigue Strength 96.5 MPa 14000 psi AA; 500,000,000 cycles completely reversed stress; RR
Moore machine/specimen
Fracture Toughness 29 MPa-m½ 26.4 ksi-in½ KIC; TL orientation.
Machinability 50 % 50 % 0-100 Scale of Aluminum Alloys
Shear Modulus 26 GPa 3770 ksi Estimated from similar Al alloys.
Shear Strength 207 MPa 30000 psi AA; Typical

Electrical Properties

Electrical Resistivity 3.99e-006 ohm-cm

Thermal Properties

CTE, linear 68°F 23.6 µm/m-°C 13.1 µin/in-°F AA; Typical; Average over 68-212°F range.

CTE, linear 250°C 25.2 µm/m-°C 14 µin/in-°F Estimated from trends in similar Al alloys. 20-300°C.

Specific Heat Capacity 0.896 J/g-°C 0.214 BTU/lb-°F

Thermal Conductivity 167 W/m-K 1160 BTU-in/hr-ft²-°F AA; Typical at 77°F

Melting Point 582 - 652 °C 1080 - 1205 °F AA; Typical range based on typical composition for

wrought products 1/4 inch thickness or greater; Eutectic

melting can be completely eliminated by homogenization.

Solidus 582 °C 1080 °F AA; Typical

Liquidus 652 °C 1205 °F AA; Typical

Processing Properties

Solution Temperature 529 °C 985 °F
Aging Temperature 160 °C 320 °F Rolled or drawn products; hold at temperature for 18 hr
Aging Temperature 177 °C 350 °F Extrusions or forgings; hold at temperature for 8 hr

Steel properties

Taken from
Engineering Materials 2
MA ASHBY + DRH JONES
Pergammon Press, 1988.

GENERIC IRON-BASED METALS

Metal	Typical composition (wt%)	Typical uses
Low-carbon ("mild") steel	Fe + 0.04 to 0.3 C (+ ≈ 0.8 Mn)	Low-stress uses. General constructional steel, suitable for welding.
Medium-carbon steel	Fe + 0.3 to 0.7 C (+ ≈ 0.8 Mn)	Medium-stress uses: machinery parts—nuts and bolts, shafts, gears.
High-carbon steel	Fe + 0.7 to 1.7 C (+ ≈ 0.8 Mn)	High-stress uses: springs, cutting tools, dies.
Low-alloy steel	Fe + 0.2 C 0.8 Mn 1 Cr 2 Ni	High-stress uses: pressure vessels, aircraft parts.
High-alloy ("stainless") steel	Fe + 0.1 C 0.5 Mn 18 Cr 8 Ni	High-temperature or anti-corrosion uses: chemical or steam plants.
Cast iron	Fe + 1.8 to 4 C (+ ≈ 0.8 Mn 2 Si)	Low-stress uses: cylinder blocks, drain pipes.

PROPERTIES OF THE GENERIC METALS

Metal	Cost (UK£ (US$) tonne^{-1})	Density ($Mg\,m^{-3}$)	Young's modulus (GPa)	Yield strength (MPa)	Tensile strength (MPa)	Ductility	Fracture toughness ($MPa\,m^{1/2}$)	Melting temperature (K)	Specific heat ($J\,kg^{-1}K^{-1}$)	Thermal conductivity ($W\,m^{-1}K^{-1}$)	Thermal expansion coefficient (MK^{-1})
ron	100 (140)	7.9	211	50	200	0.3	80	1809	456	78	12
fild steel	200–230 (260–300)	7.9	210	220	430	0.21	140	1765	482	60	12
ligh-carbon steel	150 (200)	7.8	210	350–1600	650–2000	0.1–0.2	20–50	1570	460	40	12
ow-alloy steels	180–250 (230–330)	7.8	203	290–1600	420–2000	0.1–0.2	50–170	1750	460	40	12
ligh-alloy steels	1100–1400 (1400–1800)	7.8	215	170–1600	460–1700	0.1–0.5	50–170	1680	500	12–30	10–18
ast irons	120 (160)	7.4	152	50–400	10–800	0–0.18	6–20	1403			
opper	1020 (1330)	8.9	130	75	220	0.5–0.9	>100	1356	385	397	17
rasses	750–1060 (980–1380)	8.4	105	200	350	0.5	30–100	1190		121	20
ronzes	1500 (2000)	8.4	120	200	350	0.5	30–100	1120		85	19
lickel	3200 (4200)	8.9	214	60	300	0.4	>100	1728	450	89	13
fonels	3000 (3900)	8.9	185	340	680	0.5	>100	1600	420	22	14
uperalloys	5000 (6500)	7.9	214	800	1300	0.2	>100	1550	450	11	12
luminium	910 (1180)	2.7	71	25–125	70–135	0.1–0.5	45	933	917	240	24
000 Series	910 (1180)	2.7	71	28–165	70–180	0.1–0.45	45	915			24
000 Series	1100 (1430)	2.8	71	200–500	300–600	0.1–0.25	10–50	860		180	24
000 Series	1000 (1300)	2.7	71	40–300	120–430	0.1–0.35	30–40	890		130	22
000 Series	1100 (1430)	2.8	71	350–600	500–670	0.1–0.17	20–70	890		150	24
asting alloys	1100 (1430)	2.7	71	65–350	130–400	0.01–0.15	5–30	860		140	20
itanium	4630 (6020)	4.5	120	170	240	0.25		1940	530	22	9
i–6 Al 4 V	5780 (7510)	4.4	115	800–900	900–1000	0.1–0.2	50–80	1920	610	6	8
inc	330 (430)	7.1	105		120	0.4		693	390	120	31
ead–tin solder	2000 (2600)	9.4	40					456			
iecasting alloy	800 (1040)	6.7	105		280–330	0.07–0.15		650	420	110	27