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Faculty of Engineering Science and Technology
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First Aid Equipment for Use in Cold Climate Environment: Stretcher

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Master's Thesis in Engineering Design (SHO6263) … June, 2017

Master of Science

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Abstract:

There is a need for a stretcher, which can also function as a sledge, especially for rescue missions in arctic climate, as the extraction point may only be accessible by people by foot or on skies. Existing solutions have some flaws, and some are not specifically designed for arctic conditions. The task is to develop a multi-purpose stretcher, operable by two members of the rescue team.

In solving the problem, typical engineering design methods and knowledge acquired throughout the master study is utilized, including design methodologies, CAD-modelling, material and process selection, and finite element analysis.

The solution is a modular and robust stretcher, which can be used as a sledge. It satisfies requirements set by the task description, user and the governing standard for first aid equipment.

The results are promising given the approximations and simplifications applied.

Preface

Narvik/June 6th 2017

This master thesis is written by two graduates from the master program of Engineering Design at UiT - The Arctic University of Norway, campus Narvik, under supervision from Guy B. Mauseth, Associate Professor at UiT and Andreas Seger, Research Fellow/PhD Candidate at UiT.

The assignment is given by the Department of Computer Science and Computational Engineering, Narvik, and the main purpose is to develop a stretcher that can also function as a sledge in cold climate environments.

The design process follows the methodology presented by Nigel Cross in his book *Engineering Design Methods*, and the best solution is created in 3D-modelling software *SolidWorks*. A thorough material and process selection is conducted, prior to performing comprehensive mechanical analyses, and a physical model (scaled 1:9) of the final design is 3D-printed.

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Abstract

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Table of Content

List of Figures

List of Tables

Abbreviations

CAD	Computer Aided Design
CES	Cambridge Engineering Selection
CPR	Cardiopulmonary Resuscitation
CAT	Computed Axial Tomography
FEA	Finite Element Analysis
FEM	Finite Element Method
HDPE	High Density Polyethylene
HOQ	House of Quality
PE	Polyethylene
SAR	Search and Rescue
TIG	Tungsten Inert Gas

Outline of the Master's Thesis

Chapter 1: Introduction
Gives a brief understanding of the problem and limitations for the thesis.

Chapter 2: Preliminary Study
A quick run through of general history of stretchers and a superficial study of potential competitors and existing products.

Chapter 3: Design Process
Focuses on going through all the necessary models and processes to ensure that the product fulfills its purpose and function.

Chapter 4: Material Selection
A step-by-step process for choosing a suiting material for the body and frame of the stretcher.

Chapter 5: Detailed Design
An in depth description of details of the design, with high resolution figures.

Chapter 6: Manufacturability and Cost
Brief analysis of possible manufacturing methods and cost approximations.

Chapter 7: Mechanical Analysis
An analytic and numerical computer assisted analysis of three different cases; ideal conditions, stop on top of a rock, and torsion. All results are evaluated and discussed.

Chapter 8: Discussion
Concerns further work and the authors own thoughts about learning outcome of writing the thesis.

Chapter 9: Conclusion
A quick conclusion of the master's thesis.

Chapter 1: Introduction

1.1 Background

One of the research topics of the nursing department at UiT campus Narvik is wildlife medicine, and in particular wildlife medicine in arctic environment. The university aims to unite the medicine department with technology studies increasingly, hence, the topic of this master thesis. In this case, two students from the department of Engineering Science and Technology, in the program Engineering Design, are to design and perform virtual analysis on a stretcher, which could also be used as a sledge in arctic conditions.

The stretcher is a solution to the problem where a person might have sustained an injury during outdoor activity in the winter period, and he or she is lying on the ground/snow in need of rapid transportation to the hospital. The injury might be caused due to a snowmobile accident, skiing accident, falling through the ice of a frozen lake, being taken by snow avalanche, etc. In any case, the person cannot get up on his feet. In some cases, the extraction point is only accessible by people on skis or by foot, and in such cases, there is a need of developing a stretcher, also functioning as a sledge, which can be carried or pulled by two persons of the rescue team.

There are several existing solutions of search and rescue (SAR) stretchers on the market, but feedback from people who are involved with SAR-operations (mainly Røde Kors Hjelpekorps Harstad) shows that many of the existing products have significant drawbacks – especially considering rescue missions in arctic climate.

1.2 Problem Description

The objective for this master thesis is to improve the design of a portable stretcher for use in first aid cases in cold climate. The stretcher must also function as a sledge, which can be steered by one or two skiers through technical downhill slopes and over other obstacles in the terrain.

Requirements are that the stretcher should be light-weight, foldable, robust, and possible to operate with winter gloves and keep the patient warm. It must function in subzero temperatures, on snow and ice, tolerate sharp objects like rocks, and ensure a comfortable and safe transportation for the patient.

In solving the problem, an engineering design methodology is performed prior to creating a 3D CAD-model and detailed 2D-drawings of the product. In addition, a prototype of the product is created using a rapid prototype machine (3D-printer). An in-depth material selection process is performed to eliminate materials not suited for the product, and resulting in a few appropriate materials. Virtual analysis is performed on the 3D CAD-model in *ANSYS Workbench 16.2*, including deflection of the stretcher under a given weight and reactions to torsional forces.

Full problem description of the master thesis can be found in appendix A.

1.3 Limitations

The students acknowledge their novice skills with software such as *ANSYS*, *SolidWorks* and *CES*, which are used to complete this thesis, and consider this a limitation of the project and final product.

Considering the 3D modelling of the product, smaller parts and finer mechanical details (like hinges and springs) are not the main focus. Analysis in *ANSYS* and *CES* are performed with simplifications of the problem, reasonable assumptions and with approximations. The analytical results may differ from the computer assisted numerical results. Regarding the numerical calculations, only deflection, equivalent stress and shear stress is evaluated.

Material selection in *CES* could only be solved in level 2 as level 3 is not available in the license given to us by the university, meaning limited materials to choose from, however, it should suffice.

The final report itself should not exceed 50 pages (excluding appendix) and is a physical limitation for this thesis.

Chapter 2: Preliminary Study

2.1 History

Emergency stretchers has been used all over the world for centuries. Many different types of stretchers have emerged throughout the years, including good and reliable solutions, and some are inadequate. The most commonly used is the *simple stretcher*, which is made up by a canvas or synthetic material suspended between two long poles. This classic version is still widely used by the military in various operations, whilst the western world civil ambulance and rescue organizations has started using more sophisticated and innovative stretchers.

In confined spaces, slopes, wooded terrain and other hazardous obstacles to movement, the *rescue basket*, also known as *Stokes Basket*, is a good choice. It is usually made by wiring a basket, or as a solid plastic basket, as illustrated in figure 1. The patient is strapped, face up, into the basket under transportation. The raised sides acts as a shield against external hazards, thus preventing possible post-trauma situations. This type of stretcher can either be lifted by two or more persons, towed behind skis/snowmobiles/ATV as a sledge and even hoisted by helicopters if certified, thus, making it a "go-to" product by many emergency rescuers.

Figure 1: Stokes basket [1].

2.2 Direct Research

As part of the preliminary study, interviews with people familiar with SAR-operations were conducted. The objects were asked about their experiences (positive and negative) with the stretcher they normally use, and if they could think about limitations (like mobility, weight, and functionality). It is also of interest to know how far they usually walk with the stretcher, how they carry it, and if there is any adjustments that could be made to make it easier for the personnel during SAR-missions.

Interviews were conducted with personnel from Røde Kors Harstad and our supervisor, Andreas Seger, who is a volunteer in Røde Kors Hjelpekorps Narvik. All objects said the most important parameter is safety, both for the rescue team themselves and the patient. The stretcher must be reliable, meaning that the stretcher will tolerate the given environment (extremely cold climate, being pulled over snow and rocks and such), and if a part breaks, it can easily be fixed. Partly because the personnel should be able to perform a quick fix on the stretcher at the site or during the mission, as time is of the essence, and partly because Røde Kors Hjelpekorps has limited resources, and may not afford to replace expensive parts or buy a new stretcher if something fails. This indicates that the stretcher should consist of few and simple parts, which are easy to replace.

Seger spoke of his experience with SAR-missions and one of the stretcher he has used in rescue missions, the *Tyromont* stretcher (see sub-chapter 2.4 for more information). He said he preferred a modular stretcher, so that the stretchers weight is divided on two members of the rescue team when they walk to the emergency site. Mechanisms of assembling the stretcher must be simple, intuitive and reliable.

Knowledge and information acquired in this phase of the project has been useful throughout the design process, and translated into value proposition, product requirements and characteristics.

2.3 Customer, Value Proposition and Market Need

Among possible customers, Røde Kors and the Norwegian Army are identified, in addition to all organizations in need of a reliable SAR-stretcher for cold and challenging environment.

The stretcher should give the SAR-team (direct user) a feeling of *security* and *reliability*, and the patient (indirect user) should feel *safe* and *comfortable* during the extraction. We want to give the users a unique stretcher that is simple in its design without compromising functionality.

The market need is formulated as: "*There is a need for a stretcher that can be carried or pulled by two members of the rescue team, through terrain only accessible on skis or by foot".*

2.4 Potential Competitors

The following subchapter present existing equipment and potential competitors, described with respect to behavior, structure, weight and size. Drawbacks of the products is investigated, and a comparison of the different stretchers are presented in table 1.

Light Emergency Stretcher Systems (LESS)

LESS aims to be the leading supplier of safety equipment for larger accident sites, and they deliver different kinds of stretchers and sails, in addition to other equipment, including compact heaters, containers and tents [2].

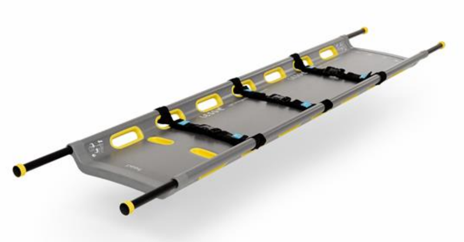

Figure 2: LESS PRO 4001 [3] .

The stretcher in figure 2 must be operated by at least two people, maneuvering the stretcher with the retractable handles. However, up to seven people could assist on each side of the stretcher. The patient is strapped to the stretcher and secured. This is a lightweight design at 6.5 kg, which also acts isolating and prevents hypothermia. The manufacturing process and sandwich structure is patented by *LESS*. The stretcher floats in water with 20 kg buoyancy, enough to keep a grown man floating. It is possible to perform CAT-scanning and X-ray while the person is on the stretcher, but MR-examinations is not possible due to the material making up the frame [3]. Drawbacks of this design is that it is not foldable and cannot be used as a sledge.

Vite

Vite a compact stretcher designed for a one-man rescue mission in snow and challenging terrain, presented in figure 3. The design/concept is not meant for professional rescuers, but for people living in the mountains. It intends to be an easy and accessible stretcher that can be collapsed into a small backpack, and carried for longer distances without the operator getting exhausted. There is some uncertainty around the fact if the concept is developed, patented or produced, as this concept is only "stumbled upon" on the internet, without any luck finding more information about it. However, it is considered to be a state-of-the-art concept design, compared to the one mentioned above.

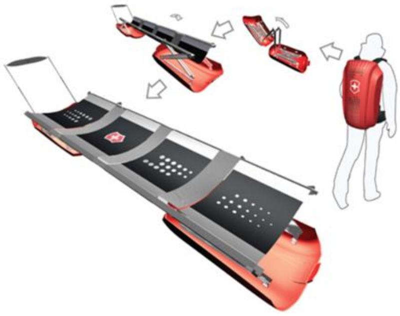

Figure 3: Vite Stretcher [4].

Tyromont

Tyromont delivers a range of stretchers, including the *UT2000* model in figure 4, which can be split into two parts, and carried to the emergency site on the back of two members of the rescue team. Tyromont claims the stretcher could be used on all kinds of terrain, as the lying part is made of a special, durable plastic, which is shock- and scratch resistant, with excellent gliding abilities. The wide and padded shoulder belt (for transportation to emergency site) ensures optimum load distribution and high comfort. Helicopter suspension belts are included.

Figure 4: Tyromont UT2000 [5].

Ferno Norden

Model 71 is designed as a basket-stretchers which is ideal for most emergency rescue operations. The stretcher is available in two different models, one model which is a solid body (left side of figure 5), and one which can separate into two bodies, for easier transportation when not in use (right side of figure 5). Both are produced in High Density Polyethylene (HDPE) with an aluminium frame which strengthens its structural characteristics. The stretcher comes with a mattress and adjustable footrest for the patient's comfort.

Figure 5: Ferno Norden model 71 (left side) [6] and model 71s (right side) [7].

Table 1: Comparing existing solutions.

	LESS PRO 4001	Vite Stretcher	Tyromont UT2000	Ferno Norden Model 71s
Selling price (inc. vat.)	NOK 5589,- [9]	Unknown	NOK 24 000,-	NOK 18 125,- [7]
Weight	6.5 kg [3]	Unknown	8.2 kg [8]	10-16 kg [6] [7]
Dimensions	Width: 442 mm Height: 92 mm Length 1925 mm	Unknown	Width: 440 mm Height: 120 mm Length 1810 mm [8]	Width: 620 mm Height: 200 mm Length 2160 mm [6]
Loading Capacity	Unknown	Unknown	160 kg (one person) [8]	272 kg [6]
Operating Temperature	-25°C to +35°C [3].	Cold Climate	-50°C to +100°C [8]	-40°C to +60°C [6]
What makes it special	20 kg buoyancy [3]. Possibility to perform CAT-scan and X-ray examinations [9].	Collapsible into a small backpack and operable by one person.	Two part stretcher, easy transportation on the back of two persons. Helicopter suspension belts incl. Lots of accessories available. Easy to fold/unfold.	Strong construction, can separate into two parts for easier transportation.
Drawbacks	Not foldable and cannot be used as a sledge.	May seem like it is not that durable and has many “fine” mechanisms that may require bare hands to adjust.	There is a “flap” on the underside which accumulate snow and dirt when dragged. Expensive.	Expensive.

Chapter 3: Design Process

3.1 Design Objectives

The objective tree in figure 6 present the main objectives for the stretcher, which are associated with safety, efficiency, convenience and ease of manufacturing. These main objectives are split into sub-objectives, among them are light weight, safe for patient and personnel, possible to operate with winter gloves, etc. In clarifying the objectives, it’s assumed that the product is designed to satisfy three different users’ needs; SAR personnel (*foldable*, *possible to operate with winter gloves*, *low weight*, *transport on snow*), patient (*comfort*, *safety*, *stability*), and medical staff (*possible to examine patient and performing CPR while he/she is lying on the stretcher*). In addition, there are objectives concerning environmental factors and manufacturing.

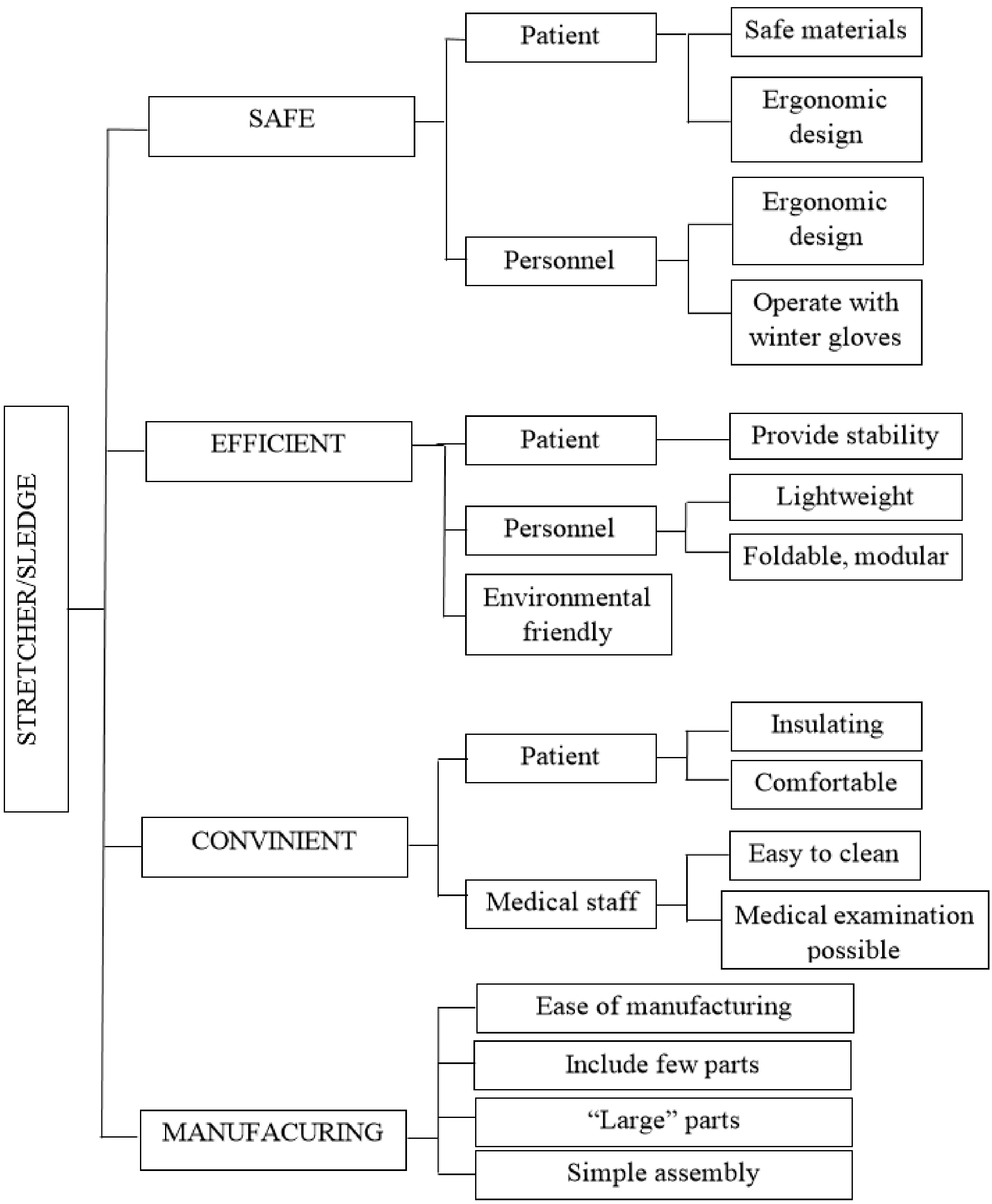

Figure 6: Objective tree.

3.2 Functions

The main purpose of the stretcher is to transport a person in need, from A to B, as safe, effortless and quick as possible. By this statement it is possible to derive four main functions and the underlying sub-functions/features, which are all vital and critical for the design and product to function properly;

1. Able to safely transport a person in need
    - Stiff enough frame/body
    - Possibility to lift or drag stretcher
2. Prevent post-traumatic injuries
    - Tightening mechanisms
    - Insulating and shock absorbent mattresses
    - Neck support
3. Function as a sledge if needed
    - Strong, hard and low friction material of gliding surface
    - Additional towing harnesses
4. Simple, intuitive and reliable mechanisms
    - Folding/splitting mechanisms has to be easy and reliable
    - Few loose components
    - Little maintenance work
    - Operable with thick gloves

3.3 Requirements

The requirements for the stretcher/sledge found in table 2 are compiled by looking at the Norwegian standard NS-EN 1865 *Patient handling equipment used in road ambulances* part 1, investigating similar concepts already on the market, talking to people familiar with SAR-missions, and by analyzing the task description. The requirements are marked as demand (D) or want (W), where demands are non-negotiable performance specifications and wants are more or less optional.

Table 2: Requirements for the stretcher/sledge.

No.	**D or W**	**Requirements**
		<u>Geometry</u>
1	W	Few parts (<10 parts)
2	D	Foldable
3	W	Total weight less than 15 kg
4	W	Fits people with different body types
5	D	Loading capacity of 150 kg [10]
6	D	Static loading capacity of 3000 N [10]
7	W	Dimensions of lying part: L: 2100mm, H: 200 mm, W: 500m
		<u>Material</u>
8	D	Light-weight
9	D	Non-toxic
10	D	Non-allergenic
11	D	Operating temperature -40°C to +50°C
12	D	Insulating
13	D	High fracture toughness, high stiffness, high strength
		<u>Safety</u>
14	D	Operate with winter gloves (folding, unfolding, adjusting and carrying)
		<u>Ergonomics</u>
15	D	Easy to fold/unfold
16	D	Easy to clean and disinfect
17	W	Easy to secure the patient
		<u>Production and Manufacturing</u>
18	W	Simple component production
19	W	Use well known production techniques
		<u>Life expectancy and Recycling</u>
20	D	Life expectancy >5 years
21	W	Ease of recycling
22	W	Environmental friendliness
		<u>Cost</u>
23	W	Selling price less than NOK 15 000,-

As the standard states, all equipment with the objective to carry a person shall be free of any sharp edges, with a minimum radius of 0.5 mm. Restraint-systems shall have a quick release system, and the carrying handles shall be fixated in extended position. The lying part (plate) of the stretcher shall be made of a strong material which is bacterial resistant, easy to clean and disinfect, washable, waterproof and petrol-oil resistant [10].

3.4 Characteristics

Using the House of Quality (HOQ) method, the most important characteristics of our product are identified as; *materials, dimensions, locking mechanism* and *weight of the product*. By focusing on optimizing these characteristics, the stretcher/sledge may have an advantage over other competitors. The HOQ-spreadsheet is found in appendix B.

3.5 Generating Alternatives

To explore some of the possible combinations of functions and features, three alternatives are generated using the Morphological Chart Method in table 3.

Table 3: Morphological chart for generating alternatives.

Function	1	2	3	4
Solution for carrying a patient	Basket [11] 	Rigid traditional [12] 	Military issue [13] 	Inflatable [14] 
Function for folding/ collapsing	Two bodies [7] 	Mid fold 1 [15] 	Mid fold 2 [16] 	Deflatable [14] 
Handles	Transverse handles [17] 	Retractable handles [12] 	Utility holes [7] 	Rotatable handles 
Tightening mechanism	Harness clips [18] 	Velcro [19] 	Airplane locking [20] 	
Provide heat and comfort, keeping patient warm	Insulating and shock absorbent mattress [21] 	Heating elements [22] 	None	
X-ray, CAT-scan compatible	Yes	No		

3.5.1 Feasible solutions

Alternative 1 is illustrated in figure 7, by the red line in table 3. It is an inflatable stretcher, similar to a standard life raft; the stretcher is compact when folded, preferably to fit into a backpack or similar. The stretcher must be stiff enough to avoid too much movement, meaning that the air pressure inside must be high. Material selection is essential considering this alternative, as the inflatable stretcher must tolerate cold climate, sharp edges (rocks, bushes), when it is used as a sledge.

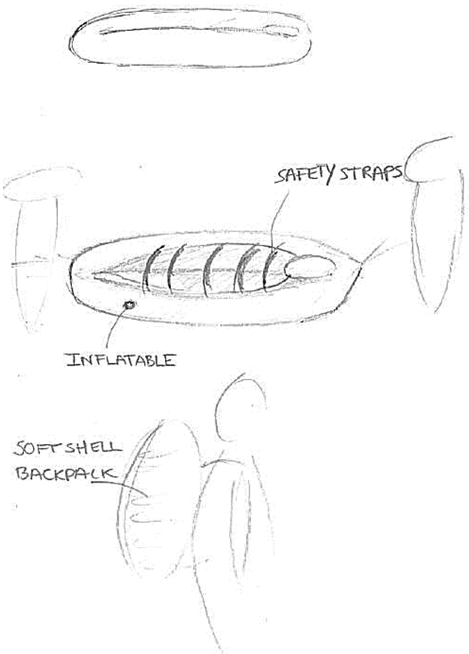

Figure 7: Conceptual sketch of alternative 1.

The SAR-personnel carry the stretcher using utility holes, in this case using ropes which are attached around the stretcher. When using the stretcher as a sledge, the rescue team may connect straps to the inflatable stretcher and their own bodies. The patient is fastened by a set of harness clips and kept warm by accessories the team brought along. The materials making up the stretcher is X-ray and CAT-scan compatible, however, the shape of the stretcher present a challenge regarding these medical examinations.

Alternative 2 is illustrated in figure 8, by the blue line in table 3, highly inspired by the common *rescue basket*. Some of the already existing products on the market has flaws with the design, considering material properties and the overall functionality of the product, including being heavy, not stiff enough, expensive and complicated mechanisms.

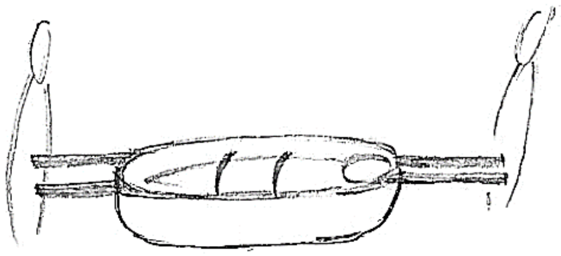

Figure 8: Conceptual sketch of alternative 2.

Alternative 2 is aiming at being a safe, as light as possible, stiff and user friendly stretcher and sledge hybrid, that can quickly be separated into two parts (see figure 9). This is obtained by making a rigid metal frame surrounded by a stiff and strong plastic body, removable handles that can quickly attach and detach to the frame, airplane inspired belt-straps to quickly and safely fasten the patient, and an insulating/shock absorbent mattress.

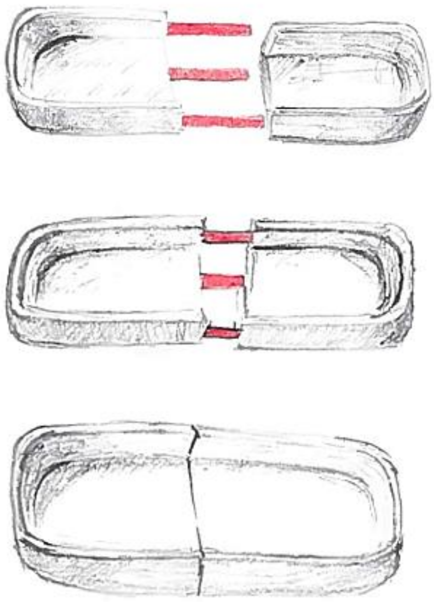

Figure 9: Folding/collapsing function of alternative 2.

The third alternative (green line in table 3) is a stretcher with a traditional cross-sectional shape, with mid folding on the longitudinal axis, harness clips for strapping the patient to the stretcher and an insulating mattress. The interesting part of alternative 3 is the rotational handles, which enables the stretcher to be used as a sledge, by mounting a pair of skis to one set of handles, as illustrated in figure 10, 11 and 12.

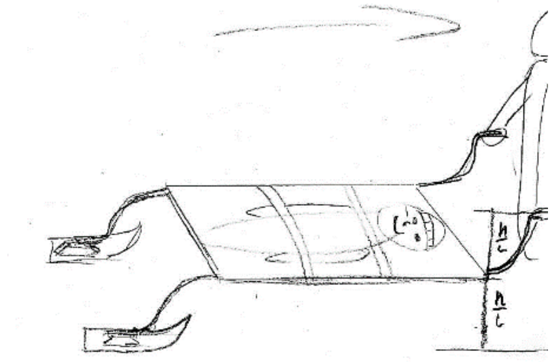

Figure 10: Detailed presentation of alternative 3, used as a sledge.

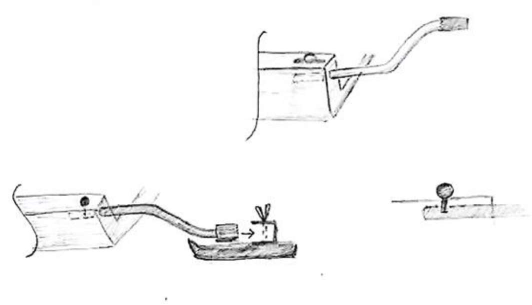

Figure 11: Rotating handles, mounting skis and locking mechanism for handles.

One (or both) members of the SAR-team can use straps attached to the stretcher/sledge to hold and steer it. The stretcher is made up of material which enables medical staff to perform medical examinations (X-ray, CAT-scan) and safety straps on the patient is placed so that CPR is possible to perform while the patient is lying on the stretcher.

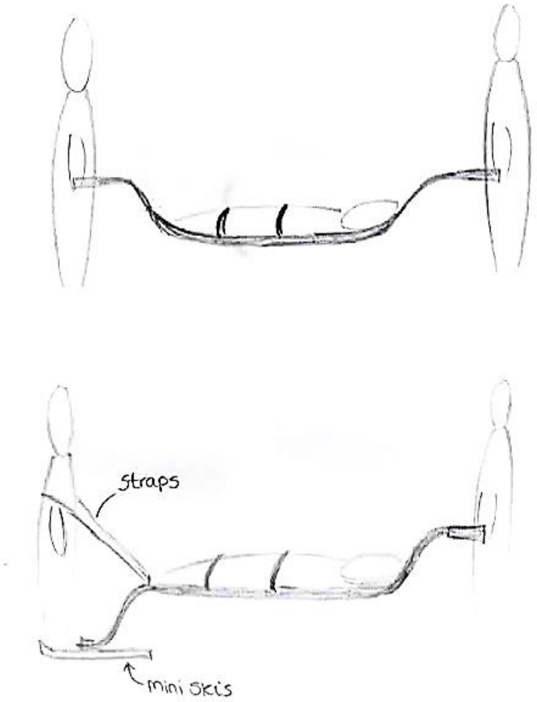

Figure 12: Conceptual sketch of alternative 3.

3.6 Evaluating Alternatives

Objectives obtained from the objective tree (figure 6) and results from HOQ are evaluated according to each other, and given a value in table 4. If objective A is more important than objective B, the respective cell will have a value of one. If objective A is considered less important than objective B, the value will be zero.

Table 4: Evaluating objectives according to each other.

Objectives		A	B	C	D	E	F	G	H	I	Row sum	Weight
Provide stability/carry an injured person	A	-	1	1	1	1	1	1	1	1	8	0,22
Function as a stretcher and a sledge	B	0	-	1	0	1	1	1	0	1	5	0,14
Foldable	C	0	0	-	0	1	1	0	0	1	3	0,08
Lightweight (easy to carry)	D	0	1	1	-	1	1	1	0	1	6	0,17
Medical examinations possible	E	0	0	0	0	-	1	0	0	1	2	0,06
Easy to clean	F	0	0	0	0	0	-	0	0	1	1	0,03
Easy to manufacture (few and "large" parts)	G	0	0	1	0	1	1	-	0	1	4	0,11
Possible to operate with winter gloves	H	0	1	1	1	1	1	1	-	1	7	0,19
Attractive design	I	0	0	0	0	0	0	0	0	-	0	0,00
Sum											**36**	**1,00**

The result is the weight in percentage at the right side of table 4. The next step is to evaluate the alternatives generated in chapter 3.5 considering each objective based on how well they meet the design objectives (score, S ranging from 0-10), and finally compare the total weighted score (Utility, $U = W \cdot S$) for all alternatives, see table 5.

Table 5: Evaluation chart for the stretcher/sledge, comparing alternative 1, 2 and 3.

Evaluating chart		Alternative 1		Alternative 2		Alternative 3	
Ranged objectives	**Weight**	**S**	**U**	**S**	**U**	**S**	**U**
Provide stability/carry an injured person	0,22	4	0,89	9	2,00	6	1,33
Possible to operate with winter gloves	0,19	5	1,11	7	1,56	5	1,11
Lightweight (easy to carry)	0,17	6	1,33	6	1,33	8	1,78
Function as a stretcher and a sledge	0,14	3	0,67	7	1,56	4	0,89
Easy to manufacture (few and "large" parts)	0,11	7	1,56	6	1,33	4	0,89
Foldable	0,08	10	2,22	8	1,78	8	1,78
Medical examinations possible	0,06	2	0,44	5	1,11	7	1,56
Easy to clean	0,03	3	0,67	8	1,78	8	1,78
Attractive design	0,00	5	1,11	5	1,11	5	1,11
Overall utility			**10,00**		**13,56**		**12,22**

From table 5, alternative 2 is considered the one who best meets the demands and objectives, and this concept will be pursued further, with a comprehensive material selection, detailed design and CAD-model, and manufacturability analysis.

Chapter 4: Material Selection

For the selection of materials, a methodology presented by Michael F. Ashby in his book *Material Selection in Mechanical Design* is followed and supplied with *CES* software, a database which contains records for materials and manufacturing methods, organized in a hierarchy.

4.1 Frame Material

For simplicity, the frame is considered a light, stiff beam, with design requirements as summarized in table 6.

Table 6: Design requirements for the frame of the stretcher/sledge.

Function	Stiff frame (light, stiff beam).
Constraints	a. Must not fail under design loads - a strength constraint, b. Dimensions (length and width) specified, c. Operating temperatures range from -40°C to +50°C, d. Weldable, e. Endure water and disinfectant (ethanol), f. Low cost.
Objective	Minimizing mass.
Free variables	Choice of material, Section shape.

Stage 1

Using the Ashby's method for a light, stiff beam with a cross-section with only one free variable (thickness), the material index that is to be maximized is as follows:

$$M = \frac{E^{\frac{1}{3}}}{\rho} \qquad \text{(Eq.1)}$$

This linear line is plotted in *CES* in a Young's modulus vs. density-chart with an index slope of 3, see figure 13. To maximize the material index *M*, all materials below the line is eliminated from the material search. After stage 1, there are 66 different materials selected (out of a total of 100). Documentation of all choices made at each of the following stages can be found in appendix C.

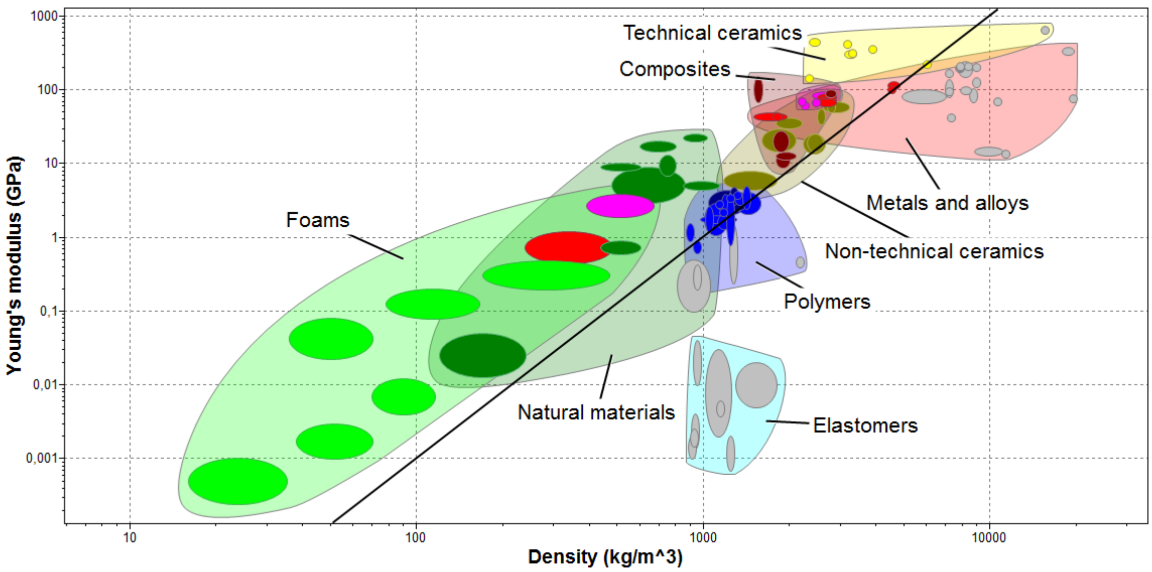

Figure 13: Young's modulus vs. density chart, obtained from CES.

Stage 2 - Thermal Properties

Operating temperatures range from -40 degrees to +50 degrees. This limit is specified as minimum and maximum service temperature. There are 65 different materials selected after stage 2, presented in figure 14.

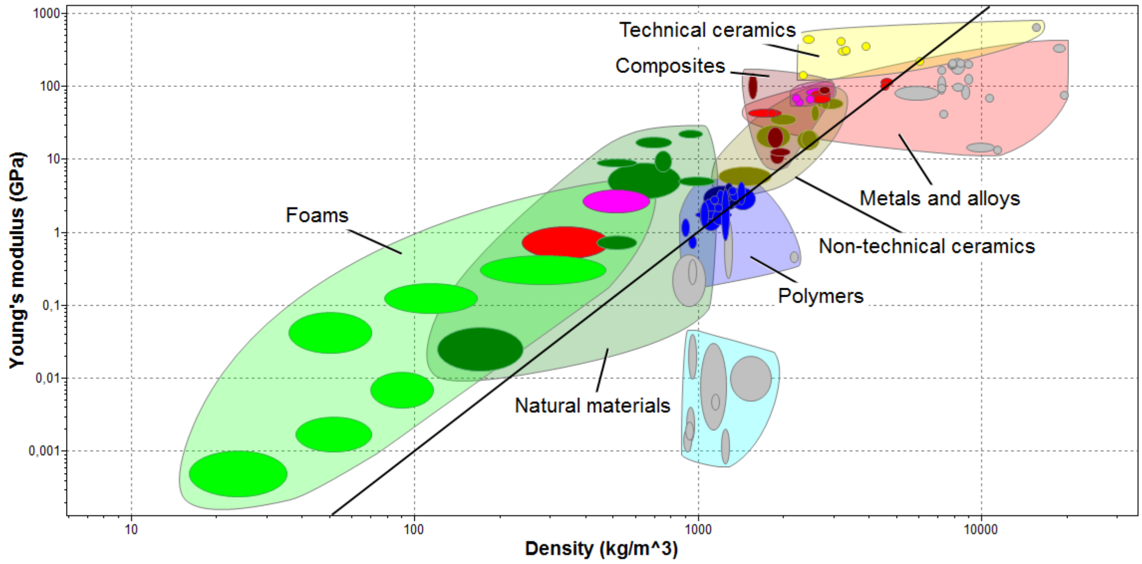

Figure 14: Result after stage 2.

Stage 3 - Mechanical Properties

To avoid too much deflection, the material must be stiff enough. To provide necessary stiffness, Young's modulus (modulus of elasticity) is set to minimum E = 5 GPa. In addition, a lower limit for fracture toughness is set to 10 $MPa \cdot m^3$, as the construction should tolerate the given environment without cracking. At this stage, there are 13 materials left to choose from, see figure 15.

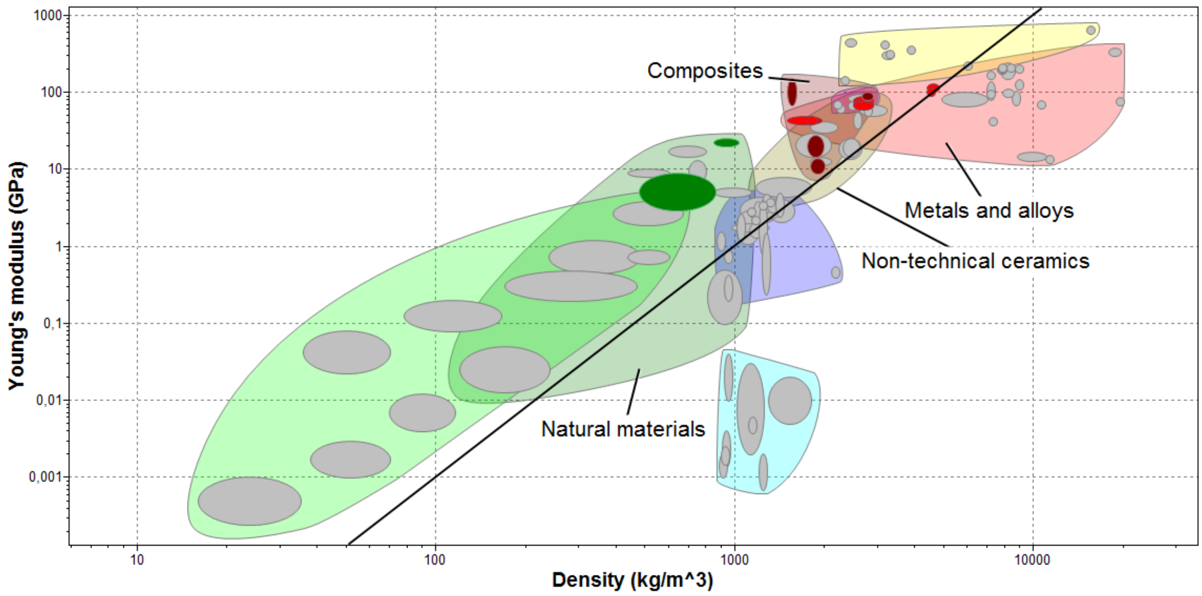

Figure 15: Result after stage 3.

Stage 4 - Durability

The frame must have excellent/acceptable durability in fresh and salt water, and in ethanol (disinfectant). Applying this limit, there are 7 materials left to choose from. Figure 16 present a graph with stage 4 applied.

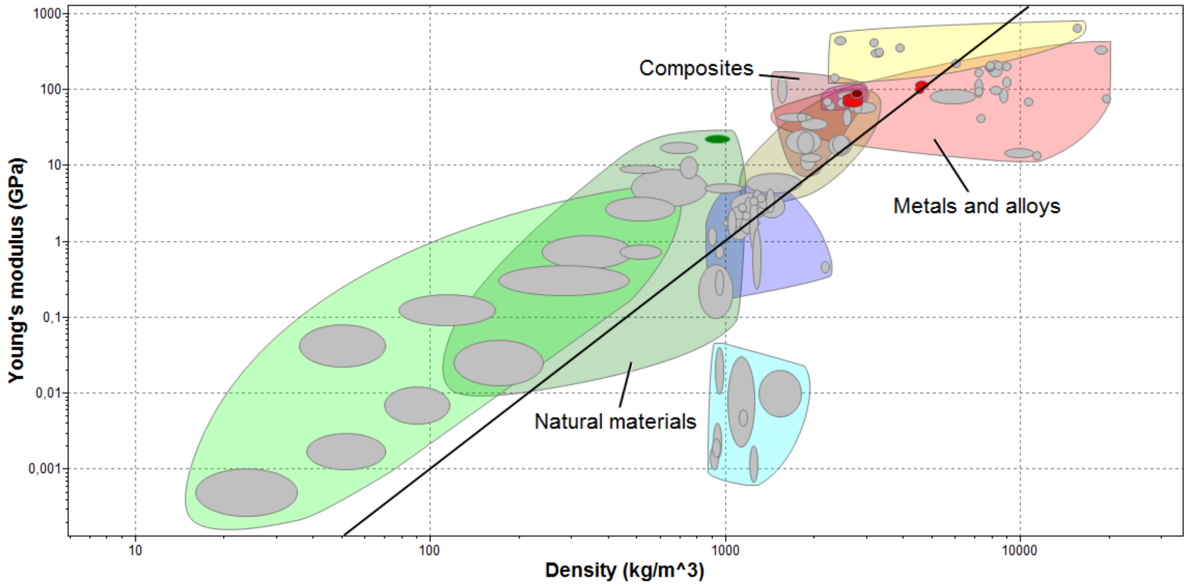

Figure 16: Result after stage 4.

Stage 5 - Environmental Requirements

The material should be recyclable and non-toxic, given environmental requirements. Figure 17 shows the result from stage 5, and after this stage, there are 6 materials to choose from.

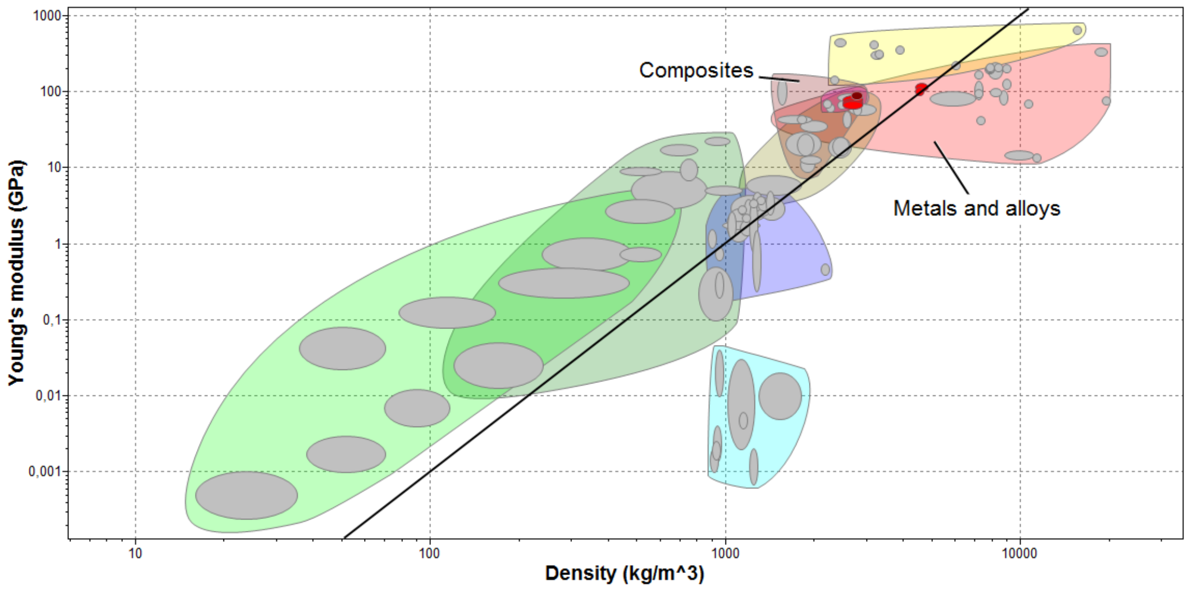

Figure 17: Result after stage 5.

Stage 6 - Processability

The design of the frame itself requires that the material must be weldable with good machinability, and we are left with 5 materials; age-hardening wrought Al-alloys, non-age-hardening wrought Al-alloys, cast Al-alloys, titanium alloys and commercially pure titanium, presented in figure 18. In the following, aluminium alloys and titanium alloys in general are evaluated.

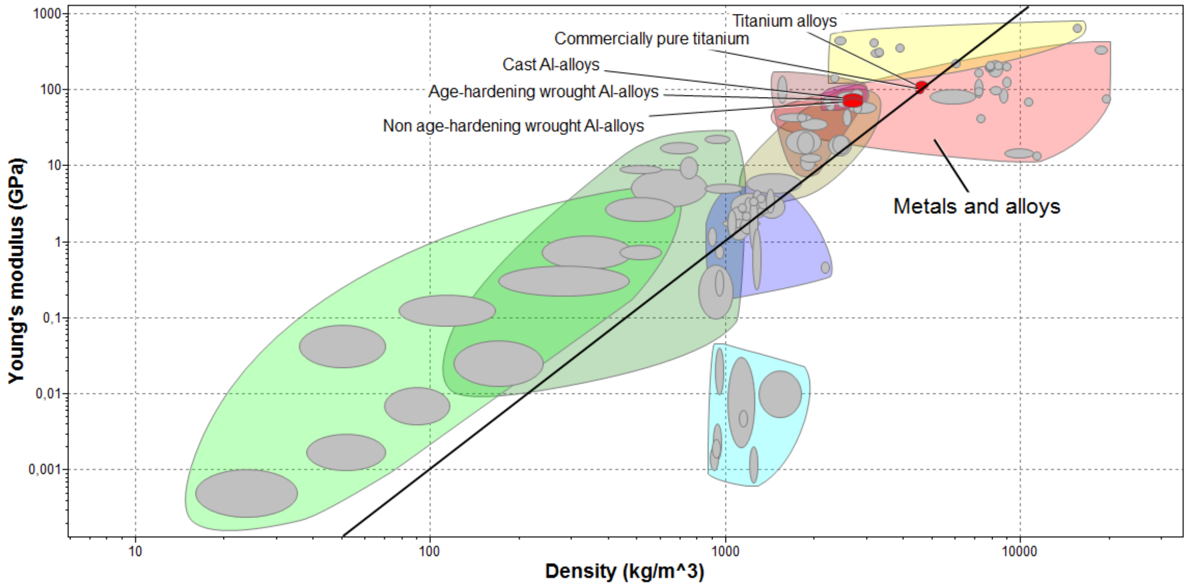

Figure 18: Result after material selection process for the frame.

Remaining materials after applying limits:

Titanium alloys have the highest strength-to-weight ratio of any structural metal, about 25 % greater than the best alloys of aluminium or steel, with excellent corrosion resistance. They are expensive (more than ten times the price of aluminium), and require vacuum processing to prevent oxygen take up, which makes the alloy brittle. Titanium alloys can be welded, but the process is difficult and requires experienced personnel. [23]

The exceptional strength and low density of titanium makes it a good candidate for the frame material, however, it is eliminated due to the high cost and manufacturing difficulties.

Aluminum alloys are generally light and strong, at a relatively low cost. Properties of al-alloys depend on the chemical composition of the alloy, as other elements are added to pure aluminium in order to enhance its properties, primarily to increase strength, however, density, workability, electrical conductivity and corrosion resistance are also affected [23]. Aluminium alloys tend to lose some of their strength when exposed to high temperatures, however, their strength can be increased at subzero temperatures, thus making them an excellent choice of material for an arctic climate SAR-stretcher.

The 6xxx series of al-alloys (age-hardening wrought al-alloys), 6060, 6061 and 6063 in particular, are considered feasible for the frame material, and they are presented with forms, characteristics and properties, and common applications in table 7. The 6xxx series are heat-treatable, weldable, and highly formable with medium to high strength and excellent/good corrosion resistance [24]. Extrusion is the first choice for manufacturing of products for structural applications, and suppliers offer a range of cross-sections, some of the forms which are mentioned in table 7.

Table 7: Comparing feasible aluminium alloys.

Alloy	Forms	Characteristics and Properties	Applications
6060	Extruded • Tube • Bar • Pipe • Rod [25]	• Very good weldability, • Medium strength, • Good formability, • Very good corrosion resistance, • Suitable for complex cross-sections. [25]	Architectural sections, frames, railing, ladders, fences, furniture, etc. [25]
6061	Extruded • Tube • Bar • Pipe • Rod [26]	• Very good weldability, • Medium to high strength, • Good workability, • Good toughness, • Excellent corrosion resistance to atmospheric conditions and good corrosion resistance to salt water, • Widely available, • Not very suitable for complex cross-sections. [26]	Aircraft and aerospace component, bicycle frames, transport, valves. [26]
6063	Extruded • Tube • Bar • Pipe • Rod [27]	• Very good weldability, • Medium strength, • Very good corrosion resistance, • Good formability. [27] [28]	Architectural applications, chassis tubes, window frames, road transport, rail transport. [27] [29]

General description of age-hardening wrought al-alloys can be found in appendix D.

4.2 Body Material

As for the frame, the body of the stretcher is also considered a light, stiff beam, with design requirements presented in table 8.

Table 8: Design requirements for the body of the stretcher/sledge.

Function	Support a load.
Constraints	a) Length L and width of lying part b is specified, b) The component must carry a load of minimum 150 kg, c) Must not distort more than δ when forces act on the component, d) When both loading force and maximum distortion is specified, the bending stiffness S is also specified, e) Operating temperatures range from -40°C to +50°C, f) Endure water and disinfectants, g) Low cost.
Objective	Minimizing mass.
Free variables	Thickness of cross-section t, Choice of material

Stage 1

Deriving the same material index as for the frame using equation (1), with a slope of 3 for the index line in a Young's modulus vs. density-chart in *CES*, see figure 19. The objective is to minimize the mass, and to do so, the material index M and the index line in *CES* must be maximized. At this stage, there are 66 materials to choose from (out of a total of 100). Documentation of the following stages can be found in appendix E.

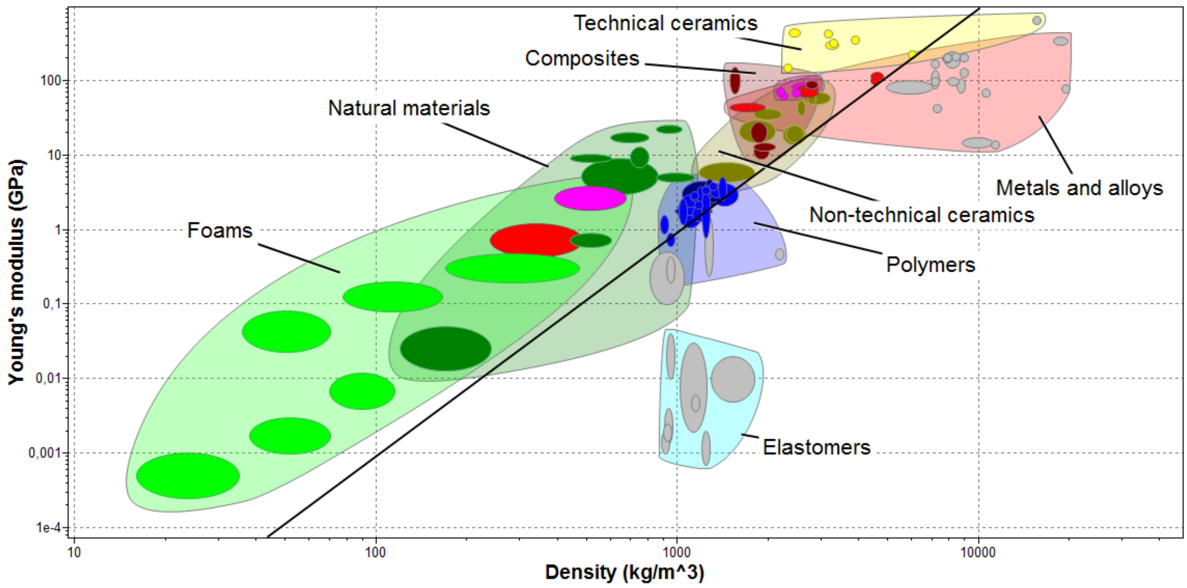

Figure 19: Young's modulus vs. density chart, obtained from CES.

Stage 2 - Thermal Properties

As for the frame, the body of the stretcher must tolerate the operating temperature ranging from -40 °C to +50 °C. After applying this limit to *CES*, there are 65 materials left, see figure 20.

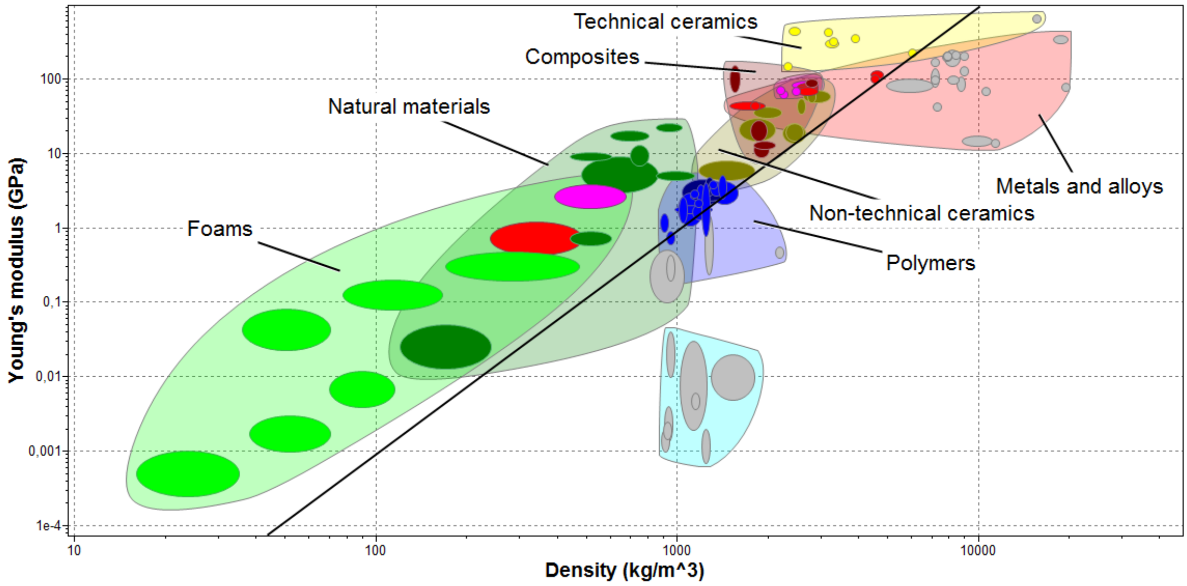

Figure 20: Results after stage 2.

Stage 3 - Density

The material must be light, and to meet this objective, a limit for the material density is set to $\rho \leq 1300\,\frac{kg}{m^3}$. Figure 21 shows the result after stage 3, when there is 33 materials to choose from.

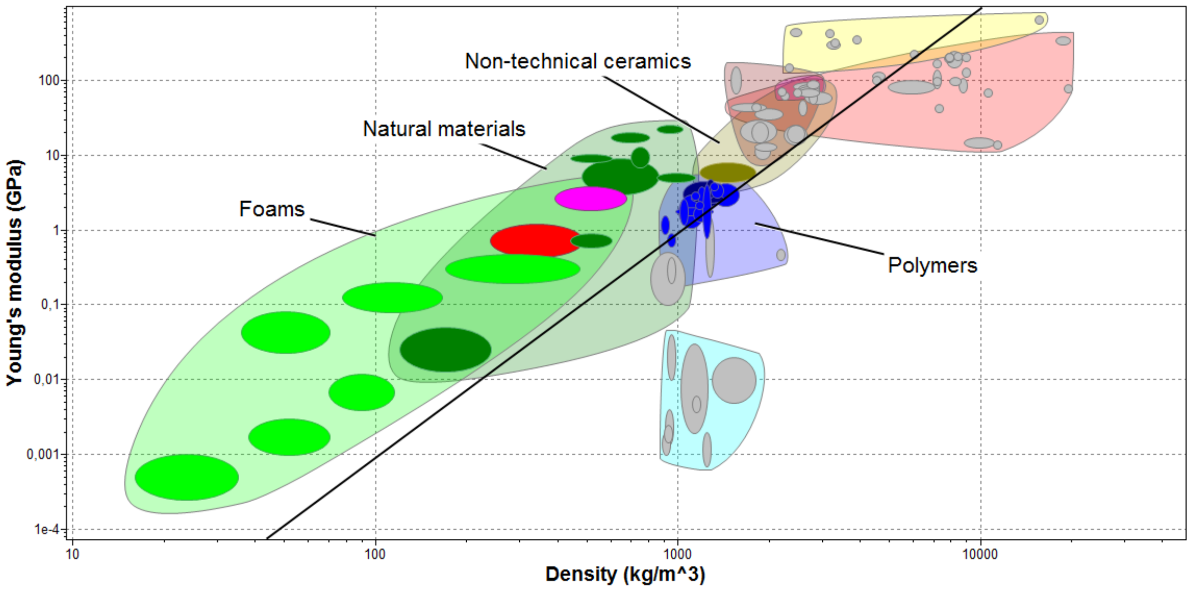

Figure 21: Result after stage 3.

Stage 4 - Durability

The body must have excellent/acceptable durability in fresh and salt water, and in ethanol (disinfectant), as for the frame. Applying this limit, there are 21 materials left to choose from. Figure 22 present a graph with stage 4 applied.

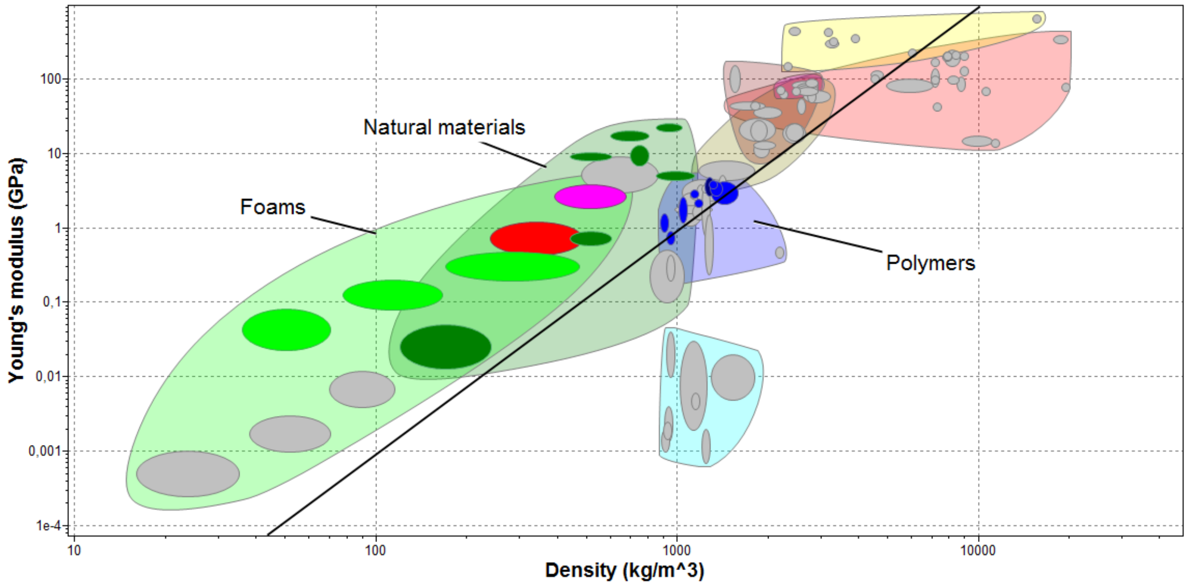

Figure 22: Result after stage 4.

Stage 5 - Environmental Requirements

The material should be recyclable and non-toxic, given environmental requirements. Figure 23 shows the result from stage 5, and after this stage, there are 9 materials to choose from.

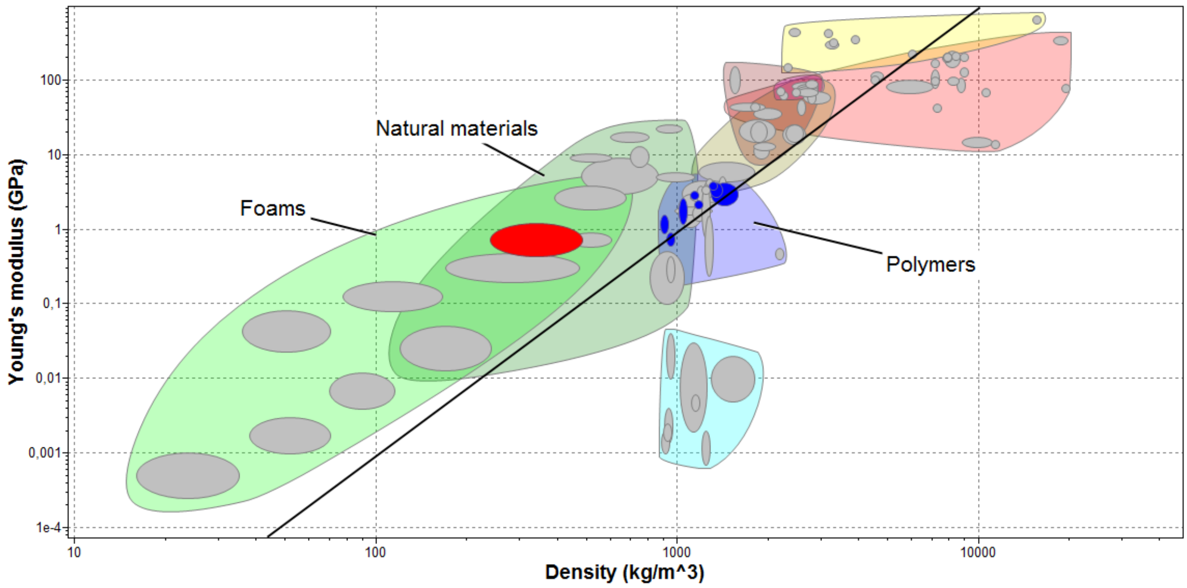

Figure 23: Result after stage 5.

Stage 6 - Processability

The design of the body requires that the material must be moldable with good machinability. Applying this as a limit to *CES*, we are left with 8 materials to choose from. These are presented in figure 24. By this stage, only polymers are considered, and these 8 materials will be investigated further.

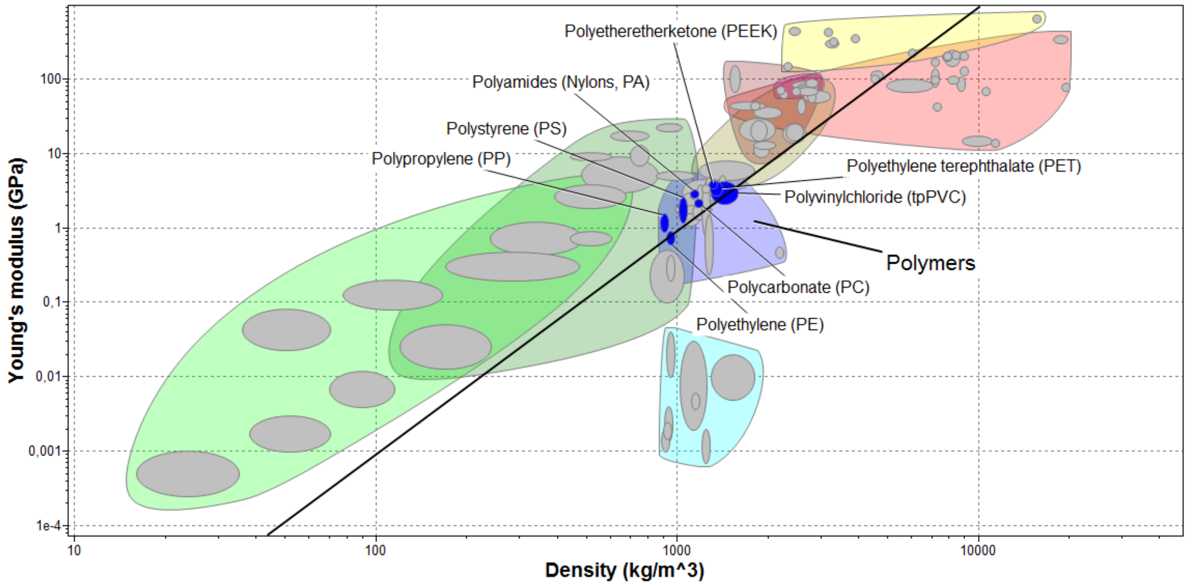

Figure 24: Result after stage 6.

Remaining materials after applying limits:

Polycarbonate (PC) has high impact resistant, and is suitable for bullet-resistant or shatter-resistant glass applications. It is manufactured by extrusion or thermoforming, techniques that impose constraints on design. PC has high strength and outstanding toughness [23].

Polyethylene (PE) has exceptional mechanical stiffness and strength, even at low temperatures. It is cheap and easy to form, either by blow molding, injection molding or extrusion [23]. High density PE (HDPE) has qualities suited for the body of the stretcher, with better mechanical and thermal properties than regular PE.

Polyethylene Terephthalate (PET) is mostly used for smaller component, such as drinking bottles. PET has higher elongations and problems with dimensional stability. The strength is lower compared to other polymers [23].

Polyamides (Nylons, PA) are tough, strong and have a low coefficient of friction. They are easily molded (injection). PA can be reinforced with glass (powder or fiber) to increase the modulus, strength and density [23].

Polypropylene (PP) is inexpensive, light and ductile. It is more rigid than PE, and can be used at higher temperature. Its properties are similar to those of HDPE, however, PP is less stiff. Stiffness and strength can be improved by reinforcing PP with class, chalk or talc. PP is easily molded. Impact resistance in subzero temperatures are poorer than those of HDPE [23].

Polystyrene (PS) is cheap and easy to mold, but it is brittle and cracks easily. Polyvinylchloride (tpPVC) is in its pure form (PVC) heavy, stiff and brittle, but can be modified to a material that is almost as elastic and soft as rubber [23].

Polyvinylchloride (tpPVC) is one of the cheapest polymers. In its pure form, it is rigid and not very tough, but it can be reinforced with glass fibers to design a material with sufficient strength and stiffness [23].

Table 9: Material properties summarized, obtained from CES.

Material	Density $[kg/\ m3]$	Young's modulus $[GPa]$	Fracture toughness $[MPa \cdot \sqrt{m}]$	Elastic limit $[GPa]$	Price $[NOK/kg]$
PC	1140 - 1210	2,0 - 2,44	2,1 - 4,6	59 - 70	33 - 36
PE	939 - 960	0,621 - 0,896	1,44 - 1,72	17,9 - 29	17,6 - 21,5
PET	1290 - 1400	2,76 - 4,14	4,5 - 5,5	56,5 - 62,3	12,8 - 15,7
PA	1120 - 1140	2,62 - 3,2	2,22 - 5,62	50 - 94,8	32,8 - 36,9
PP	890 - 910	0,896 - 1,55	3 - 4,5	20,7 - 37,2	17,4 - 19,8
PS	1040 - 1050	1,2 - 2,6	0,7 - 1,1	28,7 - 56,5	16,8 - 23,9
tpPVC	1300 - 1580	2,14 - 4,14	1,46 - 5,12	35,4 - 52,1	14,9 - 18,2

All eight materials satisfy the requirements, however, to further eliminate materials, the "heavy" materials ($\rho > 1000\,\frac{kg}{m^3}$) in table 9 will be eliminated, and we are left with PE and PP as possible materials to make up the body of the stretcher.

High density PE (HDPE) is widely used for similar applications, and is therefore the preferable choice of material. General description, mechanical and physical properties for PE from the *CES* database can be found in appendix F, as HDPE is not available.

Chapter 5: Detailed Design

Throughout the entire design process, and in particular in the process of making detailed drawings and a CAD-model of the stretcher, some changes to the design were made, as expected, since the design process is highly iterative.

5.1 Basic Sketches

A few hand sketches were constructed prior to designing the stretcher/sledge in 3D-modelling software, see figure 25 and 26. The frame consists of welded sections of round hollow aluminium pipes (to minimize mass). Note that the handles are part of the frame itself, and not separate parts as originally planned for, to minimize the number of parts and making a more rigid frame.

Figure 25: Sketch of the frame.

The body is designed with a circular edge to fit the frame inside (see figure 26), and the frame is nailed to the body along the edge. Note that several cuts are made on each longitudinal side of the body, to minimize mass and to act as utility holes (additional handles, to attach straps, and similar).

Figure 26: Front view of the body.

The assembly of the stretcher is presented in figure 27, where both the frame and the body consists of a he- and she- configuration. This enables the SAR-team to split the stretcher - and the weight - when they are walking to the emergency site. A set of pins will hold the stretcher together when it is in use. The pins are chained to the body to eliminate any loose parts. This solution is considered highly intuitive and safe, compared to numerous bolts, O-ring fittings, etc.

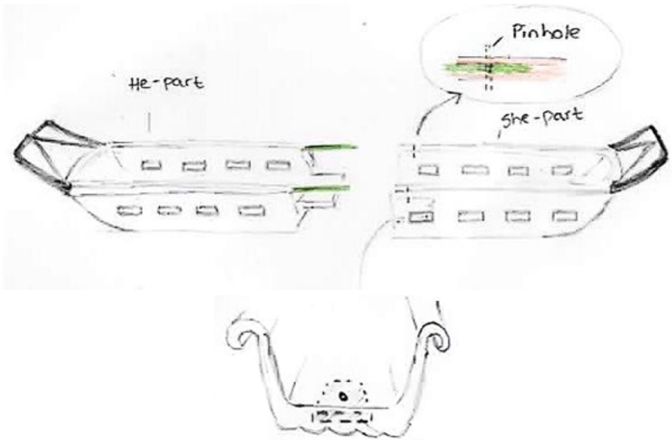

Figure 27: Details of the assembly of the stretcher.

5.2 CAD-modelling

The CAD-model is designed by using *SolidWorks*, the completed assembly is presented in figure 28 and the frame can be found in figure 29. The stretcher is symmetrical and modular, consisting of a he- and she-configuration, which are held in place by two bolts with safety pins and two screws that can be fastened/loosened by hand. Not included in the figures; a mattress, headrest/neck support and multiple belt straps, accessories that are added for the patient's safety and comfort. These types of accessories are not considered a part of the stretcher itself, thus ignored.

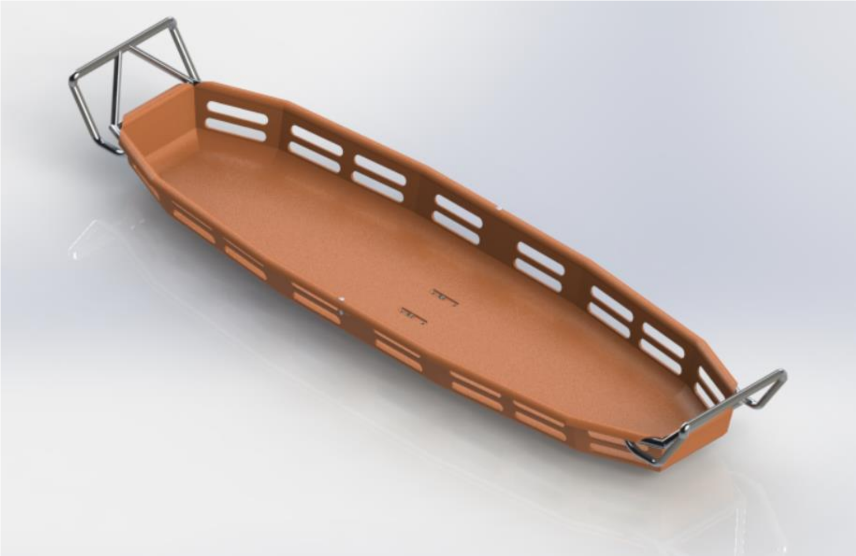

Figure 28: Assembly of the stretcher/sledge.

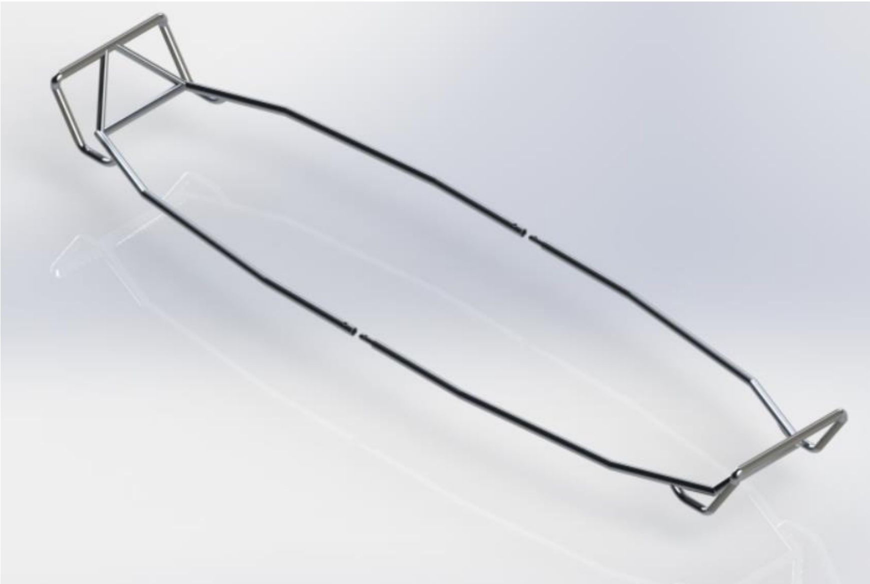

Figure 29: Exploded view of frame configuration.

In figure 30 details of the connection parts of the frame is illustrated (without the body). A bolt (figure 31) will hold the parts together. The bolt itself is meant to be chained to the stretcher, a solution which is considered intuitive, quick and reliable. It is added 1 millimeter clearance between the two connections, which will suffice for potential contamination and accumulation of dirt, snow etc. inside and outside the connection.

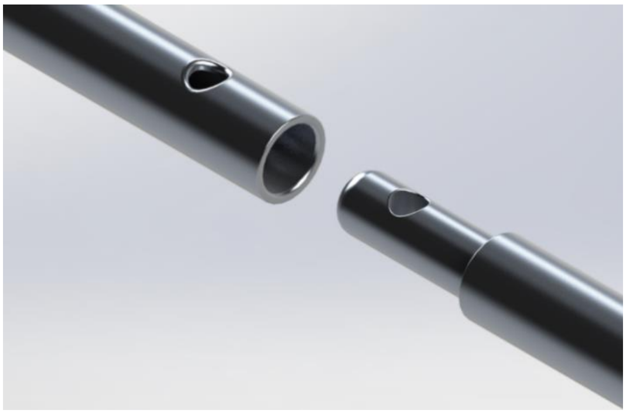

Figure 30: He- and she-configuration of the frame, connection parts.

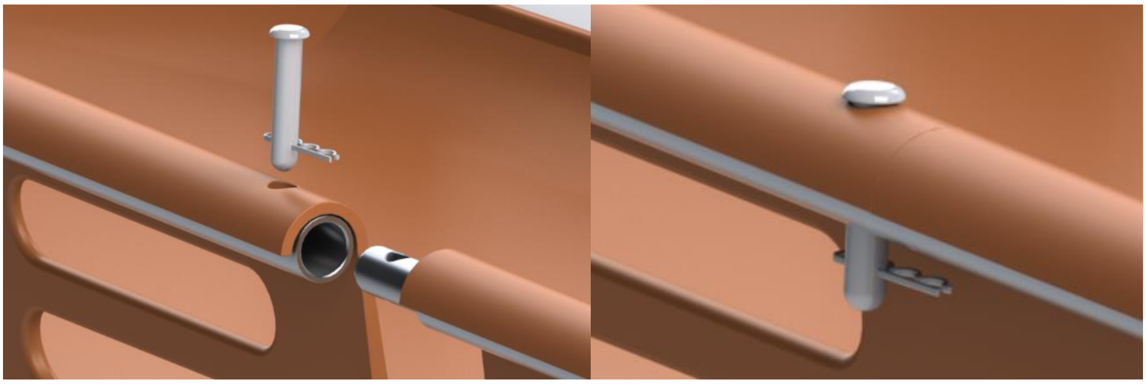

Figure 31: Concept representation of bolt with secure safety pin.

The shape of the frame is identical to the edge of the body. The intention is that after correct manufacturing it can be placed perfectly inside and fastened with "pop rivets" with ~100 mm spacing around the outer edge. Insulating and high friction rubber will be fastened on the handlebars, to insulate, increase comfort for the SAR-team and give multiple options for carrying the stretcher. This is not included in figure 32, which illustrates details of the handles.

Figure 32: Details of the handles.

When determining the dimensions of the tubes used for the frame, the overall objective is to minimize mass, without compromising strength and stiffness, so the total volume should be as small as possible, while still maintaining a proper wall thickness of minimum 3 mm. The lengths of the tubes is fixed by design, so the only free variable is the outer diameter of the tubes. At this stage, the outer diameter is set to 25 mm, however, smaller diameters are possible to achieve with 3 mm wall thickness, and may be considered if *ANSYS*-analysis of deflection is more than satisfactory for the given design dimensions.

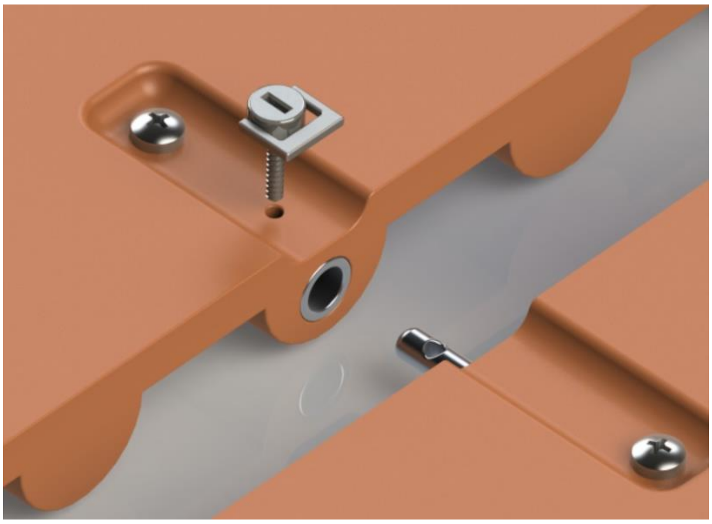

Figure 33: Details of the locking mechanism for the lying plate.

The lying plate also have a he- and she-configuration, and details of the locking mechanism for the lying plate is illustrated in figure 33. To ensure a secure locking of the two parts, a she- and he-configuration of a housing is constructed (see figure 34). Two "she-connectors" are inserted and screwed permanently into the she-configuration of the lying plate. Two "he-connectors" are fastened into the he-configuration of the lying plate. This makes it possible to mount the two parts by a simple screw (figure 35). Pins from the he-configuration is inserted in the she-configured half of the stretcher, and two fastening bolts holds the parts together. The screw does not require any tools for fastening, as they are tightened and loosened by hand, but if frozen or rusted in place, a flat headed screwdriver (preferably) can be used to loosen it up, but for convenience, coins, bread knife and more can be used as well.

Figure 34: She- and he-configuration of connection houses.

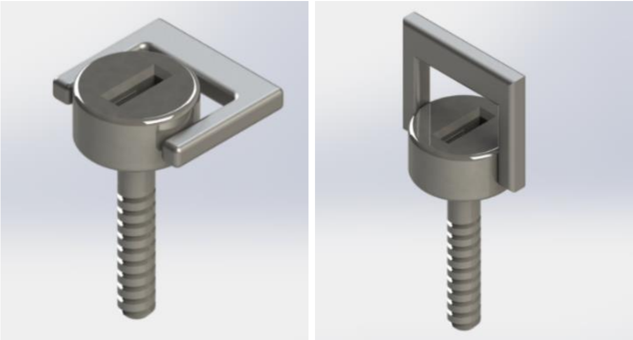

Figure 35: Concept design illustration of hand screwable screw.

As the stretcher is to be used as a sledge in arctic climate, the underside of the stretcher is designed to withstand rough environment, be more controllable and give a smooth finish (to lower friction on snow) for better glide, see figure 36.

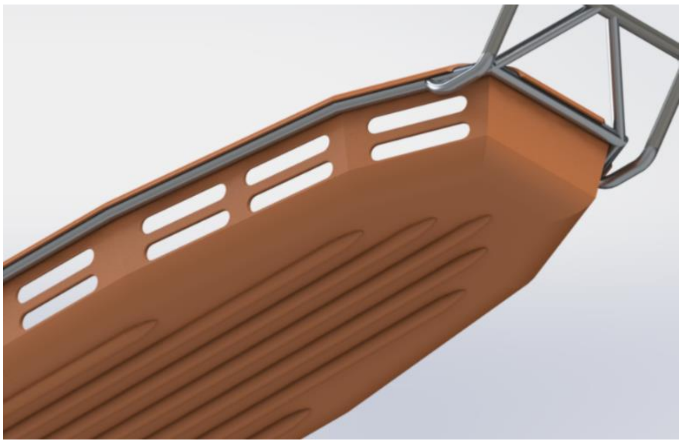

Figure 36: Details of the underside of the stretcher.

All edges have a minimum radius fillet of 0.5 mm, as prescribed by the standard for patient handling equipment require. This causes a 1 mm gap between "she" and "he" of the body, see figure 37, which in some cases can collect snow, gravel, stones etc. This can create unevenness and dents, which again can cause even more external hazards to accumulate and prevent good accessibility. Thorough maintenance is recommended after each use, such as washing, polishing and waxing/repairing if needed.

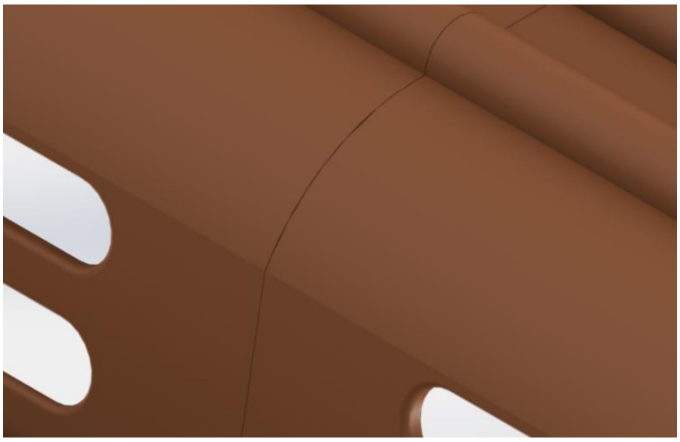

Figure 37: Underside of stretcher when assembled.

Table 10: Design specifications for the stretcher.

Feature/measurement	Specification
Total weight of the product	~20 000 g
External length	2100 mm
External width (largest value, in the middle)	600 mm
External height	180 mm
Internal length (lowest point)	2000 mm
Internal width (largest value, in the middle)	500 mm
Internal height	170 mm

Design specifications can be found in table 10, and further measurements and details for manufacturing the stretcher is found in 2D-drawings in appendix G.

5.3 Prototype

The model is scaled 1:9 or the original size and 3D-printed by a *PolyJet* printer. All sections should have a minimum wall thickness of 2 mm, so parts of the miniature model was enlarged prior to printing.

The *PolyJet* printer is a powerful machine that produces smooth and accurate parts. It sprays curable liquid photopolymer onto a tray and UV-rays instantly cures it. Layer by layer with photopolymer and support structure the 3D-printed part reveals itself. The finished prototype is presented in figure 38.

Figure 38: Printed 3D-model of the stretcher, scale 1:9.

Chapter 6 Manufacturability and Cost

Basic accessories, like mattress, insulating rubber for handles, belts/straps, bolts and safety pins, they are available on the market and fits the assembly as is. Buying parts from the market is in most cases more cost-effective than producing the parts. In addition, they are easily replaceable in case they are damaged or misplaced.

6.1 Frame

The frame is manufactured by extrusion of long, hollow tubes, which require modification as they should be machined to desired lengths and angles, before they are welded together. Extruded hollow tubes are easily available in a wide range of sizes on the internet and at local shops all over the world, however, for this project and cost analysis (chapter 6.3) extrusion of the tubes are considered manufactured by the team. General description of extrusion is found in appendix H.

Regarding welding of the machined lengths, tungsten-inert gas (TIG) is a feasible method which can be applied to most weldable materials, and often applied to pipes and tubes. It is the ideal method for welding thin pieces of material, and the result is of high quality [30]. When welding thinner materials and cross sections, filler materials are not used.

6.2 Body

The body is a part which needs to be produced. It is made up by polymers (HDPE), and in order to determine the manufacturing process, the process universe in *CES* (level 2, shaping) is used. At this level, there are 68 methods for shaping of materials. Starting off, requirements for the manufacturing of the body is summarized in table 11.

Table 11: Design requirements for stretcher body production process selection.

Function	**Stretcher body**
Constraints	Material: HDPE Shape: 3D solid Mass: 7.5 - 8.1 kg Section thickness 0.5 - 10 mm Maximum dimensions: Length: 2100 mm Width: 600 mm Height: 180 mm Roughness < 5 μm Batch size: 1000 - 10 000 units (500 - 5000 stretcher bodies in total)
Objective	Minimize cost
Free variable	Choice of process

In order to evaluate all the processes and eliminate unsuitable methods, the constraints in table 11 is translated to limits for selection in *CES*, see appendix I for more details about the limits set at each stage. The result is two feasible production processes; compression molding and injection molding (for thermoplastics).

Comparing these two, injection molding is the most common manufacturing process for polymers, with low cost per unit produced, requires little post-production work as parts have a finished look upon ejection, and full automation is possible, leading to reduced production costs. Compression molding is very cost-effective due to its simplicity and life-time of the mold, produces little waste material, and is well-suited for larger parts [31].

General description about injection molding and compression molding can be found in appendix J and K, respectively. These two methods will both be an object to cost analysis, as the objective is to minimize the cost.

6.3 Cost Analysis

CES enables cost analysis for several production methods, including extrusion, injection molding and compression molding, which is used in this project. The goal is to approximate the total costs of producing one stretcher, given a batch at 500 and 5000 products, which translates to a batch of 1000 and 10 000 units for the frame and body, as one stretcher consists of two identical units of frame and body. Prior to this, however, a production method for the body must be determined, based on relative cost analysis for compression and injection molding.

Inputs to *CES* are summarized in table 12 and 14 for molding and extrusion, respectively, based on information obtained from *SolidWorks* (weight of parts) and average material cost for PE and age-hardening wrought al-alloys, obtained from *CES*. The results are a set of graphical charts displaying relative cost per unit at increasing batch size, see figure 39 for injection molding, figure 40 for compression molding and figure 41 for extrusion of tubes. All charts are logarithmic scaled.

Mold for the body

Considering the mold for the body, both injection molding and compression molding is considered and compared in the following. Inputs in table 12 is used for both methods for displaying the resulting graphs.

Table 12: Fixed parameters, input for graphical display of relative cost per batch size for molding of the body.

Parameter	Value
Component mass [kg]	8.1
Material cost [NOK/kg]	19.5 *
Capital Write-off time [years]	10
Discount rate [%]	5 **
Load factor	0.5 **
Overhead rate [NOK/hr]	500 ***

* Average value calculated from maximum and minimum value of material cost for PE, obtained from *CES*.
** Pre-set in *CES*.
*** Estimated costs related to labor, rent, administration, etc.

The resulting plots for relative cost per unit over batch size for injection molding and compression molding is presented in figure 39 and 40, respectively.

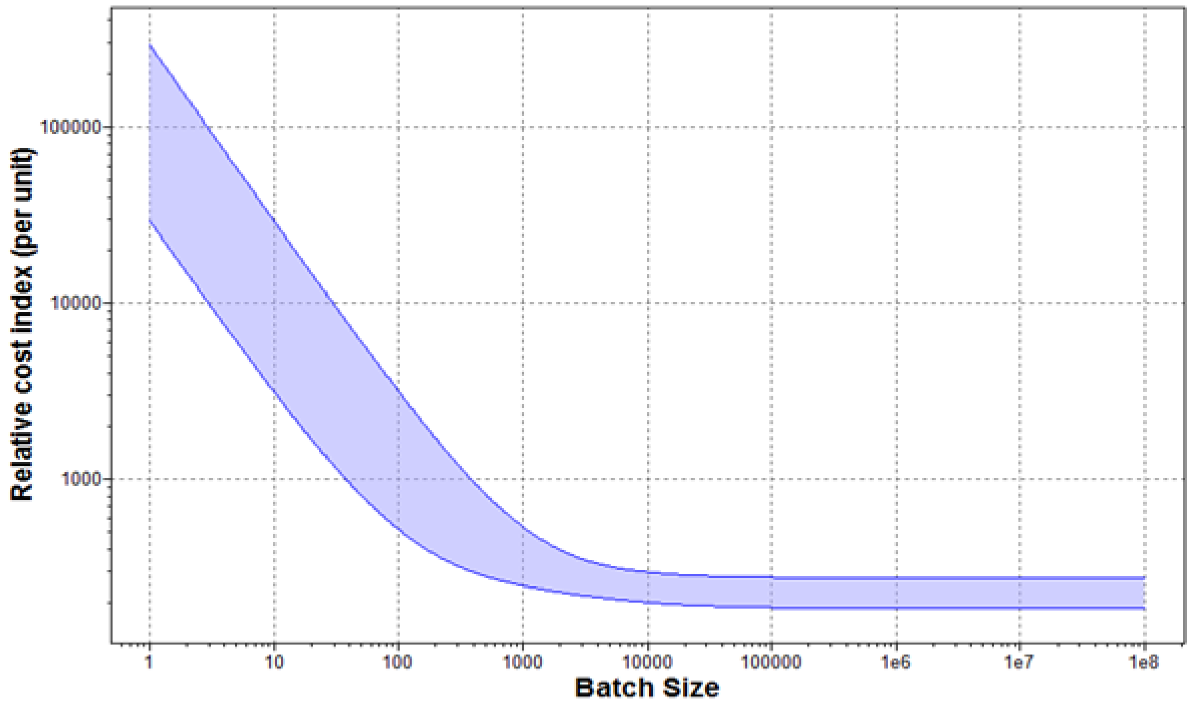

Figure 39: Relative cost index (per unit) over batch size for injection molding of the body.

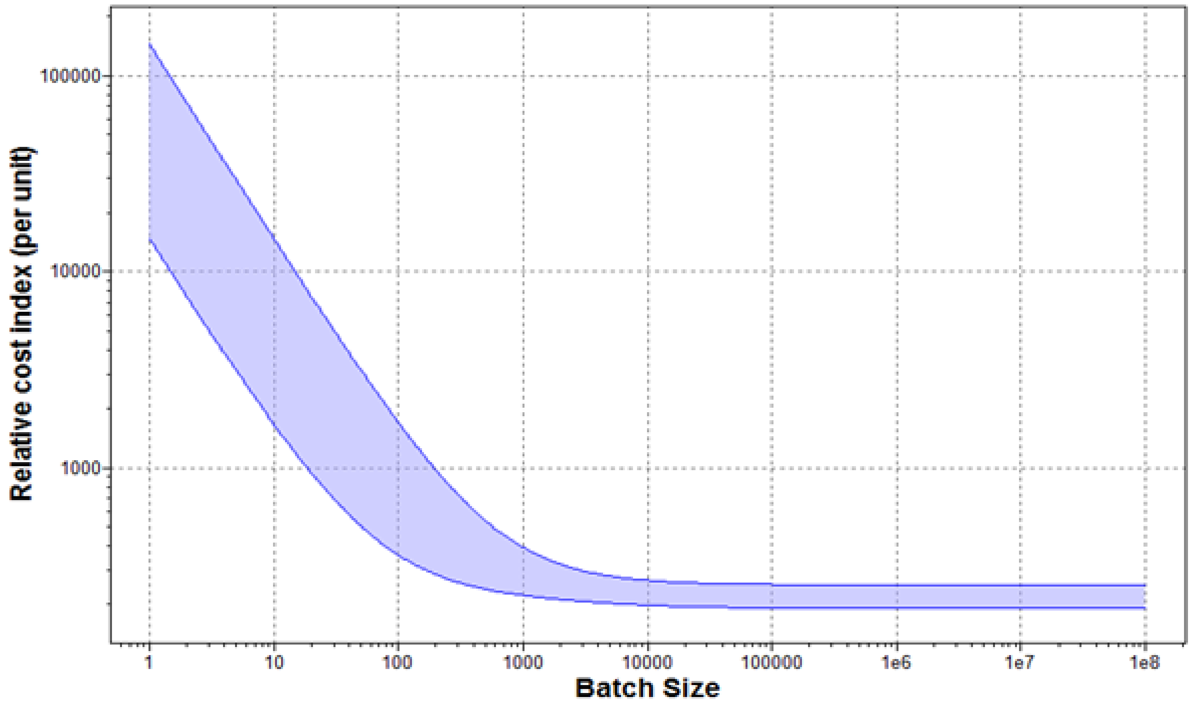

Figure 40: Relative cost index (per unit) over batch size for compression molding of the body.

Although both injection molding and compression molding are suitable methods for producing the body of the stretcher, comparing the result in table 13, it is clear that compression molding is the preferred production method due to the low costs per unit.

Table 13: Comparing relative cost per unit (NOK) for a given batch size of 1000 and 10 000 units, for injection molding and compression molding.

	Relative cost per unit (NOK)	
Batch size	**Injection molding**	**Compression molding**
1000	~280	~210
10 000	~180	~150

Given a batch size of 1000 units, the relative cost per unit is approximately 210 NOK, thus a total of 420 NOK for the body of one stretcher. At 10 000 units, producing the body of the stretcher costs approximately 300 NOK.

Extrusion of al-alloy tubes for the frame

Inputs to *CES* are presented in table 14 for approximating the relative cost per unit for extrusion of tubes.

Table 14: Fixed parameters, input for graphical display of relative cost over batch size for extrusion of al-alloy tubes.

Parameter	**Value**
Component mass [kg]	4
Material cost [NOK/kg]	21 *
Capital Write-off time [years]	10
Discount rate [%]	5 **
Load factor	0.5 **
Overhead rate [NOK/hr]	500 ***

* Average value calculated from maximum and minimum value of material cost for age-hardening wrought al-alloys, obtained from *CES*.
** Pre-set in *CES*.
*** Estimated costs related to labor, rent, administration, etc.

The resulting graph in figure 41 is obtained from *CES*, displaying relative cost per unit over batch size for extrusion of age-hardening wrought al-alloys.

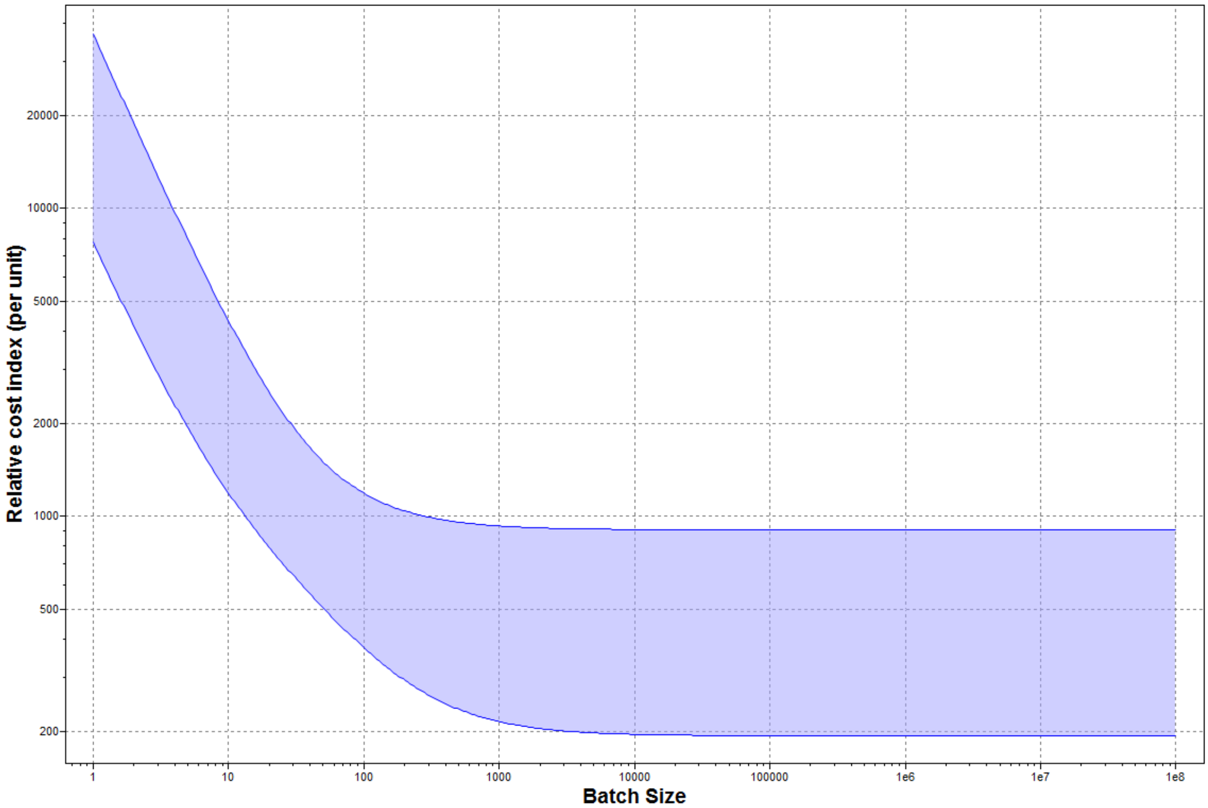

Figure 41: Relative cost index (per unit) over batch size for extrusion of al-alloy tubes.

Given a batch size of 1000 units, the relative cost per unit is approximately 450 NOK, and at 10 000 produced units, the cost is around 380 NOK per unit.

Costs related to machining of the body (cutting utility holes, creating he- and she-configuration, etc.), machining and welding of aluminium tubes, and assembling frame to body is only estimates and they are based on assumptions. Table 15 and 16 below compare an approximated total cost per one stretcher, given a batch size of 1000 units and 10 000 units, respectively. It is assumed that the value of other expenses decrease as the number of produced units increase.

Table 15: Cost-analysis for making one product, given batch size of 1000 units.

Part		**Cost per one product NOK**
Body	Production costs (materials, mold, labor)	420
	Machining body (cutting utility holes, he- and she-configuration)	100
Frame	Production cost (materials, extrusion, labor)	500
	Machining and welding tubes	300
Assembly	Assembling frame to body	100
Extra	Mattress, straps/belts, rubber for handles	350
	Total cost (approx.)	**1 770**

Table 16: Cost-analysis for making one product, given batch size of 10 000 units.

Part		**Cost per one product NOK**
Body	Production costs (materials, mold, labor)	300
	Machining body (cutting utility holes, he- and she-configuration)	50
Frame	Production cost (materials, extrusion, labor)	450
	Machining and welding tubes	200
Assembly	Assembling frame to body	50
Extra	Mattress, straps/belts, rubber for handles	250
	Total cost (approx.)	**1 300**

6.4 Compression Mold Analysis

A draft analysis is done in SolidWorks to figure out how the angles of faces in the model will turn out when molded. In this case the draw direction of the mold is perpendicular to the bottom of the stretcher. As figure 42 shows, positive (green) and negative (red) are OK drafting angles and can be molded correctly without complications. Every yellow face requires an angle draft applied to it to become "100% moldable". Since is possible to mold without adding ~1+ degree of draft, and because the stretcher will not work properly with a draft, it will be molded as is.

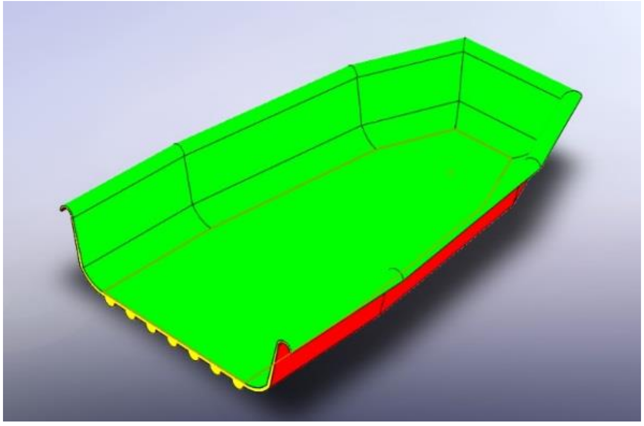

Figure 42: Draft illustration.

Chapter 7 Mechanical Analysis

When the stretcher is in use, it is subjected to forces and external effects. In this chapter, the aim is to simulate some of the cases which may occur when the stretcher is used, and evaluate the results. Approximations and assumptions is accounted for, and both numerical and analytical calculations have been derived and later compared. Three cases is of interest to analyze further; (1) when the stretcher is operated by two persons holding the handles, (2) when the stretcher is used as a sledge, clashing or gliding over a large obstacle, (3) when the stretcher is subjected to torsional forces.

For all analysis conducted, the connection for he- and she-part is assumed stiff enough, thus the joints can be neglected and the stretcher is considered one body (not modular). In addition, it is assumed that the displacement of a small element in the stretchers body is equal to the displacement of a small element in the frame. Welds present a weakness in the construction, however, all welds are neglected in the following calculations, and the frame is considered a continuous tube.

Due to complex geometry, the stretcher is reduced to a beam with dimensions given by the design of the stretcher; length L = 2100 mm, width w = 600 mm, and height 183 mm. As this is a thick block, the height is reduced to half, giving h = 91.5 mm. This is governing for all analytical calculations in the following sub-chapters.

In *ANSYS*, the assembled version of the stretcher body and frame was imported, and each part assigned a material. As HDPE is not available in the data directory of *ANSYS*, PE was chosen for the body. Aluminium alloy 6061-T6 was assigned to the frame. (Material properties can be found in the project files from *ANSYS*, appendix M and N, table 18-29, and match the ones obtained from *CES).* The solver will not proceed with the problem without the user specifying the isotropic elasticity of the aluminium alloy. This is derived from the Young's Modulus and Poisson's ratio, of 70 GPa and 0.33, respectively.

ANSYS creates mesh automatically to optimize meshing area for best approximations, see figure 43. Using element type Solid 187, a higher order 3-D, 10-node element, which is commonly applied when modelling irregular meshes on complex designs, on both the frame and body. The element is defined by 10 nodes having three degrees of freedom at each node; translations in the nodal x, y, and z direction. The assembled model has approximately 64 000 nodes in total, creating around 33 000 elements (explicit numbers can be found in table 17). General information about element type Solid 187 obtained from *ANSYS* can be found in appendix L.

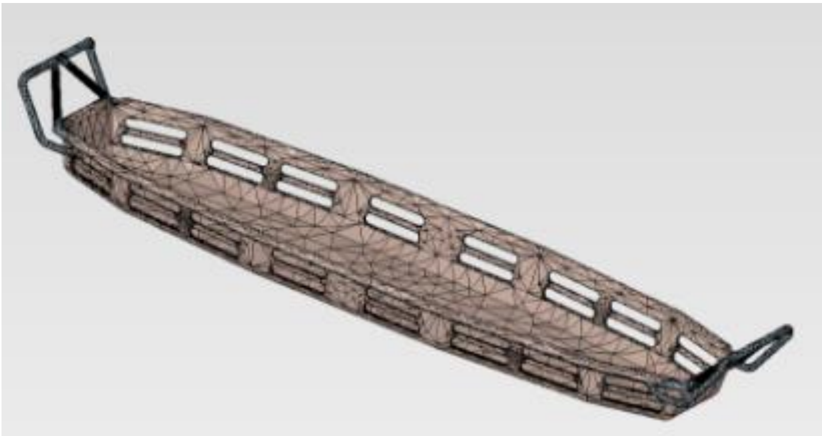

Figure 43: Meshing the stretcher.

Table 17: Physical properties and numerical values, obtained from ANSYS.

Object	Body	Frame	Assembly
Volume [m^3]	1.63e-2	1.53e-3	1.78e-2
Mass [kg]	15.45	4.22	19.67
No. of nodes	36 948	27 286	64 234
No. of elements	19 230	14 537	33 767

The project report from *ANSYS* can be found in appendix M (case 1 and 2) and appendix N (case 3).

7.1 Case 1: The Stretcher is Carried by Two Persons Holding the Handles

The aim of this calculation is to determine an approximated deflection for the stretcher, which later will be compared to numerical results. The stretcher is assumed a simply supported beam (figure 44), with a uniformly distributed load simulating the patient, roller support at point A and pinned support in B. This indicates that person A is free to rotate and move along the surface upon which the roller rest (x-direction, towards person B), while person B can only rotate and not translate in any direction.

Figure 44: Simply supported beam with uniformly distributed load.

Given a simply supported beam, the well-known formula for maximum deflection in equation (2) can be used

$$\delta = \frac{5}{384}\frac{qL^4}{EI}, \qquad \text{(Eq. 2)}$$

where q is the uniformly distributed load, E is the Young's modulus for the material, and I is the moment of inertia. In this case, $q = F/L$, where $F = 3000\ N$ (as specified in table 2 for static testing conditions), and $E = 8 \cdot 10^8\ Pa = 0.8\ GPa$ for PE. Assuming a solid, rectangular cross-section, $I = \frac{1}{12} w \cdot h^3$. Using this to solve the equation for maximum deflection we obtain;

$$\delta = \frac{5}{384}\frac{qL^4}{EI} = \frac{5}{384} \cdot \frac{\frac{3000}{2.1} \cdot 2.1^4}{8 \cdot 10^8 \cdot \frac{1}{12} \cdot 0.6 \cdot 0.0915^3} = 0.011805\ m = 11.81\ mm.$$

The analytically obtained maximum deflection is approximately 11.81 mm.

In numerical computer assisted analysis, it is of interest to investigate maximum deflection, equivalent stress and shear stress.

When selecting supports for the given situation, the goal is to simulate the problem as accurate/close to the real event as possible. Therefore, it is important to analyze the problem thoroughly and figure out what is happening when the stretcher is being carried.

In this scenario the stretcher and patient is being lifted up off the ground, and person A is standing perfectly still (0 free variables, x=y=z=constant), while person B is able to move in x-direction (1 free variable y=z=constant), towards person A, see figure 45. Using these assumptions and supports will create the most deflection of the stretcher, and is considered a feasible interpretation of the problem.

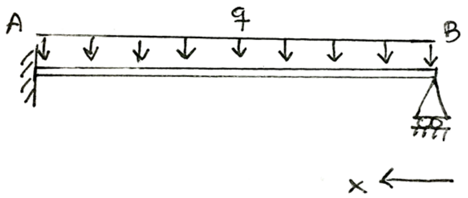

Figure 45: Supports and force for case 1.

Finally, the load of 3000 N [10] is applied to the bottom (lying) part of the stretcher as pressure, simulating a patient. The pressure equals force times the area, hence $P = F \cdot A = 3000\ N \cdot 0.64\ m^2 \cdot 1.2 = 2300\ Pa$ (using safety factor 1.2). The problem is solved, and results are presented in the following.

Results obtained from *ANSYS*

Looking at the total deformation of the stretcher, the maximum deflection for this static test is located at the center of the body with a magnitude of 5.96 mm, see figure 46.

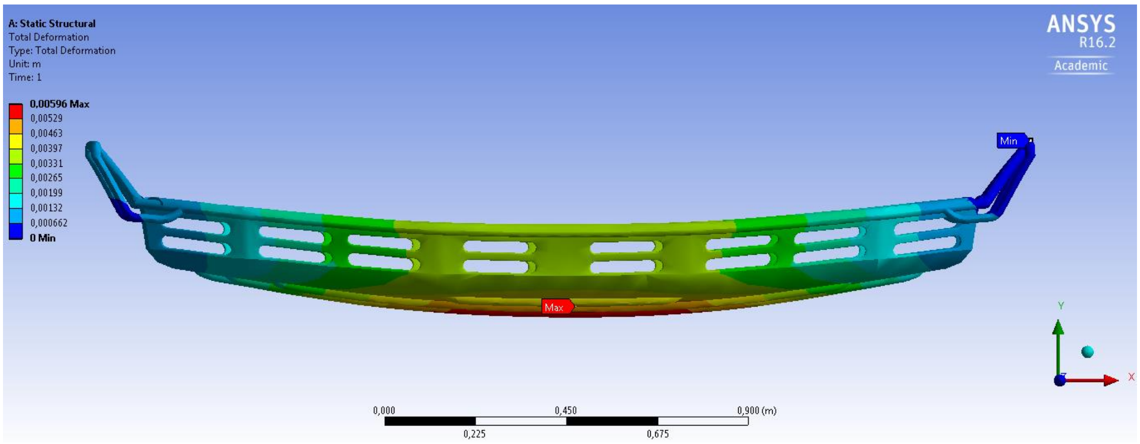

Figure 46: Isometric view of deformation.

From the coloring scheme (see figure 47) the body does not appear to have any stress that exceed 10 MPa. On the contrary, the aluminium handlebars experiences stress up to 48.1 MPa at critical notches, and varies down to around 5 MPa through the tubes (see figure 48).

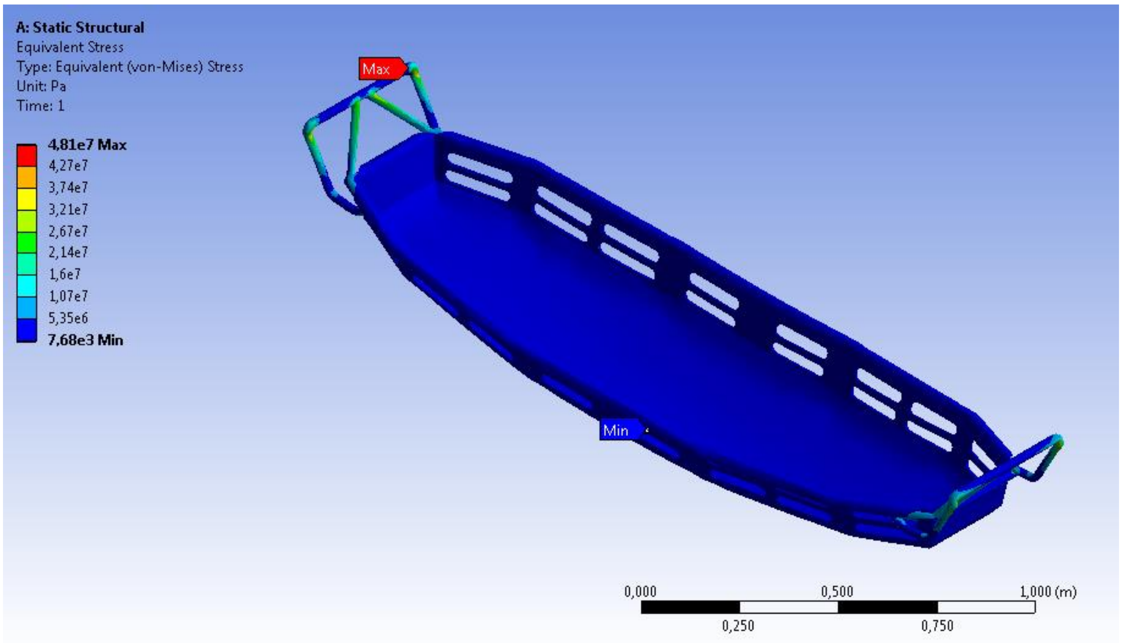

Figure 47: Equivalent (von-Mises) stress results for case 1.

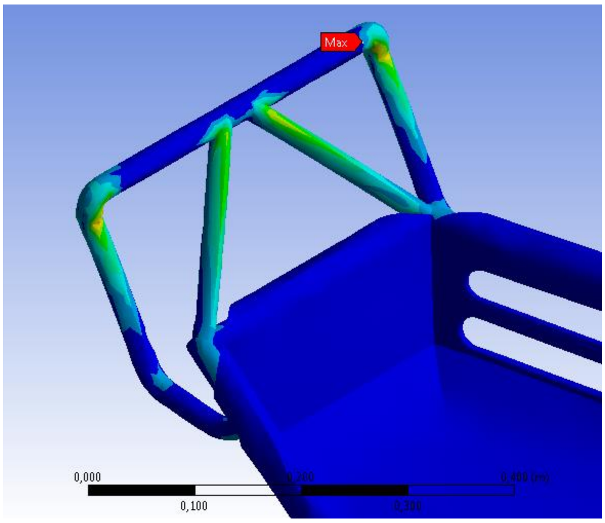

Figure 48: Close-up on handles (no. 1) for case 1.

The simulation of shear stress states that the body of the stretcher experiences roughly 1.8 MPa of shear stress (see figure 49). As the stress analysis showed, the handles are a clear weak point in the design. The maximum shear is located on the top bar with a magnitude of 17 MPa, presented in figure 50.

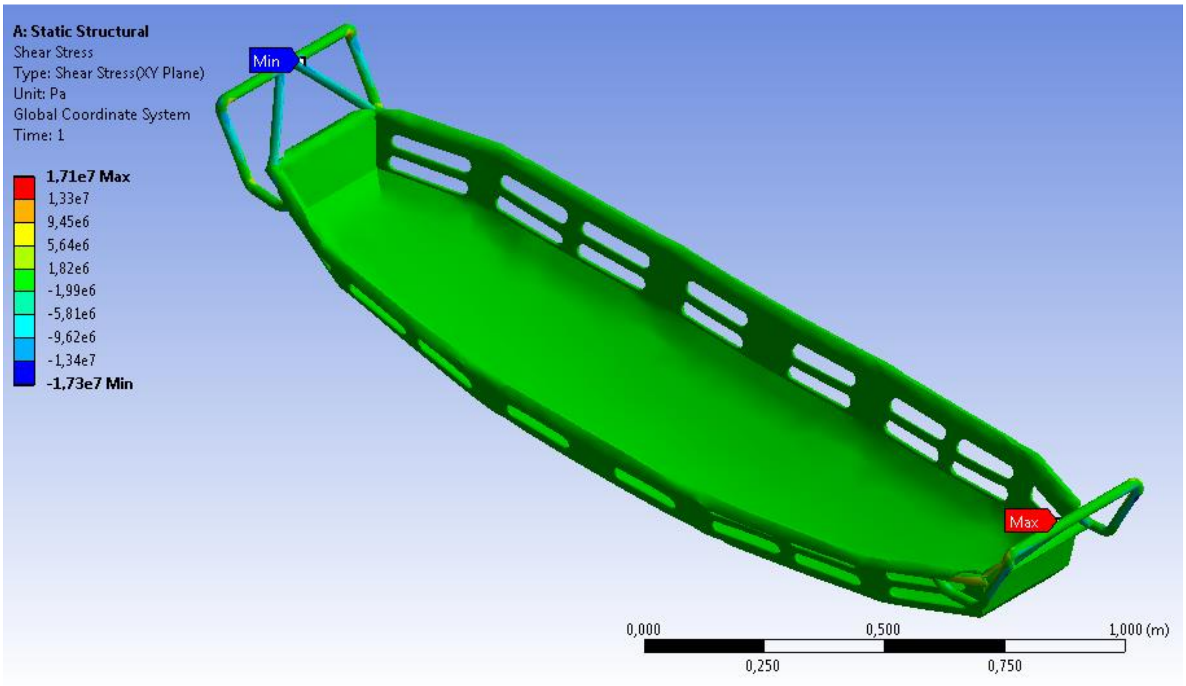

Figure 49: Shear stress results for case 1.

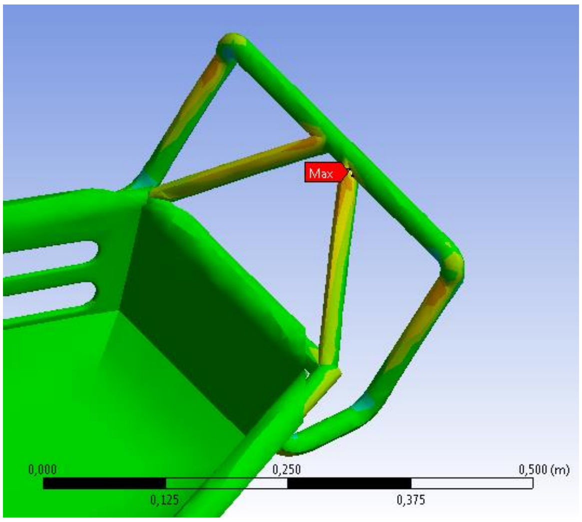

Figure 50: Close-up on handles (no. 2) for case 1.

7.2 Case 2: The Patient and the Pea

The purpose of this analysis is to determine the maximum deflection as the stretcher is stranded on an object, illustrated in figure 51, to determine if the stretcher can withstand uneven terrain, and make sure that the stretcher is comfortable for the patient.

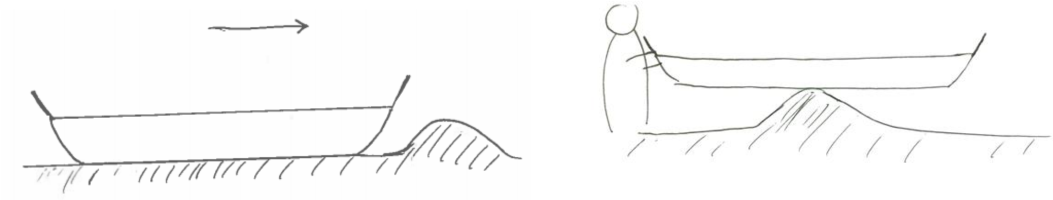

Figure 51: Sketch of the sledge encountering an obstacle.

This system is reduced to a simply supported beam with a uniformly distributed load q (simulating a person) and a concentrated load F acting in the middle of the underside of the stretcher, see figure 52. The load is calculated by $F = m \cdot g$, where m = 270 kg is the total mass of the stretcher with a patient inside, and g is the force of gravity. A safety factor 1.2 is applied, resulting in a load of 2300 N.

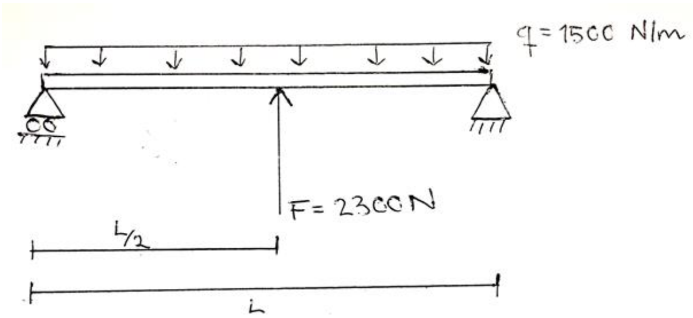

Figure 52: Supports and loads for the problem.

The problem is solved by applying well-known formulas for deflection, presented in equation (2) for uniformly distributed load and equation (3) for concentrated load.

$$\delta = \frac{FL^3}{48EI} \qquad \text{(Eq. 3)}$$

Combining the equations (2) and (3) with respect to figure 52, we obtain that

$$\delta = \frac{5}{384}\frac{qL^4}{EI} - \frac{FL^3}{48EI} = 0.01181 - \frac{2300 \cdot 2.1^3}{48 \cdot 8 \cdot 10^8 \cdot \frac{1}{12} \cdot 0.6 \cdot 0.0915^3} = -0.00775\ m = -7.75\ mm.$$

Negative value indicates that the beam will deflect up under the concentrated load, as the uniformly distributed load is smaller. The maximum deflection in the middle of the beam is calculated to 7.75 mm.

In *ANSYS*, the system is built with an equally distributed load applied as pressure (as for case 1), and the rock is represented by a roller support in the middle of the stretchers bottom, free to move in x-direction, see figure 53. The roller support at the left side illustrates a person holding the handles, only allowed to move in y-direction (up and down). The right side has no support.

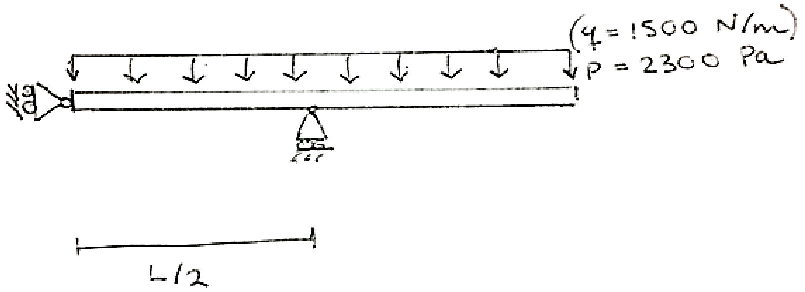

Figure 53: Support and loads for case 2.

Prior to this analysis, the *SolidWorks* model is updated with a small square in the middle of the bottom plate, where the roller support is acting on the stretcher. Applying all supports and pressure as described before solving, the following results were obtained.

Results obtained from *ANSYS*

The maximum deflection is approximately 8.1 mm. Looking at figure 54, the stretcher deflects at all areas around the support.

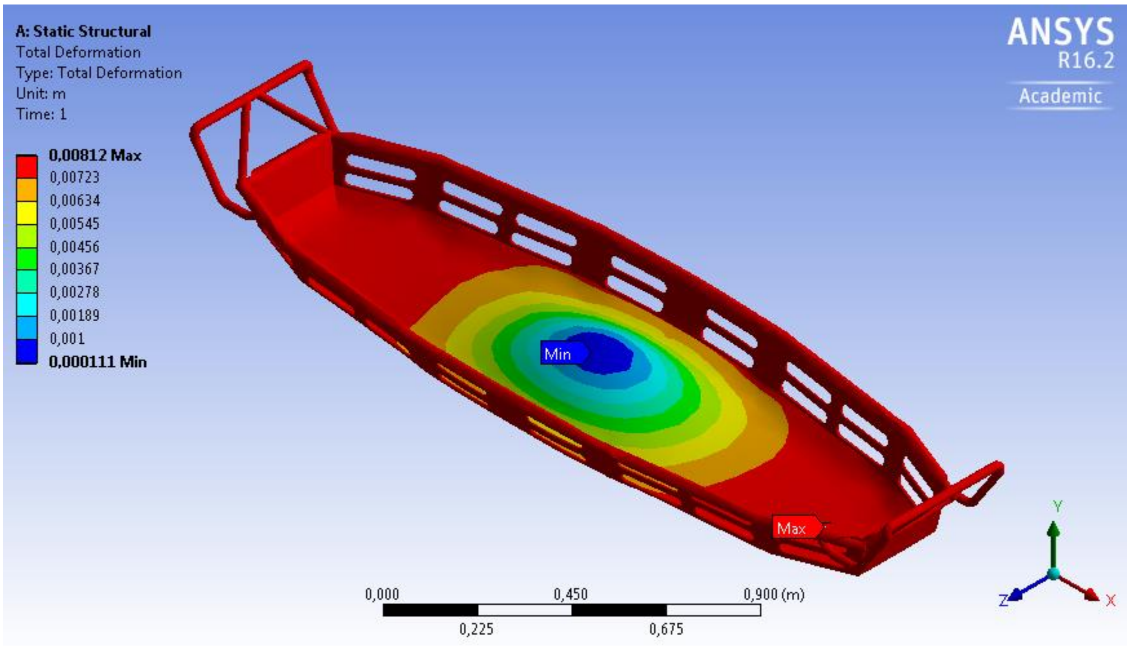

Figure 54: Deflection of the stretcher, simulating a scenario where the stretcher is stranded on an obstacle.

The equivalent stress is relatively low for almost the entire stretcher (figure 55), however, a maximum value of approximately 17.3 MPa is located at the longitudinal side of the stretcher, see figure 56.

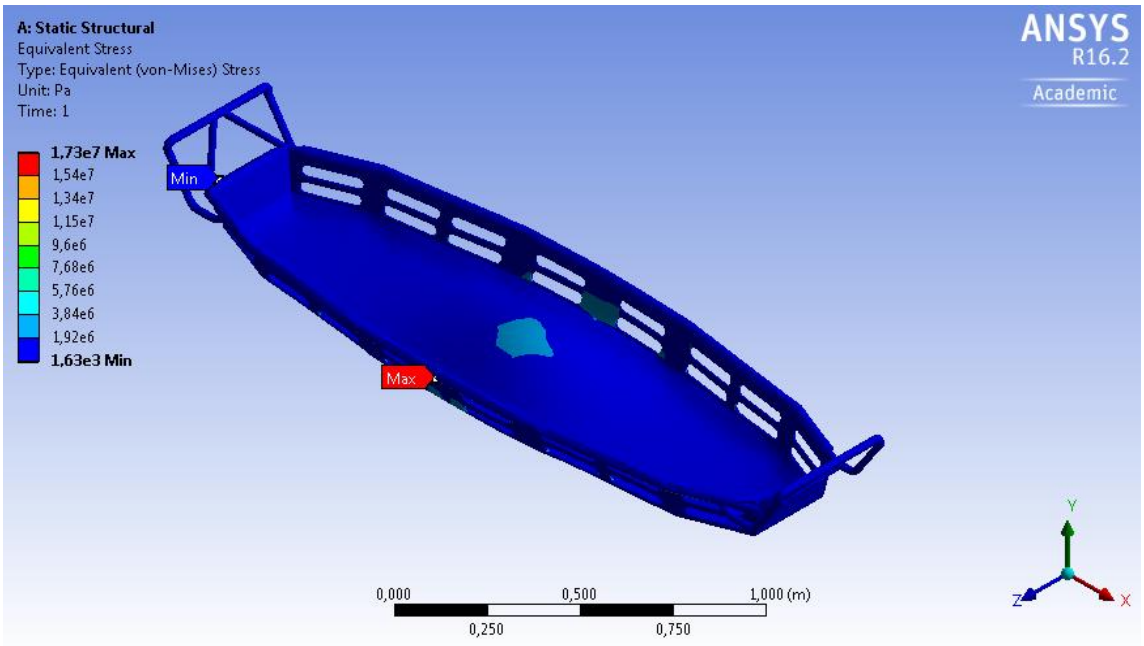

Figure 55: Equivalent stress results for case 2.

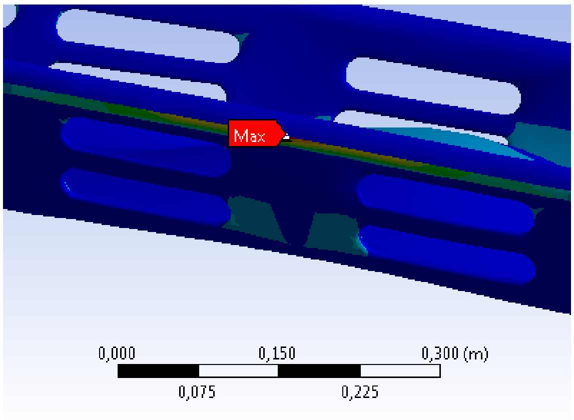

Figure 56: Close-up (no. 1) of the maximum equivalent stress.

Shear stress acting on the stretcher is for the most parts between 0.14 MPa and 1.79 MPa (see figure 57), with a maximum value of approximately 3.4 MPa acting on members of the frame (especially in the weld sections), presented in figure 58.

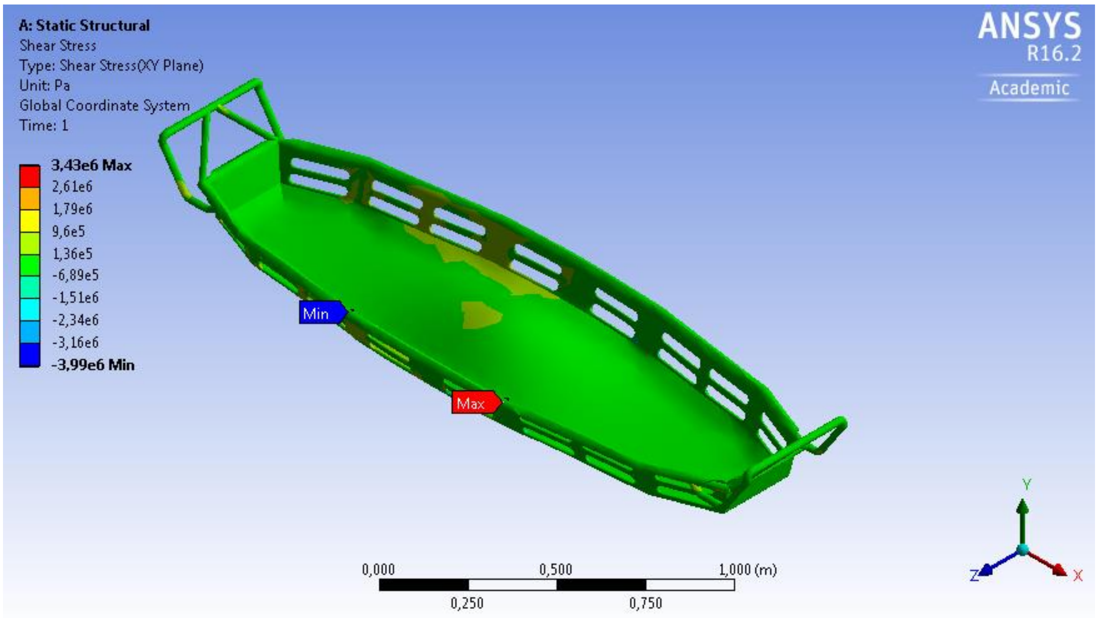

Figure 57: Shear stress results for case 2.

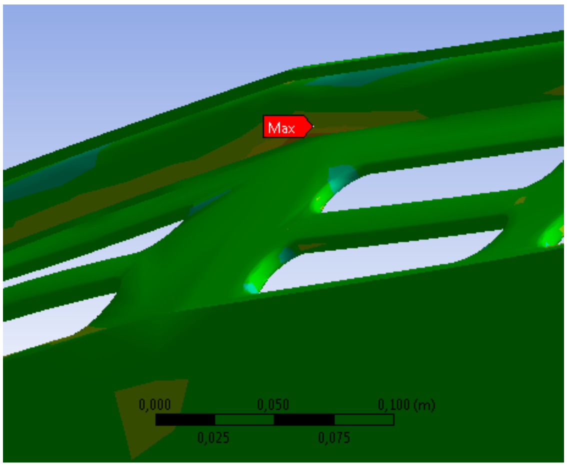

Figure 58: Close-up (no. 2) for case 2.

7.3 Case 3: Torsion

Simulating a scenario where the stretcher is being pulled over a slope with angle that induces torsion on the stretcher, the force is set to 3000 N acting 2.1 m from the fixed handles. The reduced system with supports and loads is presented in figure 59.

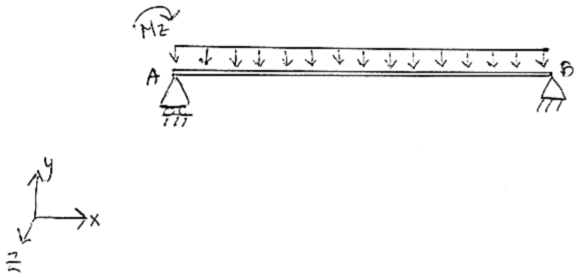

Figure 59: Illustration of moment acting on point A on z-axis.

Maximum deflection due to moment forces is presented in equation (4)

$$\delta_{max} = \frac{ML^2}{9\sqrt{3}\,EI}, \qquad \text{(Eq. 4)}$$

where the moment *M* is calculated by $M = F \cdot d$, where *F* is the force and *d* is the perpendicular distance. The length L, Young's modulus E, and moment of inertia is the same as for the previous beam problem.

Combining equation (4) with equation (2) for uniformly distributed load, we obtain a maximum deflection of

$$\delta = \frac{ML^2}{9\sqrt{3}\,EI} + \frac{5}{384}\frac{qL^4}{EI} = \frac{3000 \cdot 2.1 \cdot 2.1^2}{9\sqrt{3} \cdot 8 \cdot 10^8 \cdot \frac{1}{12} \cdot 0.6 \cdot 0.0915^3} + 0.01181$$

$$= 0.05816 + 0.01181 \approx 0.07\, m = 70\, mm.$$

The analytical result is a total deflection of approximately 70 mm when the beam is subjected to torsional and uniformly distributed forces.

There are several ways of inducing torsion onto a construction in *ANSYS*. For this simulation the stretcher is supported the same way as in Case 1, and a moment force is added to the roller support-side of the stretcher, as illustrated in figure 60.

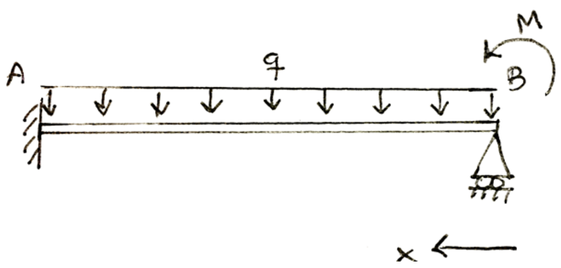

Figure 60: Support and loads for case 3.

Results

Maximum deflection of 15.9 mm occurs in the mid part of the stretchers longitudinal side, presented in figure 61 and 62.

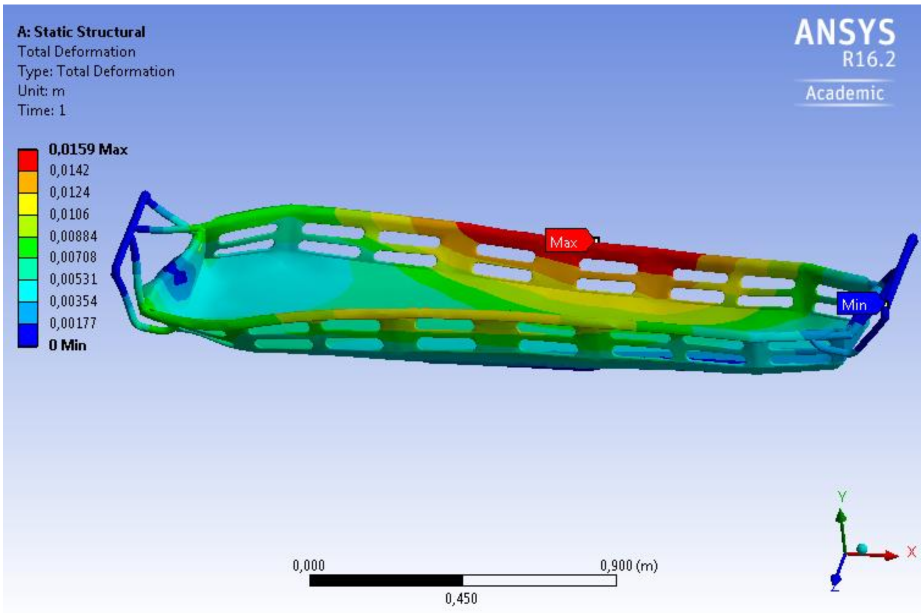

Figure 61: Maximum deflection due to torsional forces, case 3.

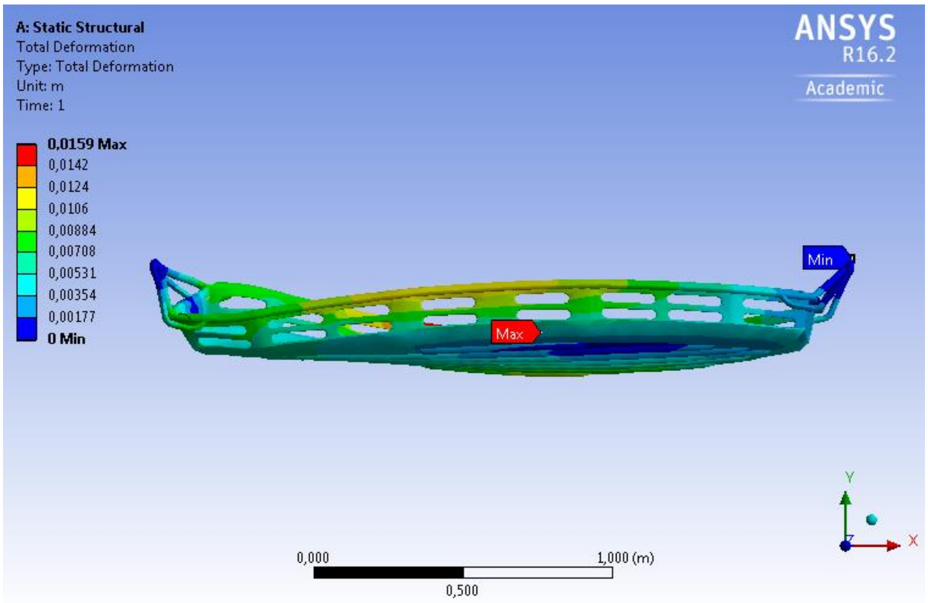

Figure 62: Total deflection due to torsional forces, case 3.

Maximum equivalent stress is 1.12 GPa, and occurs a critical notch on the frame, see figure 63 and 64.

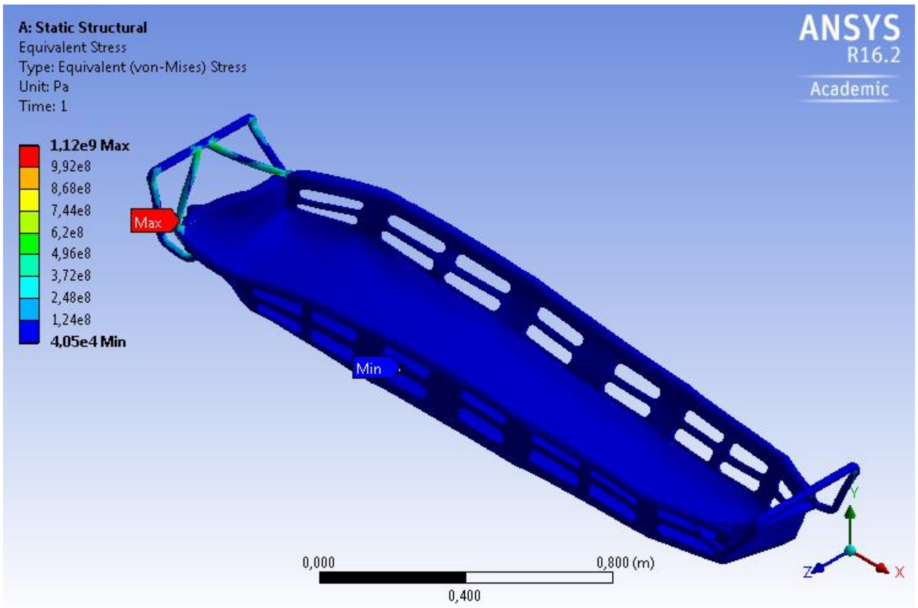

Figure 63: Equivalent stress results for case 3.

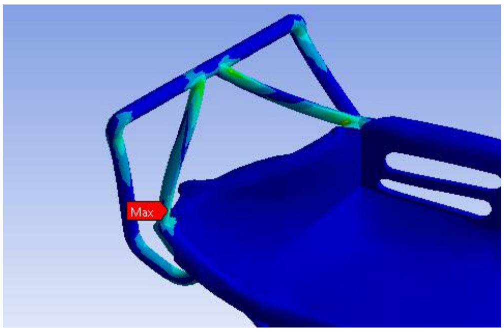

Figure 64: Close-up of maximum equivalent stress for case 2.

Maximum shear stress also occurs on a critical notch on the frame, shown in figure 66, with a magnitude of 259 MPa. Overall results for the body is presented in figure 65 below.

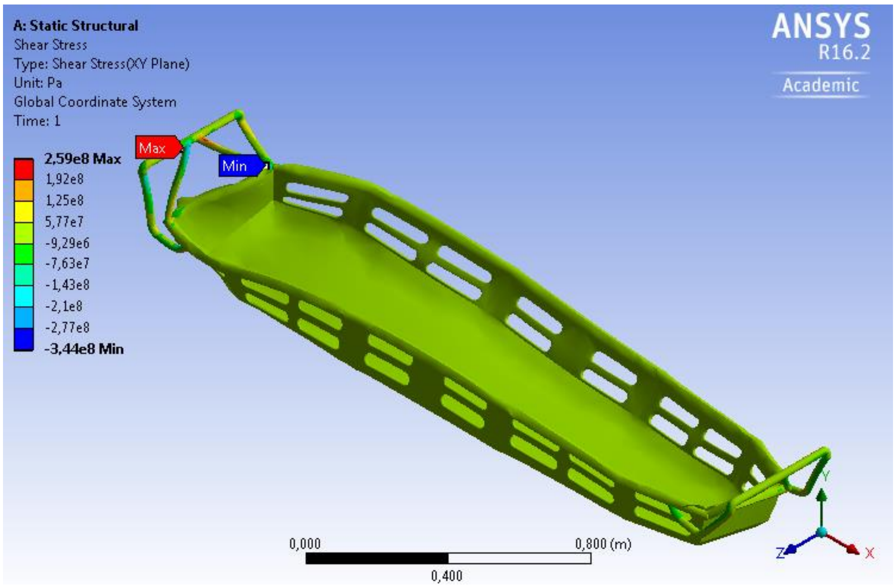

Figure 65: Shear stress results for case 3.

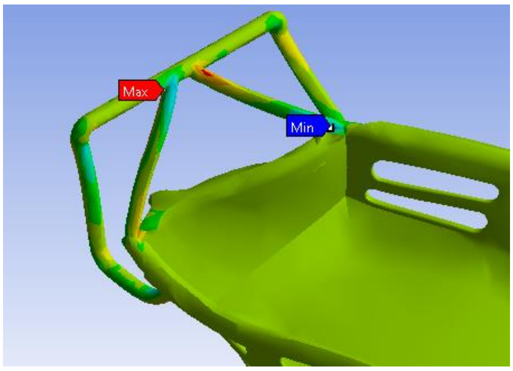

Figure 66: Close-up of the location of the maximum shear stress for case 3.

7.4 Failure Criteria

In order to check the results later obtained from *ANSYS*, maximum allowable stress and maximum allowable shear stress must be compiled, for both the material making up the body and the frame.

Maximum allowable stress is found by equation (5)

$$\sigma_{max} = \frac{\sigma_{yield}}{sf}, \qquad \text{(Eq. 5)}$$

where sf = 1.2 is safety factor, and σ_{yield} is the yield strength (also called the elastic limit) of the material. We have $\sigma_{yield,PE} = 30\ MPa$ [23] and $\sigma_{yield,Al} = 276\ MPa$ [32]. Using this to solve equation (5), we obtain

$$\sigma_{max,PE} = \frac{\sigma_{yield,PE}}{sf} = \frac{30}{1.2} = 25\ MPa,$$

for PE, and

$$\sigma_{max,Al} = \frac{\sigma_{yield,Al}}{sf} = \frac{276}{1.2} = 230\ MPa$$

for Al-alloy 6061-T6.

Maximum allowable shear stress can be found by equation (6)

$$\tau_{max} = \frac{\sigma_{yield}}{\sqrt{3} \cdot sf}, \qquad \text{(Eq. 6)}$$

which gives

$$\tau_{max,PE} = \frac{30}{\sqrt{3} \cdot 1.2} = 14.5\ MPa$$

for PE, and

$$\tau_{max,Al} = \frac{276}{\sqrt{3} \cdot 1.2} = 133\ MPa$$

for Al-alloy 6061-T6.

For the structure to be strong and reliable, the following inequalities must be satisfied

$$\sigma_{real,PE} < \sigma_{max,PE} = 25\ MPa$$

and

$$\tau_{real,PE} < \tau_{max,PE} = 14.5\ MPa$$

for PE,

$$\sigma_{real,Al} < \sigma_{max,Al} = 230\ MPa$$

and

$$\tau_{real,Al} < \tau_{max,Al} = 133\ MPa$$

for Al-alloy 6061-T6.

7.5 Evaluating Results

The maximum deflection analysis is satisfying, given that the middle connection is stiff enough to consider it as one solid body and other simplifications made. Considering deflection under ideal conditions (the stretcher is carried perfectly even by two operators), the analytical result for deflection is 11.81 mm while *ANSYS* indicate 5.96 mm deflection. The results are considered reasonable, and within an acceptable margin.

Examining deflection when the stretcher is stranded on an object, there are some distinctions in results for hand calculations and *ANSYS*-simulation. This is expected, as the loads and supports are defined slightly different for these cases. Analytically, the deflection is found to be 7.75 mm upwards in the middle of the beam (due to the concentrated load), while numerical results indicate a maximum deflection of 8.1 mm around (everywhere but) the middle point (as this point is defined as a support). However, the value of deflection is in the same range, and the results are satisfactory for this analysis, meaning that the patient will experience a comfortable transportation.

Deflection due to torsional forces varies for hand calculations and numerical computation, which can be expected, since the supports are defined different. Analytical results are of range 70 mm while numerically obtained deflection due to torsion is approximately 16 mm.

From failure calculations obtained analytically, the simulated maximum equivalent stress should not exceed the yield stress of 25 MPa for HDPE and 230 MPa for Al-6061-T6, and the shear stress should not exceed 14.5 MPa for HDPE and 133 MPa for aluminium, at any point in the construction (for the given materials). The result is therefore an important discovery which has to be evaluated and taken into utmost consideration in further work. Given that the numerical approach is correct, equivalent stress and shear stress in case 1 and case 2 is within the failure criteria, while it exceeds the limits rather drastically in case 3.

The highest amount of shear stress due to torsion will often occur at the surface where the radius to the fixed point is largest. These types of stress concentrations can also relate to the geometry of the surface, often called rough spots. Thus, it is possible to smooth down the surface and adjust some angles of tubes to reduce this stress.

Chapter 8 Discussion

8.1 Further Work and Challenges

At this point the product is considered too heavy compared to the investigated competitors' products (the total weight is approximately 20 kg). There are numerous ways of reducing the weight of the design, for instance by adjusting/configuring the geometry of the frame, and/or reducing the tube diameter. Another possibility to reduce mass is to look into the material and process selection of the body, and consider making the body as a sandwich construction. Sandwiches are much stronger and lighter, but challenges the geometry and manufacturing process. This is an interesting subject that require more time and resources than available at this stage.

From *ANSYS* simulations, some results are alarmingly high (equivalent stress and shear stress in case 3), and should be investigated further. The design of the frame could be optimized and analyzed to enhance the performance.

The demand for a two-part modular, lightweight, strong stretcher, that can also function as a sledge is a difficult task. Making the connection/mounting function reliable and stiff enough requires a lot of simulation and iteration design. This is one part of the design that require more work.

Some accessories remain to be developed; such as a shock resistant, light weight, compact and insulating mattress, possible neck support and custom fastening belts for patient. Importantly, the whole point of having a two part stretcher is that one can share the load of transporting it to a site. Therefore, it is vital to have the correct gear to do so. So the development of harnesses for sledge-mode and backpack solutions for carrying the part is needed.

8.2 Learning Outcome

Eisenhower once said "*plans are nothing, planning is everything*", which in many ways summarizes our experience with this master thesis. We started off with a plan, executed it, learned a lot, which again forces us to go back and make changes.

For a long time, we pursued a concept which turned out was not as feasible as we first thought. The design was innovative and unlike any stretcher on the market today, and we were proud of the product we had created. However, we had neglected the voice of the customer, and the product did not satisfy the user's needs and requirements. This became clear during conversations with our supervisor Andreas Seger, who is extremely talented and has an eye for details. He guided us towards a more feasible design, the one we present in this report, which is similar to already existing products, but has an advantage as it is designed specifically for arctic climate and rough environment.

We also learned a lot about how to approach structural analyses, including the way to think when you reduce a real scenario/event into a simplified structural simulation with supports and loads, reflecting the real event as exact as possible.

As we were located in two different cities this semester, the decentralization presented a challenge. This obstacle has been maneuvered through rapid skype-meetings and a detailed time schedule, a deep understanding of responsibility, communication and great teamwork. We learned a lot from this, and consider it a valuable experience, as many projects in the future may be conducted this way. We have taken on different roles, from creative driver to critical thinkers. As a designing team with different backgrounds, we have been both leaders and followers in different fields and phases of the project. For us, this is considered a good environment for innovation.

This experience has been both challenging and inspiring. Eventually, after lots of discussion and hard work, we are more than proud of our efforts and the final result.

Chapter 9 Conclusion

This report introduced three conceptual designs of a multi-purpose stretcher for SAR-missions in arctic environment, and an in-depth study of concept 2. The concept consists of a frame and a shell-body, both with a he- and she-configuration, enabling modularity. A well-documented material selection is conducted for each of these parts, and a detailed 3D CAD-model is made and illustrated with figures and 2D-drawings. Manufacturability and costs are analyzed, resulting in compression molding and extrusion as preferred production methods for the body and the frame, respectively. Given that the assumptions of costs is correct, the profit of manufacturing and distributing these stretchers are satisfying.

Analytical and numerical calculations are built on simplifications of the problem, and may differ from real events. However, given that the applied assumptions are correct, the results are satisfying. The stretcher deflects within reasonable limits for the three cases analyzed, and equivalent stress and shear stress is acceptable for case 1 and 2.

The resulting product is a stretcher that meets the requirements set by the customers, satisfies the voice of the customer and the given task description. It is foldable/modular, and the large components enables the stretcher to be operated with winter gloves. It is comfortable and provide a high level of safety for the patient, as the stretcher is stiff enough to tolerate operating conditions. Environmental requirements are satisfied, as the materials making up the stretcher is recyclable and non-toxic.

Acknowledgement

First and foremost, we want to thank our two supervisors, Andreas Seger with his incredible academic knowledge and invaluable SAR-experience, and Guy Mauseth for valuable guidance in the design process and helping us when we were struggling the most.

In addition we want to thank Erlend Bjørk for his time and dedication regarding the 3D-printing process, and Magnus Aanstad for valid information and help related to material selection, aluminium alloys and TIG welding.

We could not have done this without the feedback from Røde Kors Harstad early in the process.

Lastly, we want to thank the talented faculty at the University for inspiring us on a daily basis with interesting lectures, and our fellow classmates in Engineering Design for all the support and motivation, and for a remarkable work environment over the past two years.

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Appendix

Appendix A – Problem Description

Faculty of Engineering Science and Technology
Department of Computer Science and Computational Engineering, Narvik

Master of Science

First aid equipment for use in cold climate environment: Stretcher

—

Karoline Bratteng, Eirik Søreng
Master thesis in Engineering Design … Spring 2017

Background

One of the research topics of the nursing department in UiT campus Narvik is wildlife medicine and in particularly wildlife medicine in arctic environment.
In the case, we look upon a situation where a person might have sustained an injury during outdoor activity, during the winter the period. We look at a case where a person is laying on the ground/ snow and might sustained an injury, which needs a rapid transportation to the hospital.
The injury could be caused due to a snow scooter accident, skiing accident, falling through the ice of a frozen lake, being taken by a snow avalanche etc.
In any case, the person cannot get up on his feet, and due to the uncertainty regarding the severity of the injury, one needs to transport the injured person to the hospital, as fast as possible.
In some cases, the extraction point is only accessible by people on skies or by foot. In such case, there is a need of developing a stretcher, which can be pulled/ carried by two persons.
There are several existing solutions of such stretchers in the market but feedback from people which are involved with search and rescue operations (Hjelpekorps - Rødekors) shows that many of the existing products have significant drawbacks.

Problem description

Designing and optimizing portable a stretcher for use in first aid cases where the location of the injured person is difficult to access by other means then ski/ foot. In addition, the stretcher must function as a "sledge" which can be steered by two skiers through technical downhill slopes and over other obstacles in the terrain.
Key words associated with the problem:

- low weight
- foldable
- compact
- robust
- safe
- "warm"
- easy to operate with winter gloves
- transport on snow by skiers.
- symmetry
- modular

The work shall include:

1. **A literature study** both in terms of finding state-of –the art for these types of products, existing equipment on the market and potential competitors, as well as other literature that is necessary with a view to solving the problem (regulations, standards for materials, patents etc.). Existing equipment described with respect to behaviour, structure, performance, weight, and size.
2. **Develop a specification** for the product based on demands for performance under the given physical conditions, requirements for stiffness, strength, weight, reliability, comfort, regulations and other requirements and demands of the customer.
3. **Conduct a systematic design** ending up with a final proposal to the technical solution for the product/system.

4. **Analysis of the product/system** shall be made in order to determine which aspects/ parts of the system/ product should undergo numerical and analytical calculations.
5. **Modelling of the system** in a 3D parametric CAD system and simulation/visualization of for instance movements. A set of 2D drawings should be generated. These drawings should include assembled drawings of the system in open and closed position and complete part production drawings with tolerances.
6. **Modelling and numerical analysis** of the product/ system will (also) be carried out using an appropriate numerical calculation tool (such as Ansys) and should be compared with the analytical calculations of the product / system.
7. **Construction/making** a (physical) prototype or a model of the product/system/structure.
8. **Suggestions** for future work and description of remaining work

The solution of the task should be based on typical engineering design methods and areas of study for the Master Program Engineering Design at UiT – campus Narvik.

General information

This master thesis should include:

- ❄ Preliminary work/literature study related to actual topic
  - A state-of-the-art investigation
  - An analysis of requirement specifications, definitions, design requirements, given standards or norms, guidelines and practical experience etc.
  - Description concerning limitations and size of the task/project
  - Estimated time schedule for the project/ thesis
- ❄ Selection & investigation of actual materials
- ❄ Development (creating a model or model concept)
- ❄ Experimental work (planned in the preliminary work/literature study part)
- ❄ Suggestion for future work/development

Limitations of the task/project

Eventual ownership of product and documentation, restrictions and closure to be filled up here.

Preliminary work/literature study

After the task description has been distributed to the candidate a preliminary study should be completed within 4 weeks. It should include bullet pints 1 and 2 in "The work shall include", and a plan of the progress. The preliminary study may be submitted as a separate report or "natural" incorporated in the main thesis report. A plan of progress and a deviation report (gap report) can be added as an appendix to the thesis.

In any case the preliminary study report/part must be accepted by the supervisor before the student can continue with the rest of the master thesis. In the evaluation of this thesis emphasis will be placed on the thorough documentation of the work performed.

Reporting requirements

The thesis should be submitted as a research report and should include the following parts; Abstract, Introduction, Analysis (analytical and numerical) & Materials & Methods & Calculations, Results & Discussion, Conclusions, Acknowledgements, Bibliography, References and Appendices. Choices should be well documented with evidence, references, or logical arguments.

The candidate should in this thesis strive to make the report survey-able, testable, accessible, well written, and documented.

Materials which are developed during the project (thesis) such as software/codes or physical equipment are considered to be a part of this paper (thesis). Documentation for correct use of such information should be added, as far as possible, to this paper (thesis).

The text for this task should be added as an appendix to the report (thesis).

The report (Abstract, Introduction, Analysis (analytical and numerical) & Materials & Methods & Calculations, Results & Discussion, Conclusions, Acknowledgements, Bibliography, References) should not exceed 50 pages, with 12pt. font size. Any additional material should be included in the appendix.

General project requirements

If the tasks or the problems are performed in close cooperation with an external company, the candidate should following the guidelines or other directives given by the management of the company.

The candidate does not have the authority to enter or access external companies' information system, production equipment or likewise. If such should be necessary for solving the task in a satisfactory way a detailed permission should be given by the management in the company before any action are made.

Any travel cost, printing and phone cost must be covered by the candidate themselves, if and only if, this is not covered by an agreement between the candidate and the management in the enterprises.

If the candidate enters some unexpected problems or challenges during the work with the tasks and these will cause changes to the work plan, it should be addressed to the supervisor at the UiT Campus Narvik or the person which is responsible, without any delay in time.

Submission requirements

This thesis should result in a final report with an electronic copy (i.e. CD/DVD, memory stick) of the report included appendices and necessary software codes, simulations and calculations. The final report with its appendices will be the basis for the evaluation and grading of the thesis. The report with all materials should be delivered in one signed loose-leaf copy, together with three bound. If there is an external company that needs a copy of the thesis, the candidate must arrange this. A standard front page, which can be found on the UiT Campus Narvik internet site, should be used. Otherwise, refer to the "General guidelines for thesis" and the subject description for master thesis.

The final report with its appendices should be submitted no later than the decided final date. The final report should be delivered to the adviser at the office of the Department of Computer Science and Computational Engineering.

Date of distributing the task:	xx.x.2017
Date for submission (deadline):	xx.x.2017

Contact information

Supervisor at the UiT Campus Narvik   Andreas Seger

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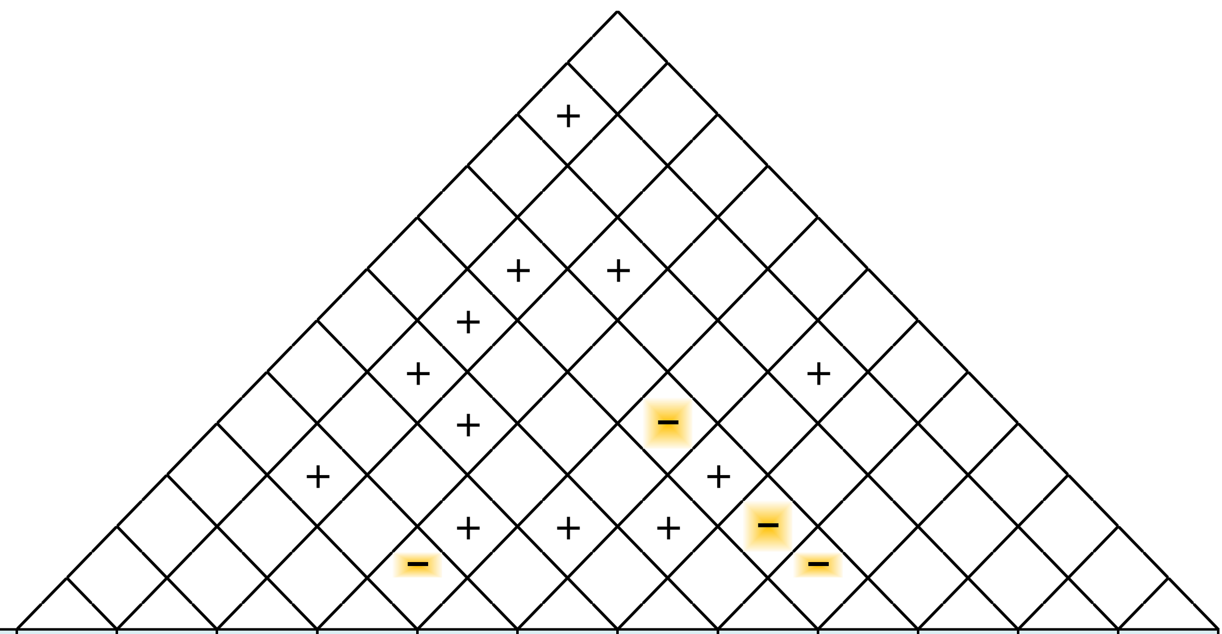
Appendix B – House of Quality (HOQ)

QFD: House of Quality

Project:
Revision:
Date:

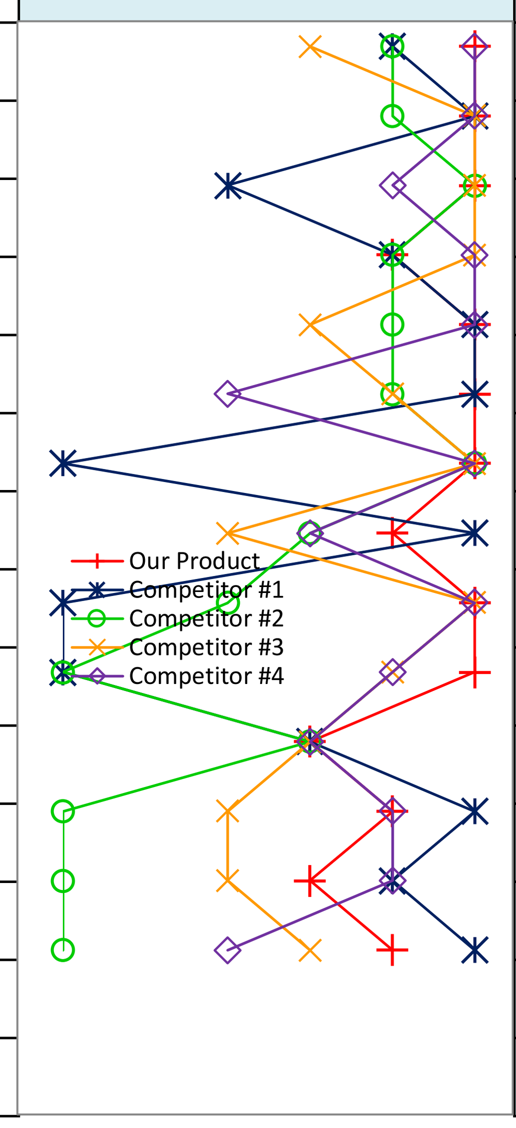
Correlations	
Positive	+
Negative	−
No Correlation	

Relationships	
Strong	●
Moderate	○
Weak	▽



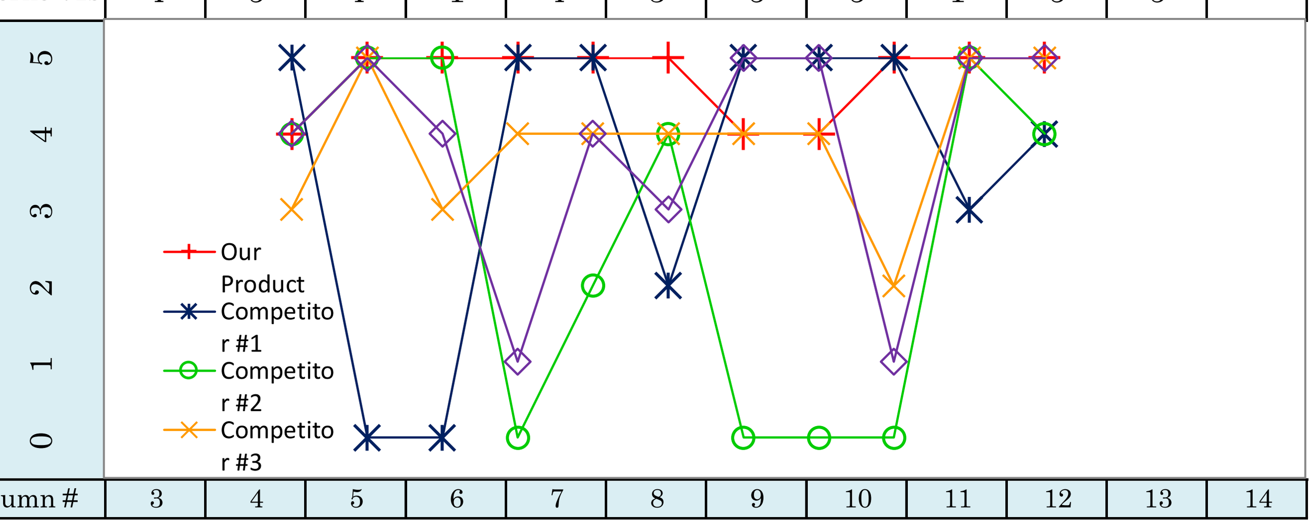
Row #	Relative Weight	Customer Importance	Maximum Relationship	Customer Requirements (Explicit and Implicit) \ Functional Requirements	3 Amount of parts	4 Foldable	5 Folding method	6 Product weight	7 Locking mechanism	8 Materials	9 Manufacturing	10 Weight capasity	11 Price	12 Operating temperatures	13 Dimensions	14	Our Product	Competitor #1 LESS PRO 4001	Competitor #2: Vite Concept Design	Competitor #3: Tyromont UT2000	Competitor #4: Ferno 71s	Row #
				Direction of Improvement	◇	◇	▲	◇	◇	◇	▲	◇	◇	▲	◇							
1	6 %	5	9	Comfortable (Patient)			▽	▽	●	●	▽			▽	●		5	4	4	3	5	1
2	10 %	9	9	Safe/provide stability (P)	▽	▽	▽	▽	●	●	▽	▽		▽	▽		5	5	4	5	5	2
3	9 %	8	9	Warm/insulating (P)	▽			▽		●				●			5	2	5	5	4	3
4	8 %	7	9	Ergonomic design (P)	▽		▽	●	▽	●		▽			●		4	4	4	5	5	4
5	10 %	9	9	Reliable (Rescuer)	●		▽	▽	●	●	●	▽		●	▽		5	5	4	3	5	7
6	7 %	6	9	Light-weight (R)	▽	●	●	●		●	●	▽	▽		●		5	5	4	4	2	8
7	9 %	8	9	Easy to fold/unfold (R)		●	●		●				▽	▽	●		5	0	5	5	5	9
8	9 %	8	9	Does not cause post-traumatic injury (R)				▽									4	5	3	2	3	10
9	7 %	6	9	Modular (R)	▽	●	●	●		▽		▽			●		5	0	2	5	5	11
10	9 %	8	9	Function as stretcher and sledge (R)	▽				●	●		▽	▽		●		5	0	0	4	4	12
11	6 %	5	9	Fit different body types (R)					▽			●			●		3	3	3	3	3	13
12	7 %	6	9	Easy to clean (Medical staff)	▽					●							4	5	0	2	4	14
13	2 %	2	9	Perform medical examinations (M)						●							3	4	0	2	4	15
14	3 %	3	9	Low selling price		●	▽	●		▽		▽	●		▽		4	5	0	3	2	16

Customer Competitive Assesment



Column #	3	4	5	6	7	8	9	10	11	12	13	14
Target	Less than 10	Easy to fold	Simple and intuitive	Less than 10 kg	Simple and intuitive	Light, comfortable, low price, arctic climate	Easy to manufacture, low complexity	150 kg	Less than NOK 15 000	Down to -40 °C	L: 190 cm, h: 10 cm, w: 44 cm	
Max Relationship	9	9	9	9	9	9	9	9	9	9	9	
Technical Importance Rating	145,56	240	236,67	263,33	403,33	610	165,56	103,33	54,444	194,44	473,33	0
Relative Weight	5 %	8 %	8 %	9 %	14 %	21 %	6 %	4 %	2 %	7 %	16 %	0 %
Weight Chart												
Our Product	4	5	5	5	5	5	4	4	5	5	5	
Competitor #1 LESS	5	0	0	5	5	2	5	5	5	3	4	
Competitor #2: Vite Concept Design	4	5	5	0	2	4	0	0	0	5	4	
Competitor #3: Tyromont UT2000	3	5	3	4	4	4	4	4	2	5	5	
Competitor #4: Ferno 71s	4	5	4	1	4	3	5	5	1	5	5	

Technical Competitive Assessment



Column #	3	4	5	6	7	8	9	10	11	12	13	14

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Christopher Battles

Appendix C – Limits Applied to Material Selection for Frame

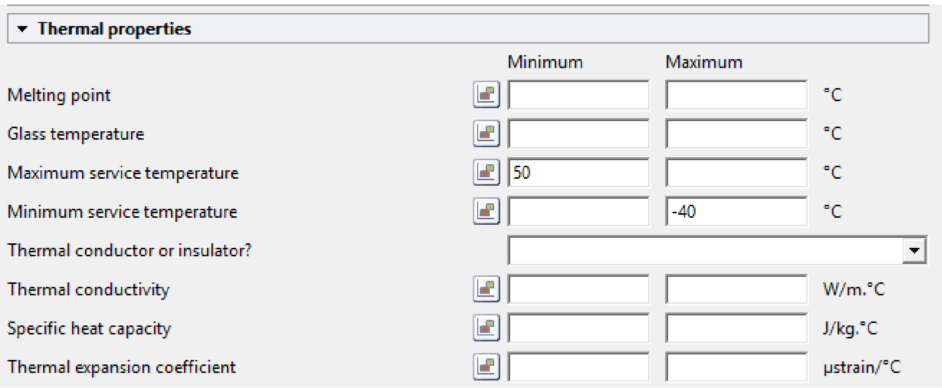


Figure C-1: Limits for minimum and maximum service temperature.

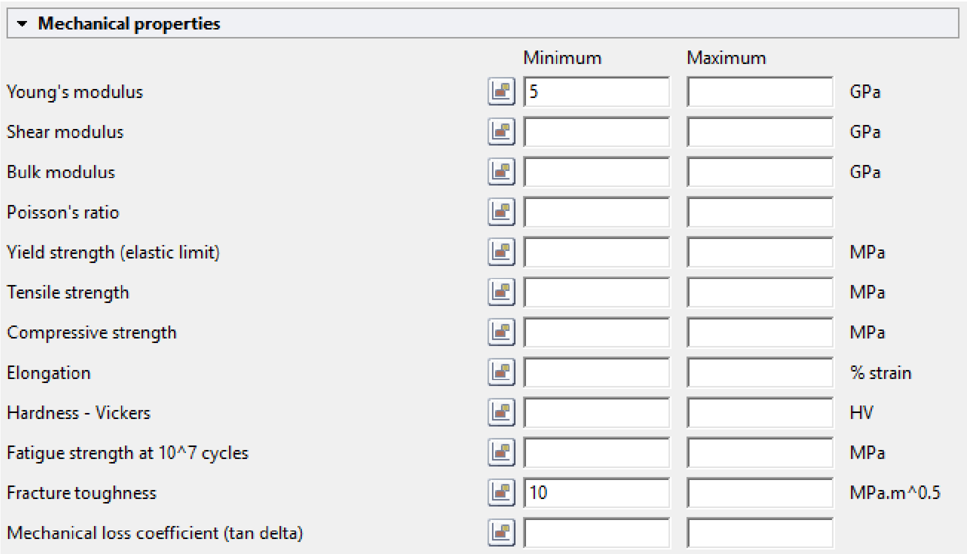


Figure C-2: Mechanical property limits

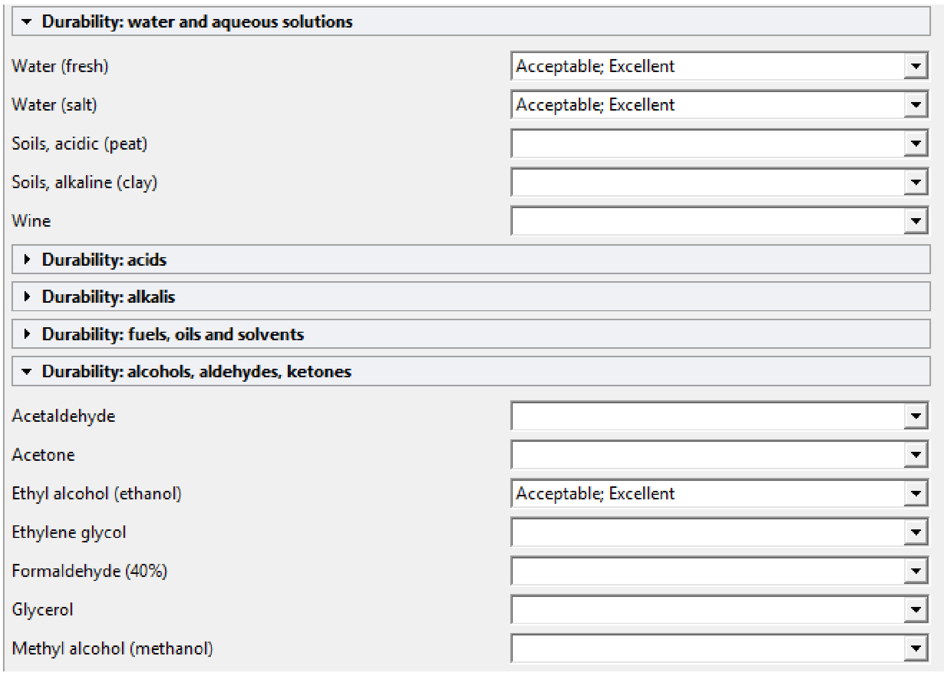


Figure C-3: Durability limits considering fresh and salt water, and ethanol (disinfectant).

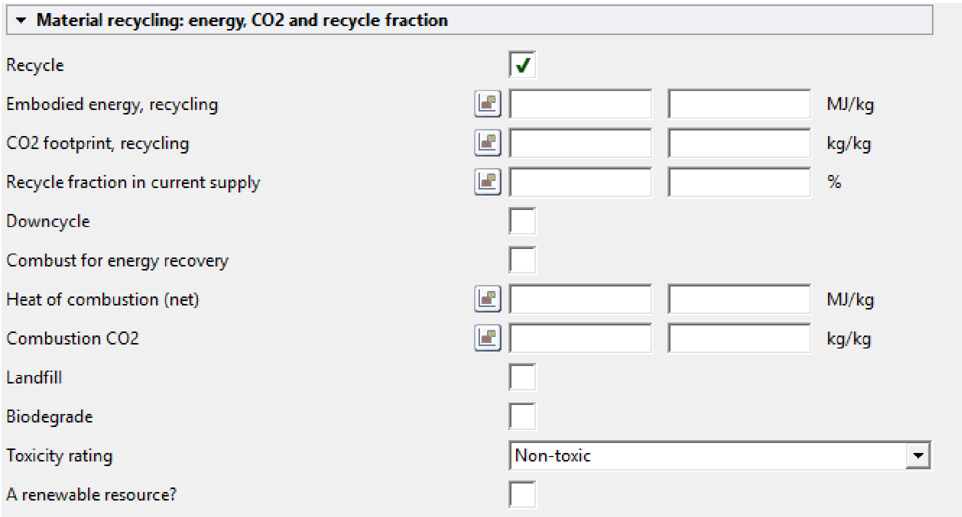


Figure C-4: Environmental requirements

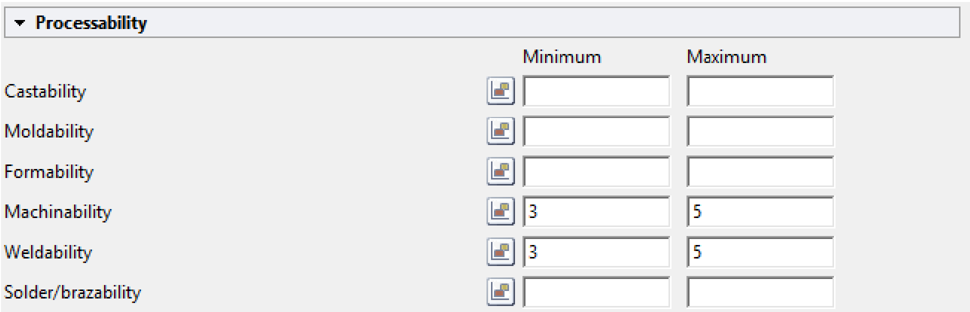


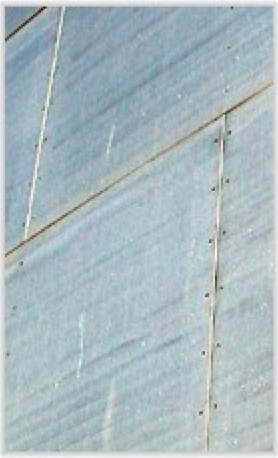
Figure C-5: Processability limits

Appendix D – Age-hardening Wrought Al-alloys Properties

Age-hardening wrought Al-alloys

Description

Image



Caption

1. A close-up of building cladding made from wrought aluminum alloy . © John Fernandez 2. Chassis of a personal computer. © Chris Lefteri 3. The 2000 and 7000 series age-hardening aluminum alloys are the backbone of the aerospace industry.

The material

The high-strength aluminum alloys rely on age-hardening: a sequence of heat treatment steps that causes the precipitation of a nano-scale dispersion of intermetallics that impede dislocation motion and impart strength. This can be as high as 700 MPa giving them a strength-to-weight ratio exceeding even that of the strongest steels. This record describes for the series of wrought Al alloys that rely on age-hardening requiring a solution heat treatment followed by quenching and ageing. This is recorded by adding TX to the series number, where X is a number between 0 and 8 that records the state of heat treatment. They are listed below using the IADS designations (see Technical notes for details).2000 series: Al with 2 to 6% Cu -- the oldest and most widely used aerospace series.6000 series: Al with up to 1.2% Mg and 1.3% Si -- medium strength extrusions and forgings.7000 series: Al with up to 8% Zn and 3% Mg -- the Hercules of aluminum alloys, used for high strength aircraft structures, forgings and sheet. Certain special alloys also contain silver. So this record, like that for the non-age hardening alloys, is broad, encompassing all of these.

Compositional summary

2000 series: Al + 2 to 6% Cu + Fe, Mn, Zn and sometimes Zr
6000 series: Al + up to 1.2%Mg + 0.25% Zn + Si, Fe and Mn
7000 series: Al + 4 to 9 % Zn + 1 to 3% Mg + Si, Fe, Cu and occasionally Zr and

General properties

Density		2,5e3	-	2,9e3	kg/m^3
Price	*	19,6	-	22,4	NOK/kg
Date first used		1916			

Mechanical properties

Young's modulus	68	-	80	GPa
Shear modulus	25	-	28	GPa
Bulk modulus	64	-	70	GPa
Poisson's ratio	0,32	-	0,36	
Yield strength (elastic limit)	95	-	610	MPa
Tensile strength	180	-	620	MPa
Compressive strength	95	-	610	MPa

Elongation	1	-	20	% strain
Hardness - Vickers	60	-	160	HV
Fatigue strength at 10^7 cycles	57	-	210	MPa
Fracture toughness	21	-	35	MPa.m^0.5
Mechanical loss coefficient (tan delta)	1e-4	-	0,001	

Thermal properties

Melting point	495	-	640	°C
Maximum service temperature	120	-	200	°C
Minimum service temperature	-273			°C
Thermal conductor or insulator?	Good conductor			
Thermal conductivity	118	-	174	W/m.°C
Specific heat capacity	890	-	1,02e3	J/kg.°C
Thermal expansion coefficient	22	-	24	µstrain/°C

Electrical properties

Electrical conductor or insulator?	Good conductor			
Electrical resistivity	3,8	-	6	µohm.cm

Optical properties

Transparency	Opaque

Processability

Castability	4	-	5
Formability	3	-	4
Machinability	4	-	5
Weldability	3	-	4
Solder/brazability	2	-	3

Durability: water and aqueous solutions

Water (fresh)	Excellent
Water (salt)	Acceptable
Soils, acidic (peat)	Unacceptable
Soils, alkaline (clay)	Excellent
Wine	Excellent

Durability: acids

Acetic acid (10%)	Limited use
Acetic acid (glacial)	Unacceptable
Citric acid (10%)	Acceptable
Hydrochloric acid (10%)	Acceptable
Hydrochloric acid (36%)	Unacceptable
Hydrofluoric acid (40%)	Unacceptable
Nitric acid (10%)	Limited use
Nitric acid (70%)	Limited use

Phosphoric acid (10%)	Unacceptable
Phosphoric acid (85%)	Unacceptable
Sulfuric acid (10%)	Unacceptable
Sulfuric acid (70%)	Unacceptable

Durability: alkalis

Sodium hydroxide (10%)	Unacceptable
Sodium hydroxide (60%)	Unacceptable

Durability: fuels, oils and solvents

Amyl acetate	Excellent
Benzene	Excellent
Carbon tetrachloride	Excellent
Chloroform	Excellent
Crude oil	Excellent
Diesel oil	Excellent
Lubricating oil	Excellent
Paraffin oil (kerosene)	Excellent
Petrol (gasoline)	Excellent
Silicone fluids	Excellent
Toluene	Excellent
Turpentine	Excellent
Vegetable oils (general)	Excellent
White spirit	Excellent

Durability: alcohols, aldehydes, ketones

Acetaldehyde	Excellent
Acetone	Excellent
Ethyl alcohol (ethanol)	Acceptable
Ethylene glycol	Excellent
Formaldehyde (40%)	Excellent
Glycerol	Limited use
Methyl alcohol (methanol)	Acceptable

Durability: halogens and gases

Chlorine gas (dry)	Limited use
Fluorine (gas)	Unacceptable
O2 (oxygen gas)	Excellent
Sulfur dioxide (gas)	Acceptable

Durability: built environments

Industrial atmosphere	Excellent
Rural atmosphere	Excellent
Marine atmosphere	Excellent

UV radiation (sunlight)	Excellent			

Durability: flammability

Flammability	Non-flammable			

Durability: thermal environments

Tolerance to cryogenic temperatures	Excellent			
Tolerance up to 150 C (302 F)	Acceptable			
Tolerance up to 250 C (482 F)	Unacceptable			
Tolerance up to 450 C (842 F)	Unacceptable			
Tolerance up to 850 C (1562 F)	Unacceptable			
Tolerance above 850 C (1562 F	Unacceptable			

Geo-economic data for principal component

Annual world production, principal component	3,69e7			tonne/yr
Reserves, principal component	4,74e10	-	5,24e10	tonne

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 198	-	219	MJ/kg
CO2 footprint, primary production	* 12,2	-	13,4	kg/kg
Water usage	* 1,14e3	-	1,26e3	l/kg
Eco-indicator 95	780			millipoints/kg
Eco-indicator 99	710			millipoints/kg

Material processing: energy

Extrusion, foil rolling energy	* 10,2	-	11,3	MJ/kg
Rough rolling, forging energy	* 5,24	-	5,79	MJ/kg
Wire drawing energy	* 37,4	-	41,3	MJ/kg
Metal powder forming energy	* 20,2	-	24,4	MJ/kg
Vaporization energy	* 1,55e4	-	1,71e4	MJ/kg
Coarse machining energy (per unit wt removed)	* 1,22	-	1,35	MJ/kg
Fine machining energy (per unit wt removed)	* 7,9	-	8,73	MJ/kg
Grinding energy (per unit wt removed)	* 15,3	-	16,9	MJ/kg
Non-conventional machining energy (per unit wt removed	155	-	171	MJ/kg

Material processing: CO2 footprint

Extrusion, foil rolling CO2	* 0,764	-	0,844	kg/kg
Rough rolling, forging CO2	* 0,393	-	0,434	kg/kg
Wire drawing CO2	* 2,81	-	3,1	kg/kg
Metal powder forming CO2	* 1,62	-	1,96	kg/kg
Vaporization CO2	* 1,16e3	-	1,28e3	kg/kg
Coarse machining CO2 (per unit wt removed)	* 0,0913	-	0,101	kg/kg
Fine machining CO2 (per unit wt removed)	* 0,593	-	0,655	kg/kg
Grinding CO2 (per unit wt removed)	* 1,15	-	1,27	kg/kg
Non-conventional machining CO2 (per unit wt removed	11,6	-	12,8	kg/kg

Material recycling: energy, CO2 and recycle fraction

Recycle	✓			
Embodied energy, recycling	* 33,5	-	37	MJ/kg
CO2 footprint, recycling	* 2,63	-	2,91	kg/kg
Recycle fraction in current supply	33	-	55	%
Downcycle	✓			
Combust for energy recovery	✗			
Landfill	✓			
Biodegrade	✗			
Toxicity rating	Non-toxic			
A renewable resource?	✗			

Environmental notes

Aluminum ore is abundant. It takes a lot of energy to extract aluminum, but it is easily recycled at low energy cost.

Supporting information

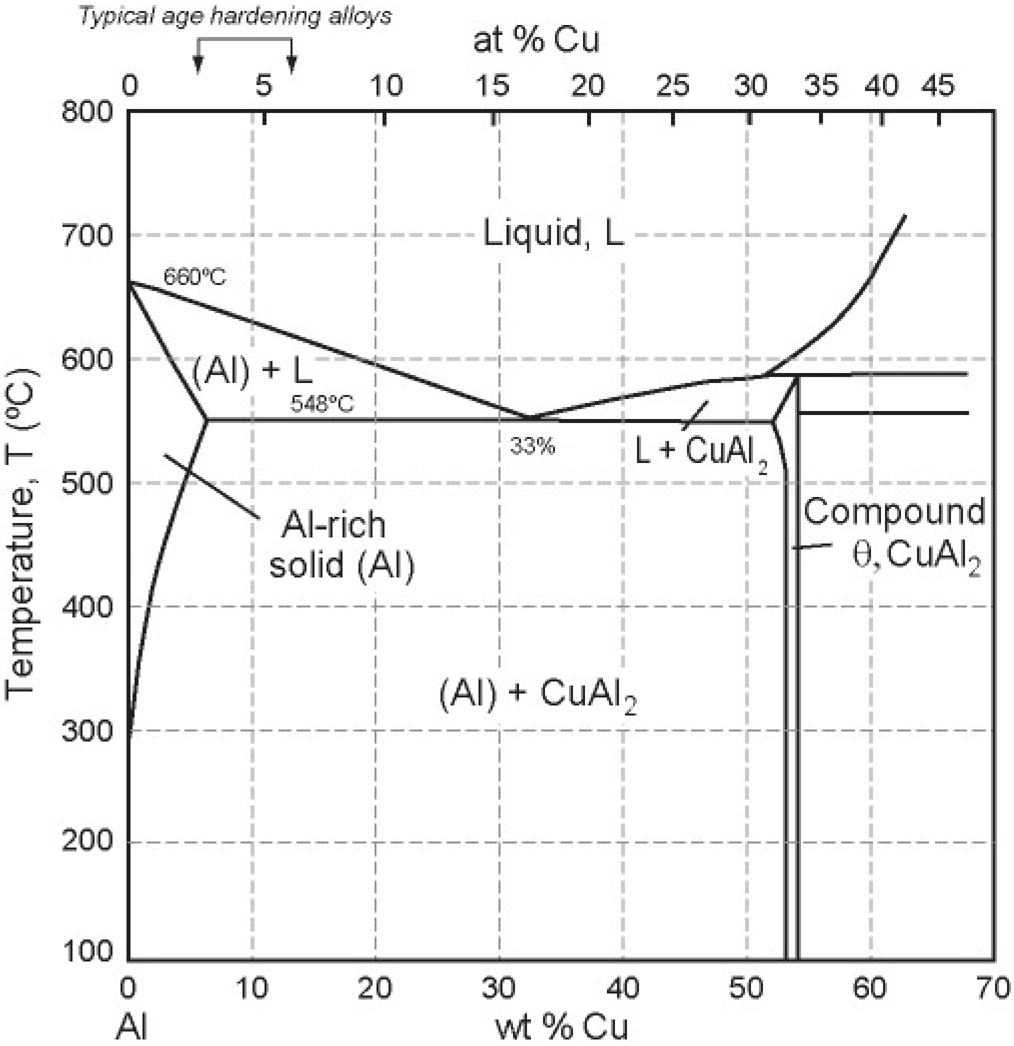
Design guidelines

The age-hardening alloys have exceptional strength at low weight, but the origin of the strength -- age hardening -- imposes certain design constraints. At its simplest, age-hardening involves a three step heat treatment.
Step 1: the wrought alloy, as sheet, extrusion or forging, is solution heat treated -- held for about 2 hours at around 550 C (it depends on the alloys) to make the alloying elements (Cu, Zn, Mg, Si etc) dissolve.
Step 2: the material is quenched from the solution-treatment temperature, typically by dunking or spraying it with cold water. This traps the alloying elements in solution. Quenching is a savage treatment that can cause distortion and create internal stresses that may require correction, usually by rolling.
Step 3: the material is aged, meaning that it is heated to between 120 and 190 C for about 8 hours during which the alloying elements condense into nano-scale dispersions of intermetallics (CuAl, CuAl2, Mg2Si and the like). It is this dispersion that gives the strength.
The result is a material that, for its weight, has remarkably high strength and corrosion resistance. But if it is heated above the solution treatment temperature -- by welding, for example -- the strength is lost. This means that assembly requires fasteners such as rivets, usual in airframe construction, or adhesives. Some 6000 series alloys can be welded, but they are of medium rather than high strength.

Technical notes

Until 1970, designations of wrought aluminum alloys were a mess; in many countries, they were simply numbered in the order of their development. The International Alloy Designation System (IADS), now widely accepted, gives each wrought alloy a 4-digit number. The first digit indicates the major alloying element or elements. Thus the series 1xxx describe unalloyed aluminum; the 2xxx series contain copper as the major alloying element, and so forth. The third and fourth digits are significant in the 1xxx series but not in the others; in 1xxx series they describe the minimum purity of the aluminum; thus 1145 has a minimum purity of 99.45%; 1200 has a minimum purity of 99.00%. In all other series, the third and fourth digits are simply serial numbers; thus 5082 and 5083 are two distinct aluminum-magnesium alloys. The second digit has a curious function: it indicates a close relationship: thus 5352 is closely related to 5052 and 5252; and 7075 and 7475 differ only slightly in composition. To these serial numbers are added a suffix indicating the state of hardening or heat treatment. The suffix F means 'as fabricated'. Suffix O means 'annealed wrought products'. The suffix H means that the material is 'cold worked'. The suffix T means that it has been 'heat treated'. More information on designations and equivalent grades can be found on the Granta Design website at www.grantadesign.com/designations

Phase diagram



Phase diagram description

The 2000 series of wrought aluminum alloys are based on aluminum (Al) with 2.5 - 6% copper (Cu). This is the relevant part of the phase diagram.

Typical uses

2000 and 7000 series: aerospace structures, pressure vessels, ultralight land-based transport systems; sports equipment such as golf clubs and bicycles.
6000 series: cladding and roofing; medium strength extrusions, forgings and welded structures for general engineering and automotive such as connecting rods.

Links

Reference

ProcessUniverse

Producers

Appendix E – Limits Applied to Material Selection for Body

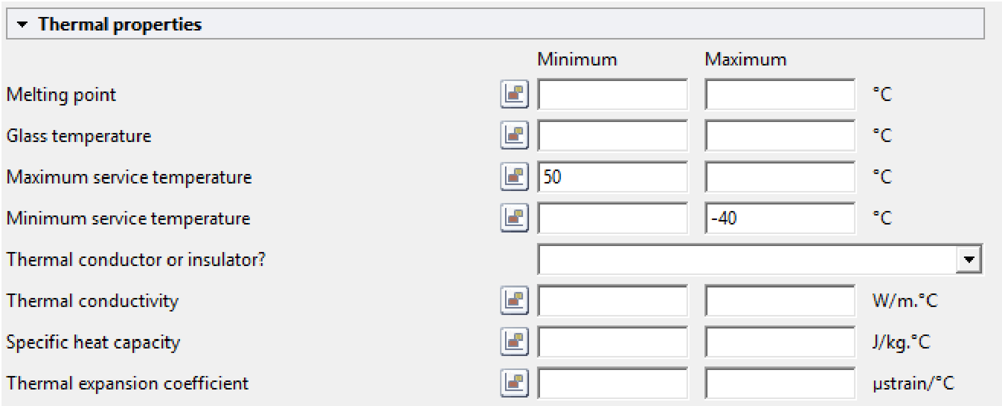


Figure E-1: Limits for minimum and maximum service temperature.

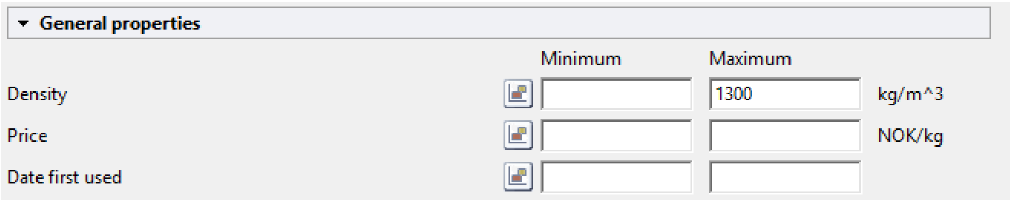


Figure E-2: Applying maximum density.

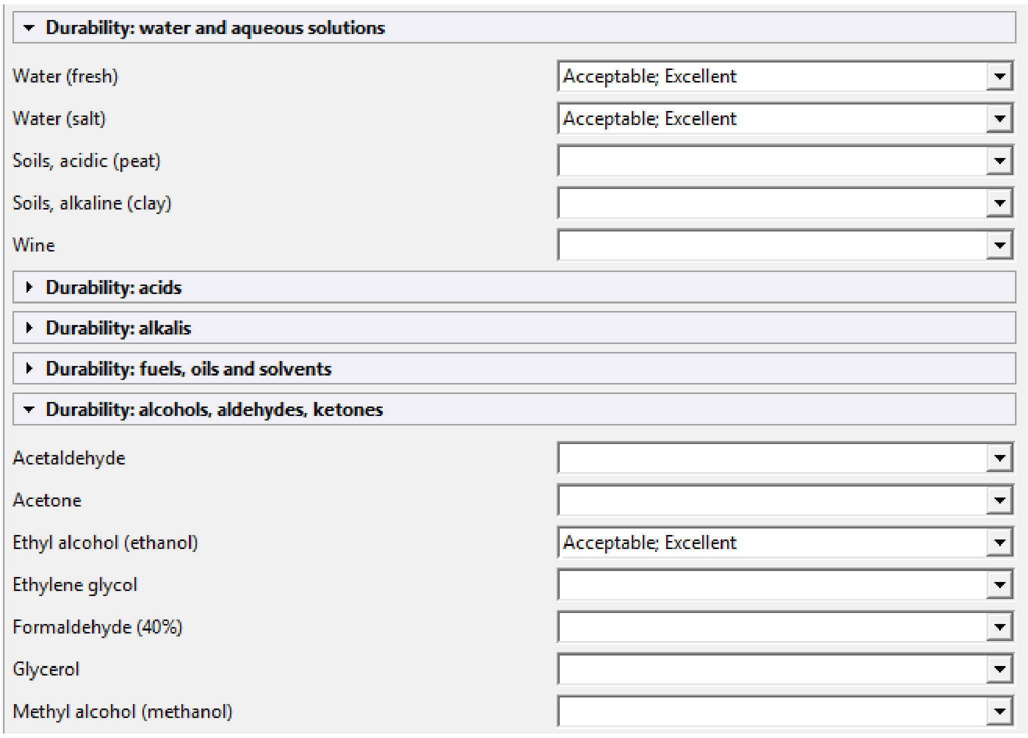


Figure E-3: Durability limits considering fresh and salt water, and ethanol (disinfectant).

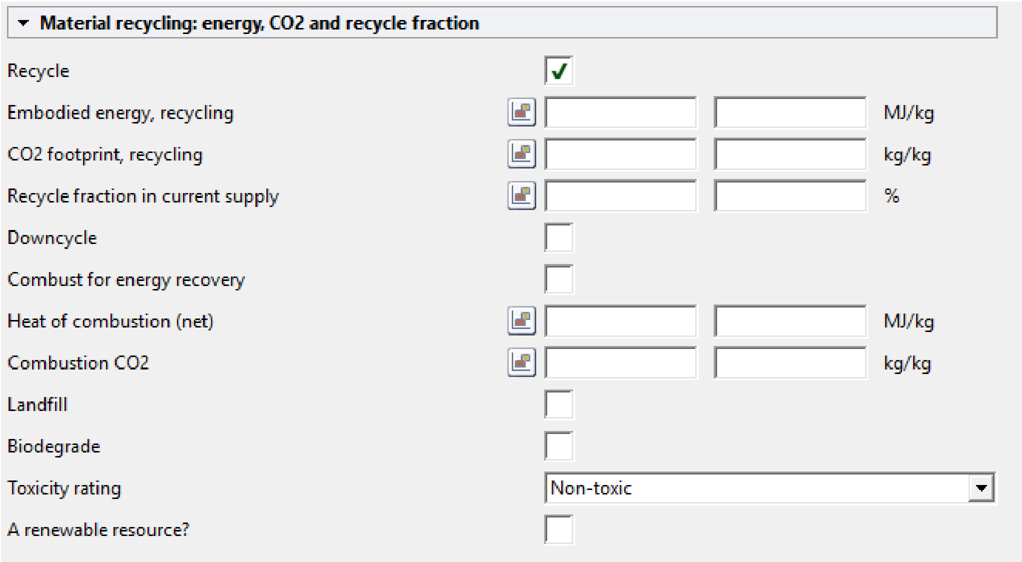


Figure E-4: Environmental requirements set as attribute.

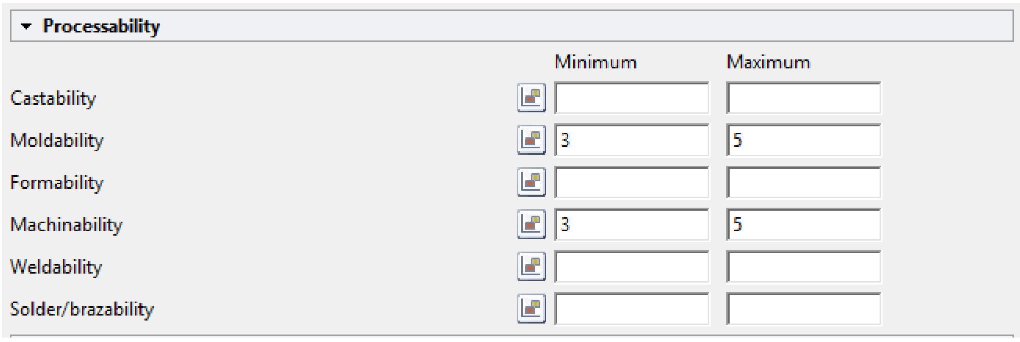
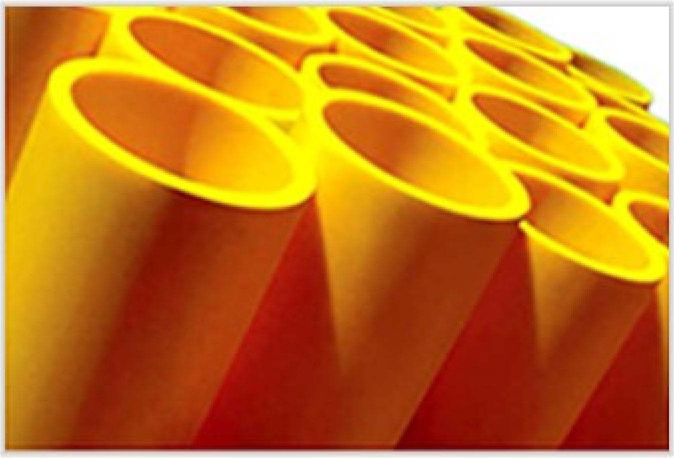


Figure E-5: Processability limit.

Appendix F – Polyethylene Properties

Description

Image



Caption

1. Low-density PE bottle. © Granta Design 2. Medium-density PE pipe. © Granta Design

The material

POLYETHYLENE, (-CH2-)n, first synthesized in 1933, looks like the simplest of molecules, but the number of ways in which the - CH2 - units can be linked is large. It is the first of the polyolefins, the bulk thermoplastic polymers that account for a dominant fraction of all polymer consumption. Polyethylene is inert, and extremely resistant to fresh and salt water, food, and most water-based solutions. Because of this it is widely used in household products, food containers like Tupperware and chopping boards. Polyethylene is cheap, and particularly easy to mold and fabricate. It accepts a wide range of colors, can be transparent, translucent or opaque, has a pleasant, slightly waxy feel, can be textured or metal coated, but is difficult to print on.

Compositional summary

(-CH2-CH2-)n

General properties

Density		939	-	960	kg/m^3
Price	*	17,6	-	21,5	NOK/kg
Date first used		1936			

Mechanical properties

Young's modulus		0,621	-	0,896	GPa
Shear modulus	*	0,218	-	0,314	GPa
Bulk modulus		2,15	-	2,25	GPa
Poisson's ratio	*	0,418	-	0,434	
Yield strength (elastic limit)		17,9	-	29	MPa
Tensile strength		20,7	-	44,8	MPa
Compressive strength		19,7	-	31,9	MPa
Elongation		200	-	800	% strain
Hardness - Vickers		5,4	-	8,7	HV
Fatigue strength at 10^7 cycles		21	-	23	MPa
Fracture toughness	*	1,44	-	1,72	MPa.m^0.5
Mechanical loss coefficient (tan delta)	*	0,0446	-	0,0644	

Thermal properties

Melting point		125	-	132	°C
Glass temperature		-25,2	-	-15,2	°C
Maximum service temperature	*	90	-	110	°C
Minimum service temperature	*	-123	-	-73,2	°C
Thermal conductor or insulator?		Good insulator			
Thermal conductivity		0,403	-	0,435	W/m.°C
Specific heat capacity	*	1,81e3	-	1,88e3	J/kg.°C
Thermal expansion coefficient		126	-	198	µstrain/°C

Electrical properties

Electrical conductor or insulator?		Good insulator			
Electrical resistivity		3,3e22	-	3e24	µohm.cm
Dielectric constant (relative permittivity)		2,2	-	2,4	
Dissipation factor (dielectric loss tangent)	*	3e-4	-	6e-4	
Dielectric strength (dielectric breakdown)		17,7	-	19,7	1000000 V/m

Optical properties

Transparency		Translucent			
Refractive index		1,5	-	1,52	

Processability

Castability		1	-	2	
Moldability		4	-	5	
Machinability		3	-	4	
Weldability		5			

Durability: water and aqueous solutions

Water (fresh)	Excellent
Water (salt)	Excellent
Soils, acidic (peat)	Excellent
Soils, alkaline (clay)	Excellent
Wine	Excellent

Durability: acids

Acetic acid (10%)	Excellent
Acetic acid (glacial)	Excellent
Citric acid (10%)	Excellent
Hydrochloric acid (10%)	Excellent
Hydrochloric acid (36%)	Excellent
Hydrofluoric acid (40%)	Excellent
Nitric acid (10%)	Excellent
Nitric acid (70%)	Acceptable
Phosphoric acid (10%)	Excellent

Phosphoric acid (85%)	Excellent
Sulfuric acid (10%)	Excellent
Sulfuric acid (70%)	Excellent

Durability: alkalis

Sodium hydroxide (10%)	Excellent
Sodium hydroxide (60%)	Excellent

Durability: fuels, oils and solvents

Amyl acetate	Excellent
Benzene	Acceptable
Carbon tetrachloride	Acceptable
Chloroform	Limited use
Crude oil	Acceptable
Diesel oil	Excellent
Lubricating oil	Excellent
Paraffin oil (kerosene)	Excellent
Petrol (gasoline)	Excellent
Silicone fluids	Acceptable
Toluene	Acceptable
Turpentine	Excellent
Vegetable oils (general)	Excellent
White spirit	Excellent

Durability: alcohols, aldehydes, ketones

Acetaldehyde	Excellent
Acetone	Acceptable
Ethyl alcohol (ethanol)	Excellent
Ethylene glycol	Excellent
Formaldehyde (40%)	Excellent
Glycerol	Excellent
Methyl alcohol (methanol)	Excellent

Durability: halogens and gases

Chlorine gas (dry)	Acceptable
Fluorine (gas)	Limited use
O2 (oxygen gas)	Unacceptable
Sulfur dioxide (gas)	Excellent

Durability: built environments

Industrial atmosphere	Excellent
Rural atmosphere	Excellent
Marine atmosphere	Excellent
UV radiation (sunlight)	Fair

Durability: flammability

Flammability	Highly flammable

Durability: thermal environments

Tolerance to cryogenic temperatures	Unacceptable
Tolerance up to 150 C (302 F)	Acceptable
Tolerance up to 250 C (482 F)	Unacceptable
Tolerance up to 450 C (842 F)	Unacceptable
Tolerance up to 850 C (1562 F)	Unacceptable
Tolerance above 850 C (1562 F	Unacceptable

Geo-economic data for principal component

Annual world production, principal component		6,8e7	-	6,9e7	tonne/yr
Reserves, principal component	*	1,66e9	-	1,88e9	tonne

Primary material production: energy, CO2 and water

Embodied energy, primary production	*	77	-	85,1	MJ/kg
CO2 footprint, primary production	*	2,64	-	2,92	kg/kg
Water usage	*	55,3	-	61,1	l/kg
Eco-indicator 95		330			millipoints/kg
Eco-indicator 99		287			millipoints/kg

Material processing: energy

Polymer extrusion energy	*	5,9	-	6,52	MJ/kg
Polymer molding energy	*	20,8	-	23	MJ/kg
Coarse machining energy (per unit wt removed)	*	0,688	-	0,76	MJ/kg
Fine machining energy (per unit wt removed)	*	2,6	-	2,88	MJ/kg
Grinding energy (per unit wt removed)	*	4,73	-	5,23	MJ/kg

Material processing: CO2 footprint

Polymer extrusion CO2	*	0,442	-	0,489	kg/kg
Polymer molding CO2	*	1,56	-	1,73	kg/kg
Coarse machining CO2 (per unit wt removed)	*	0,0516	-	0,057	kg/kg
Fine machining CO2 (per unit wt removed)	*	0,195	-	0,216	kg/kg
Grinding CO2 (per unit wt removed)	*	0,355	-	0,392	kg/kg

Material recycling: energy, CO2 and recycle fraction

Recycle		✓			
Embodied energy, recycling	*	47,1	-	52	MJ/kg
CO2 footprint, recycling	*	3,7	-	4,09	kg/kg
Recycle fraction in current supply		7,5	-	9,5	%
Downcycle		✓			
Combust for energy recovery		✓			
Heat of combustion (net)	*	44	-	46,2	MJ/kg
Combustion CO2					

	* 3,06 - 3,22 kg/kg
Landfill	✓
Biodegrade	✗
Toxicity rating	Non-toxic
A renewable resource?	✗

Environmental notes

PE is FDA compliant - indeed it is so non-toxic that it can be embedded in the human body (heart valves, hip-joint cups, artificial artery). PE, PP and PVC are made by processes that are relatively energy-efficient, making them the least energy-intensive of commodity polymers. The ethylene from which it is made at present is an oil derivative, but PE can be produced from renewable resources - from alcohol derived from the fermentation of sugar or starch, for instance. Its utility per kilogram far exceeds that of gasoline or fuel-oil (and its energy is stored and still accessible), so that production from oil will not disadvantage it in the near future. Polyethylene is readily recyclable if it has not been coated with other materials, and - if contaminated - it can be incinerated to recover the energy it contains.

Recycle mark

Supporting information

Design guidelines

PE is commercially produced as film, sheet, rod, foam and fiber. Drawn PE fiber has exceptional mechanical stiffness and strength, exploited in geo-textile and structural uses. PE is a good electrical insulator with low dielectric loss, so suitable for containers for microwave cooking. It has poor resistance to aromatics and chlorine; it is slow burning in fire. PE is cheap, easy to form, biologically inert and recyclable; it is one of the materials of the next 20 years.

Technical notes

Low density polyethylene (LDPE), used for film and packaging, has branched chains which do not pack well, making it less dense than water. Medium (MDPE) and High (HDPE) density polyethylenes have longer, less branched chains, making them stiffer and stronger; they are used for containers and pipes. Modern catalysis allows side-branching to be suppressed and molecular length to be controlled precisely, permitting precise tailoring both of the processing properties critical for drawing, blow molding, injection molding or extrusion and the use-properties of softening temperature, flexibility and toughness. Linear low-density polyethylene (LLPDE) is an example. In its pure form it is less resistant to organic solvents, but even this can be overcome by converting its surface to a fluoro-polymer by exposing it to fluorine gas. Treated in this way (when it known is known as 'Super PE') it can be used for petrol tanks in cars and copes with oil, cleaning fluid, cosmetics and that most corrosive of substances: cola concentrate. Very low density polyethylene (VDLPE) is similar to EVA and plasticized PVC.

Typical uses

Oil container, street bollards, milk bottles, toys, beer crate, food packaging, shrink wrap, squeeze tubes, disposable clothing, plastic bags, paper coatings, cable insulation, artificial joints, and as fibers - low cost ropes and packing tape reinforcement.

Tradenames

Alathon, Aquathene, Bapolene, Dowlex, Eltex, Empee, Eraclene, Ferrene, Fortiflex, HiVal, Hid, Kemcor, Lacqtene, Lupolen, Marlex, Nortuff, Novapol, Paxon, Petrothene, Polyfort, Rigidex, Sclair, Stamylyn, Statoil, Unival, Zemid

Links

Reference

ProcessUniverse

Producers

Appendix G – Detailed 2D-drawings

G1 – Overall 1 Body

G2 – Overall 2 Body

G3 – He-Configuration Body

G4 – She-Configuration Body

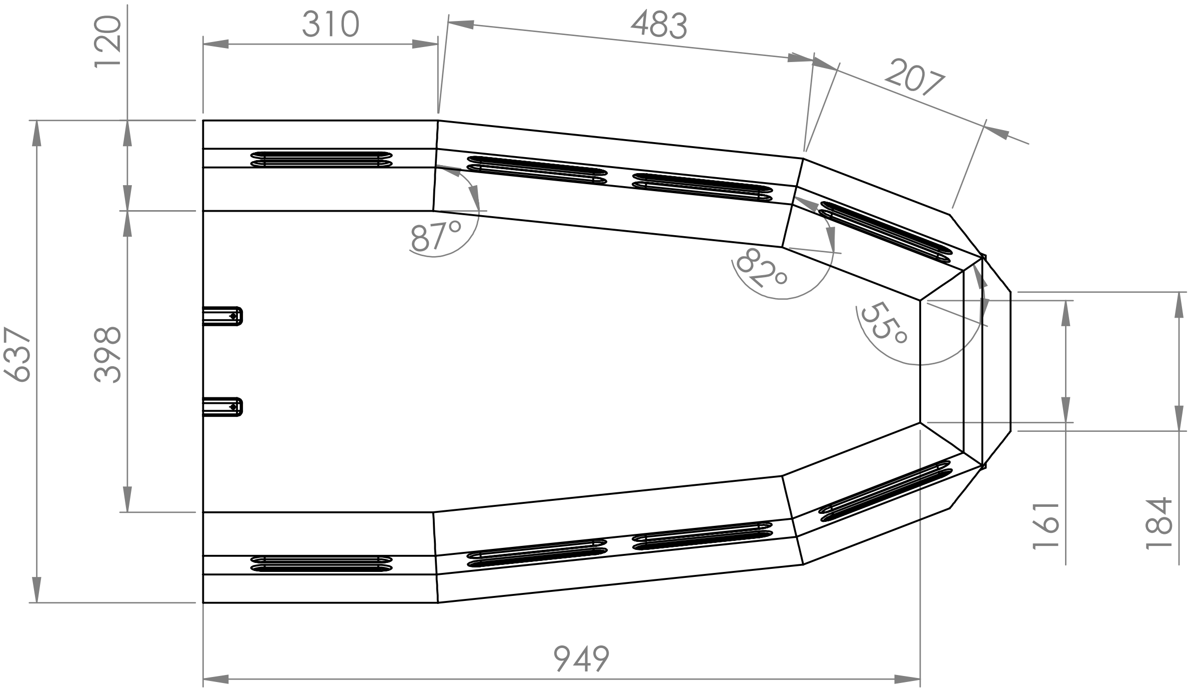
G5 – Overall Frame

G6 – He-Configuration of Frame

G7 – She-Configuration of Frame

G8 – He-Connector

G9 – She-Connector



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH: Smooth
TOLERANCES:
LINEAR: 1 mm
ANGULAR: 2

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION 1

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

Overall Body
Messurements 1

MATERIAL: HDPE

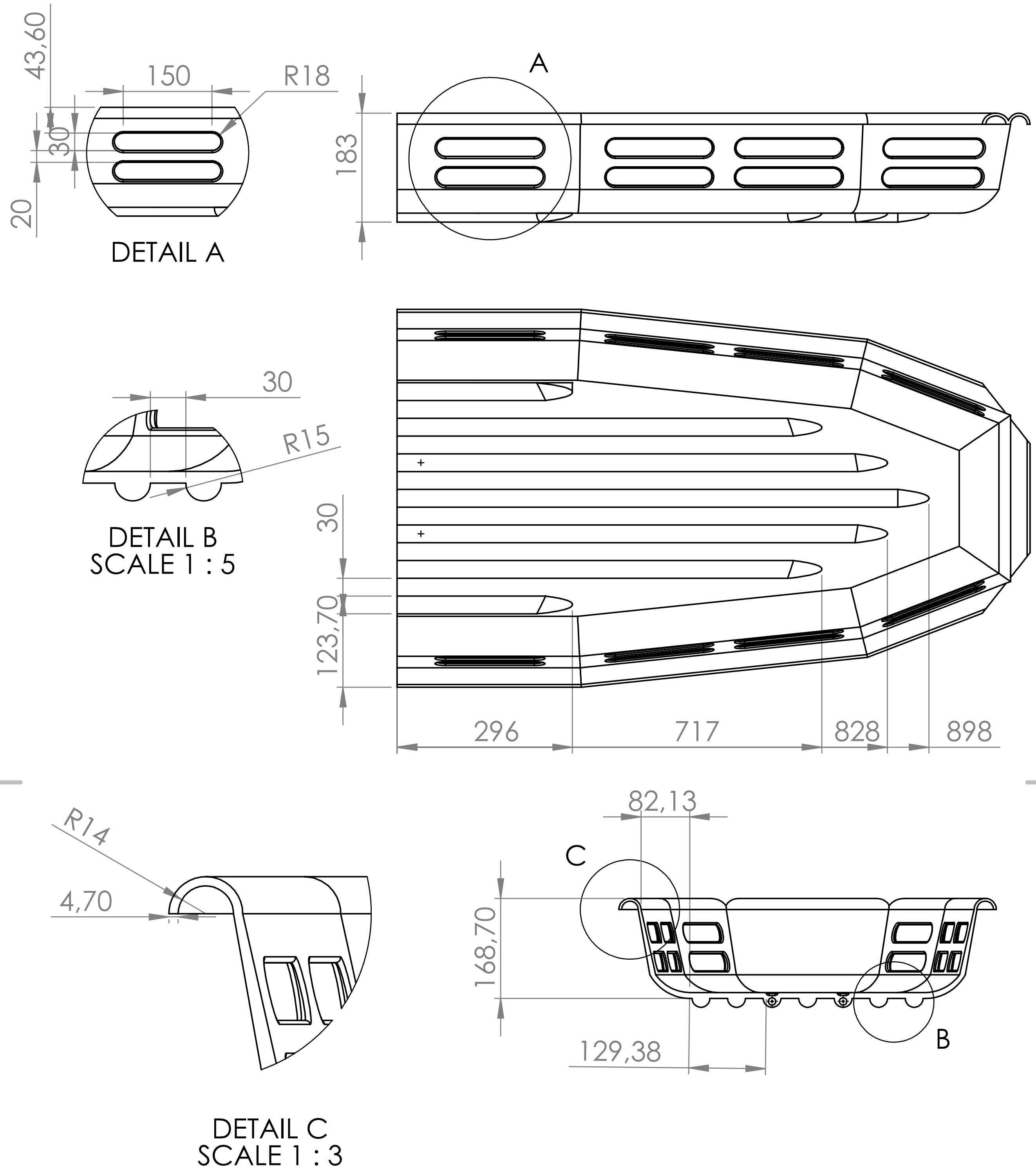
DWG NO. G1

A4

WEIGHT: tot. both configs:15 822 g

SCALE:1:10

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH: Smooth
TOLERANCES:
LINEAR: 1 mm
ANGULAR: 2

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION 1

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE: Overall Body Messurements 2

MATERIAL: HDPE

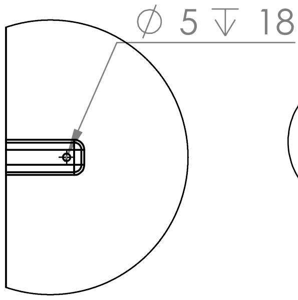
DWG NO. G2

A4

WEIGHT:

SCALE:1:10

SHEET 1 OF 1



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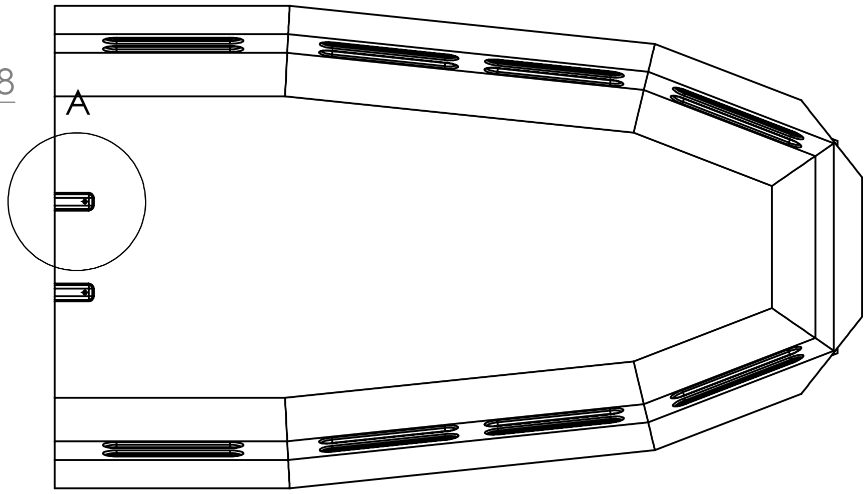
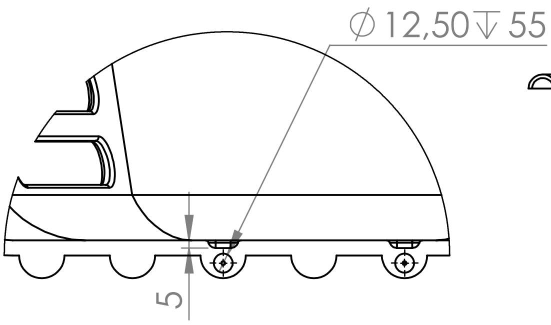
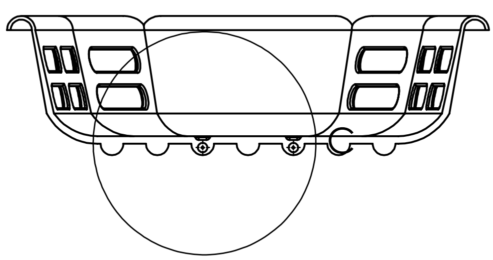




DETAIL C
SCALE 1 : 5



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH: Smooth
TOLERANCES:
LINEAR: 1 mm
ANGULAR: 2

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION 1

	NAME	SIGNATURE	DATE		
DRAWN					
CHK'D					
APPV'D					
MFG					
Q.A					

TITLE: He-Configuration Body

MATERIAL: HDPE

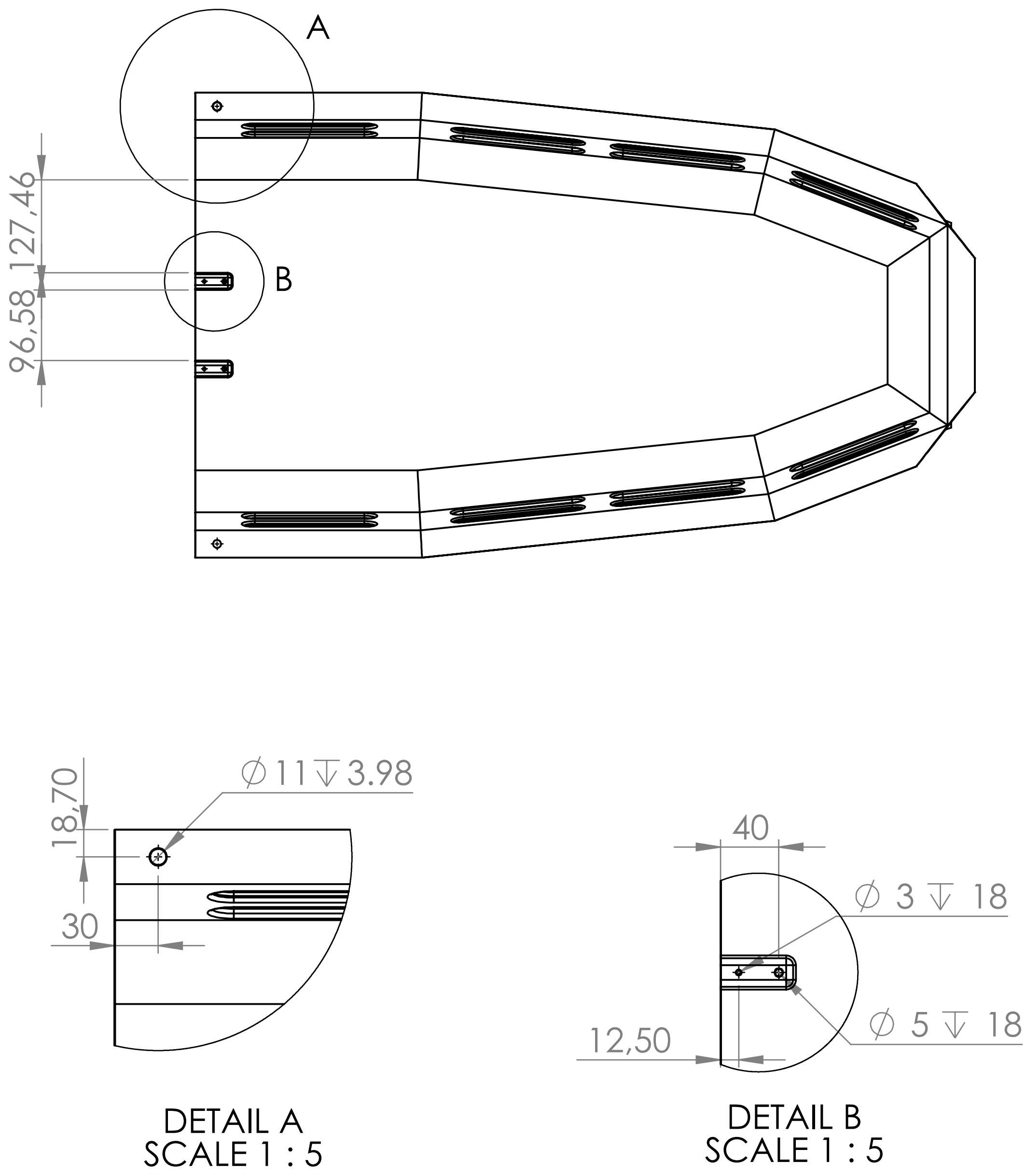
DWG NO. G3

A4

WEIGHT: 7717 g

SCALE:1:10

SHEET 1 OF 1



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DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH: Smooth
TOLERANCES:
LINEAR: 1 mm
ANGULAR: 2

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION 1

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL: HDPE

WEIGHT: 8105 g

TITLE:

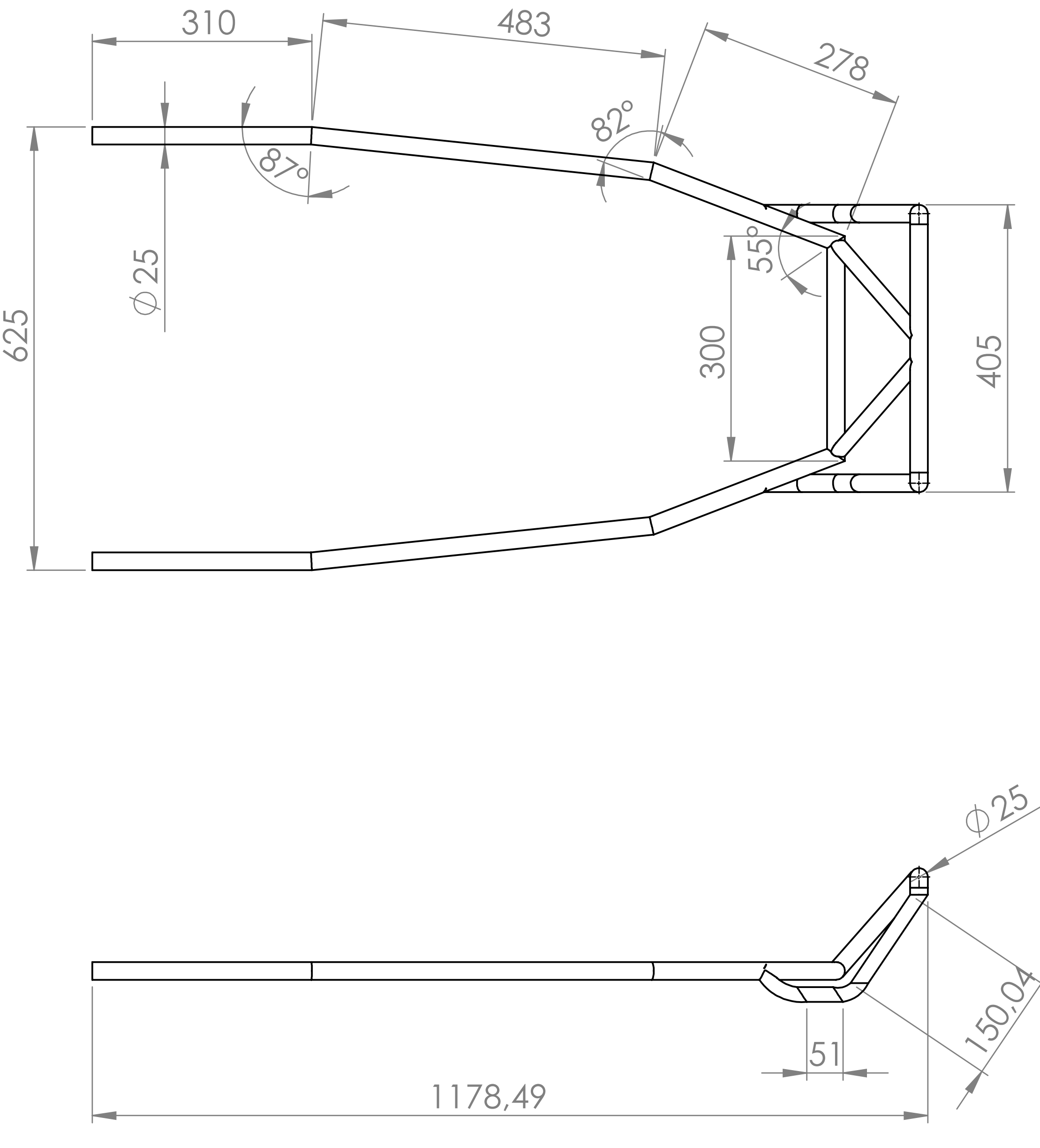
She-Configuration Body

DWG NO. G4

A4

SCALE:1:10

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH: Smooth
TOLERANCES:
LINEAR: 1 mm
ANGULAR: 2

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION 1

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

Overall Messurements of Frame

MATERIAL: Al-Alloy 6061-T6

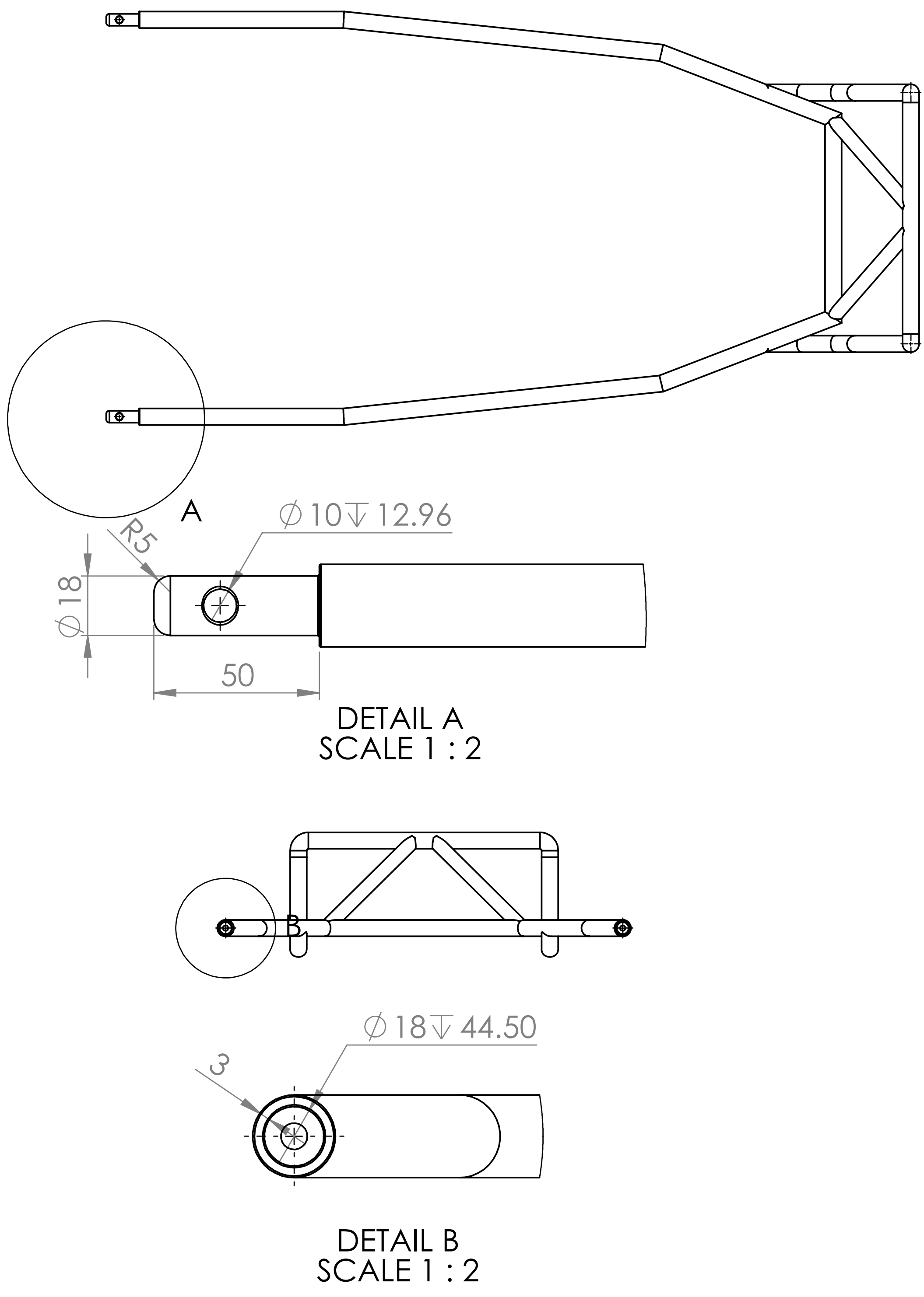
DWG NO. G5

A4

WEIGHT: tot. both configs: 4217 g

SCALE:1:10

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: Smooth TOLERANCES: LINEAR: 1 mm ANGULAR: 2	FINISH:	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING / REVISION 1

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE: He-Configuration of Frame

MATERIAL: Al-Alloy 6061-T6

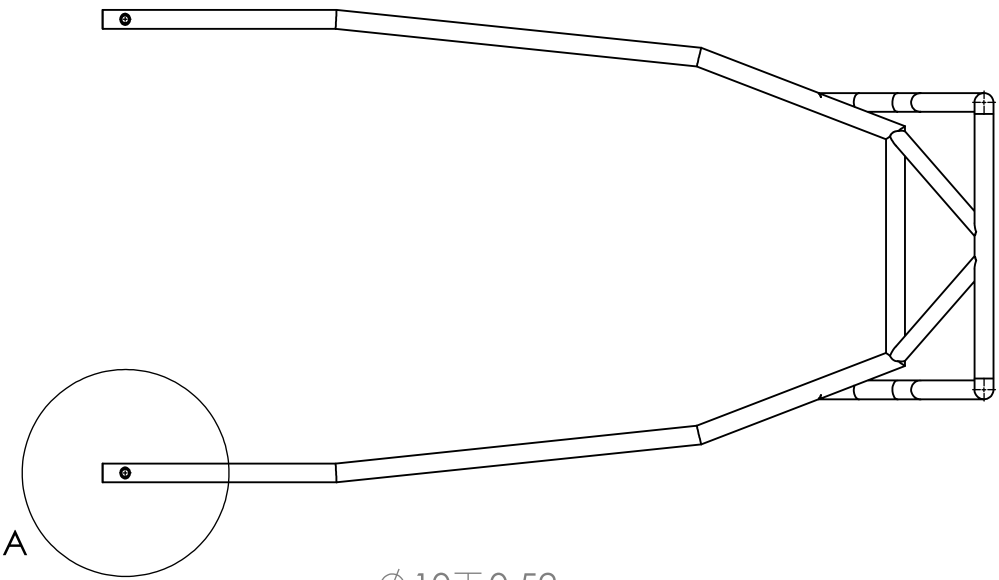
WEIGHT: 2155 g

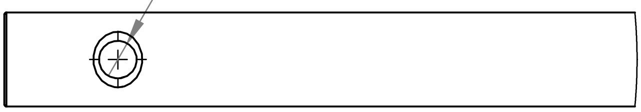
DWG NO. G6

A4

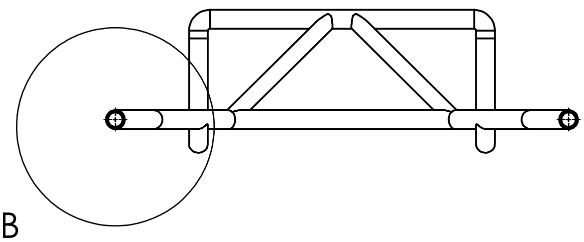
SCALE:1:10

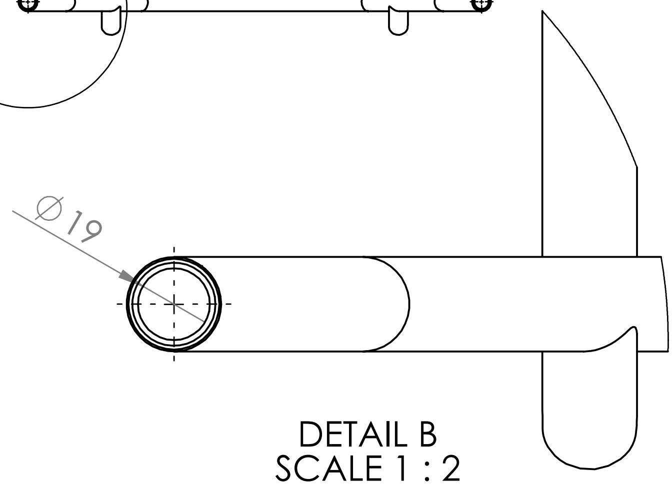
SHEET 1 OF 1





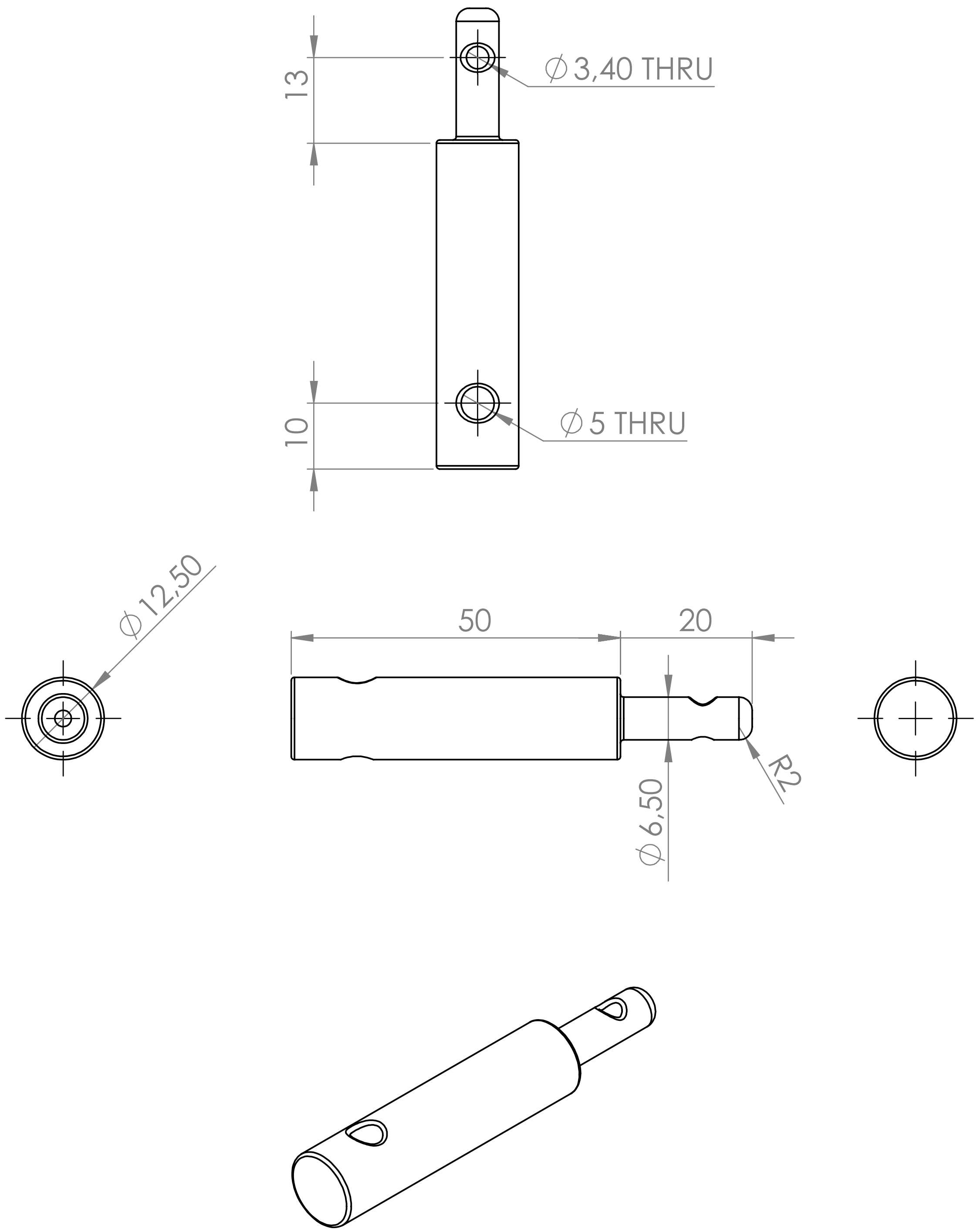
DETAIL A
SCALE 1 : 2





DETAIL B
SCALE 1 : 2

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: Smooth TOLERANCES: LINEAR: 1 mm ANGULAR: 2	FINISH:	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION 1	
	NAME	SIGNATURE	DATE	TITLE: She-Configuration of Frame	
DRAWN					
CHK'D					
APPV'D					
MFG					
Q.A			MATERIAL: Al-Alloy 6061-T6	DWG NO. G7	A4
			WEIGHT: 2062 g	SCALE:1:10	SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH: Smooth
TOLERANCES:
LINEAR: 0.5 mm
ANGULAR: 1

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION 1

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE: He-Connector

MATERIAL: Cast Alloy Steel

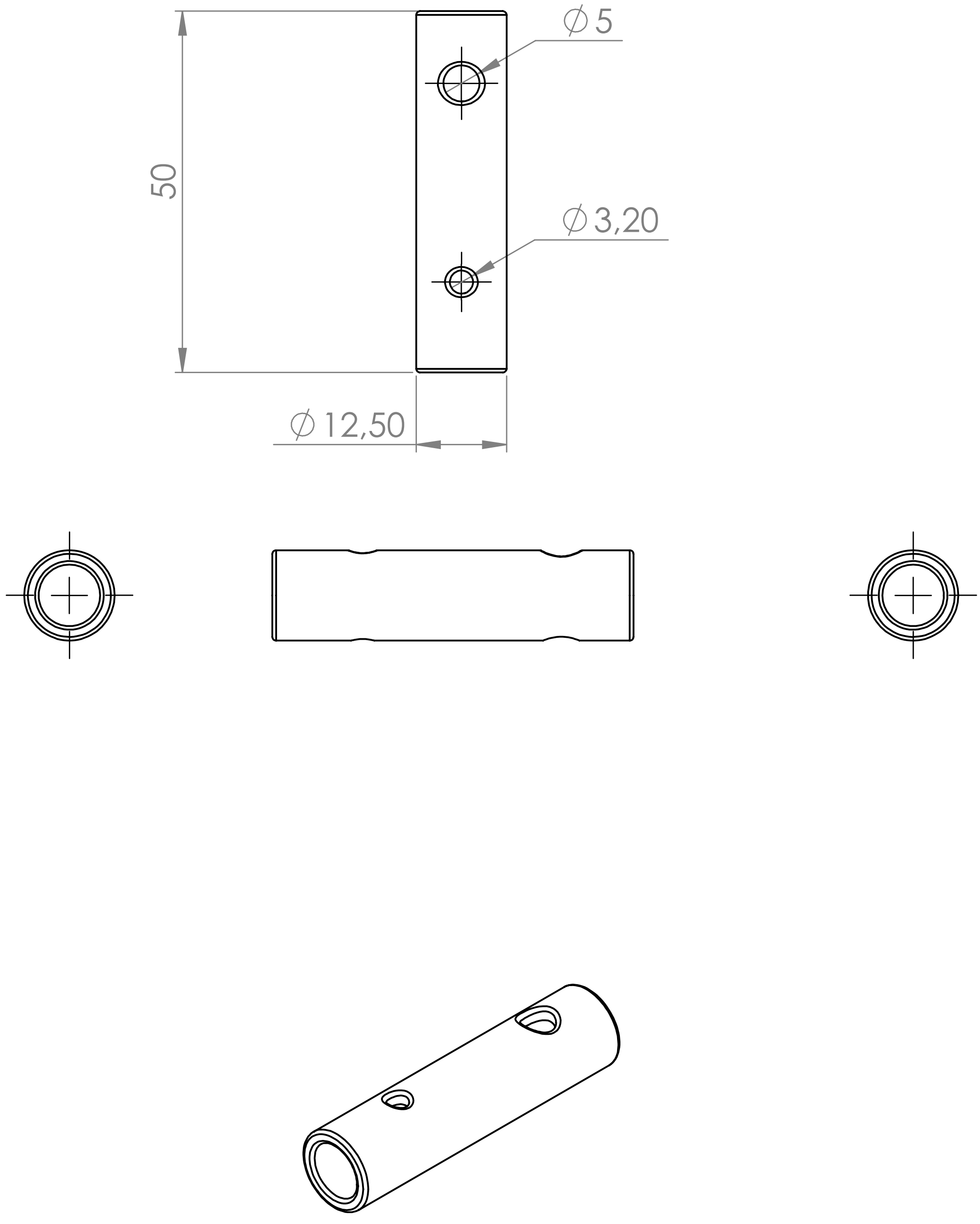
DWG NO. G8

A4

WEIGHT: 47 g

SCALE:1:1

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH: Smooth
TOLERANCES:
LINEAR: 0.5 mm
ANGULAR: 1

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION 1

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE: She-Connector

MATERIAL: Cast Alloy Steel

DWG NO. G9

A4

WEIGHT: 23 g

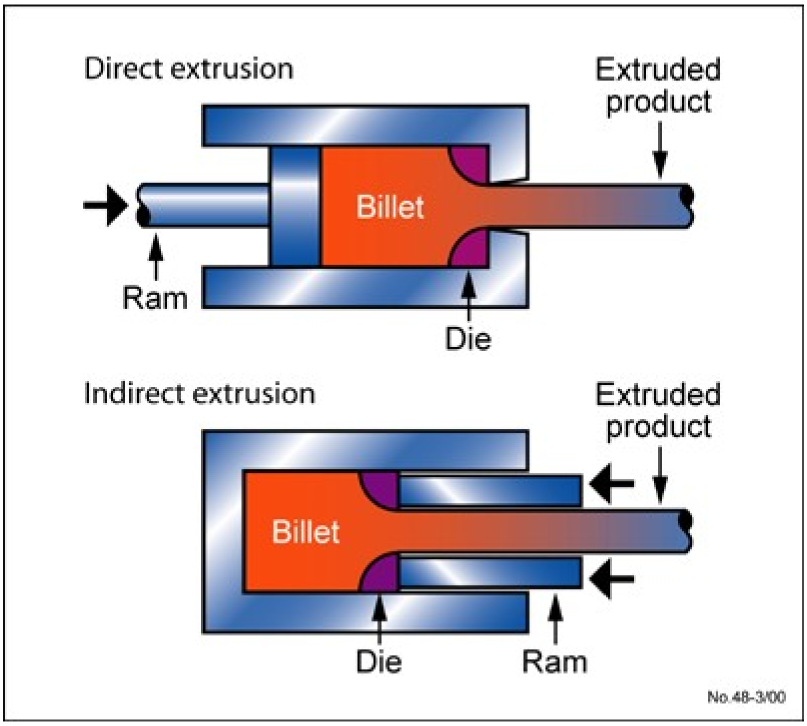
SCALE:1:1

SHEET 1 OF 1

Appendix H – Extrusion Properties (Process)

Description

Process schematic



The process

The process of squeezing toothpaste from its tube is one of extrusion. The gooey toothpaste - or the gooey polymer or metal in the industrial process - is forced by pressure to flow through a shaped die, taking up the profile of the die orifice. In co-extrusion two materials are extruded at the same time and bond together - a trick used in toothpaste to create colored stripes in it.

Material compatibility

Ceramics	✓
Metals - non-ferrous	✓

Shape

Circular prismatic	✓
Non-circular prismatic	✓

Economic compatibility

Relative tooling cost	high
Relative equipment cost	high
Labor intensity	low

Physical and quality attributes

Mass range	1	-	1e3	kg
Range of section thickness	1	-	900	mm
Tolerance	0,5	-	1	mm
Roughness	0,8	-	3,2	µm
Surface roughness (A=v. smooth	B			

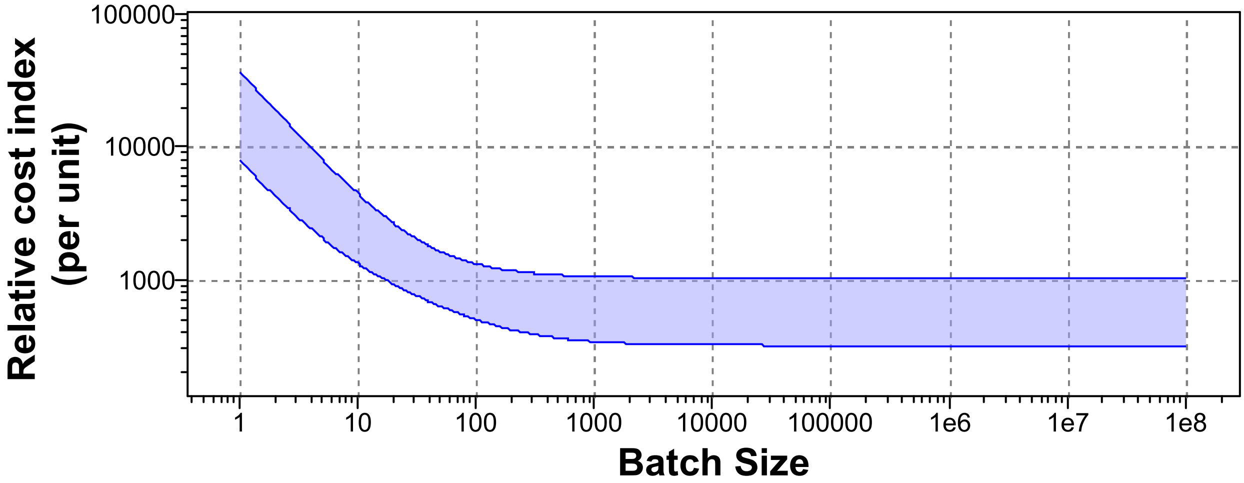
Process characteristics

Primary shaping processes	✓
Continuous	✓

Cost model and defaults

Relative cost index (per unit)	* 340	-	1,05e3	

Parameters: Material Cost = 19,6NOK/kg, Component Mass = 8,1kg, Batch Size = 1e3, Overhead Rate = 500NOK/hr, Discount Rate = 5%, Capital Write-off Time = 10yrs, Load Factor = 0,5



Material Cost=19,6NOK/kg, Component Mass=8,1kg, Overhead Rate=500NOK/hr,

Capital cost	* 1,45e6	-	1,45e7	NOK
Material utilization fraction	* 0,9	-	0,97	
Production rate (units)	* 1	-	10	/hr
Tooling cost	* 7,26e3	-	3,63e4	NOK
Tool life (units)	* 100	-	1e4	

Supporting information

Design guidelines

Metals extrusion is limited to ductile materials with melting points below 1700oC, commonly aluminum, copper, magnesium, low and medium carbon steels, low alloy steels and stainless steels. The extrusion of steel usually requires the addition of a molten glass lubricant. The tolerance is often lower than expected because of creep and die wear; it can be improved by cold drawing as a secondary process. Symmetric cross-sections, constant wall thickness and generous radii are the easiest to form; the aspect ratio of the section should not exceed 14:1 for steel or 20:1 for magnesium. Impact extrusion is a cold process for metals (aluminum, copper, lead, magnesium, tin, zinc, carbon steels, low alloy steels) which combines the principles of forging and extrusion. Polymer extrusion begins powder or pellets; pressure is built up by a rotating screw, forcing the polymer through a heating chamber and through the die. The extrusion cools as it leaves the die and can then be drawn to a smaller cross-section. Most polymers can be extruded (including those with particulate and short fiber-reinforcement). In ceramic extrusion ceramic powder is mixed with a polymer binder and extruded like a polymer. The extruded section is then fired, burning off the polymer and sintering the ceramic powder.

Technical notes

There are two variants of the extrusion process: direct - where the die is stationary and the metal is forced through it; and indirect - where the die itself compresses the metal. Indirect extrusion has less friction between the billet and die, so there are lower extrusion forces but the equipment is more complex and the product length is restricted.

Typical uses

Tubing, window frame sections, building and automotive trim, aircraft structural parts, railings, rods, channels, plastic-coated wire, seals, filaments, film, sheet, pellets, bricks.

The economics

Equipment and tooling costs are low - much lower than for injection molding - but cycle times are longer than any other molding process, and it is labor-intensive.

The environment

No special problems here.

Links

MaterialUniverse

Reference

Appendix I – Limits Applied to Production Selection for Body

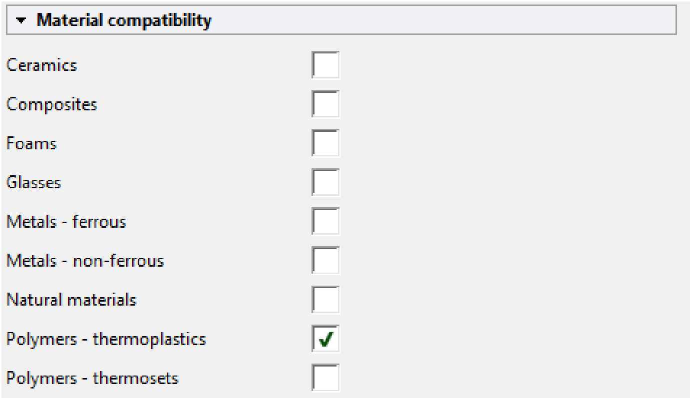


Figure I-1: Material compatibility.

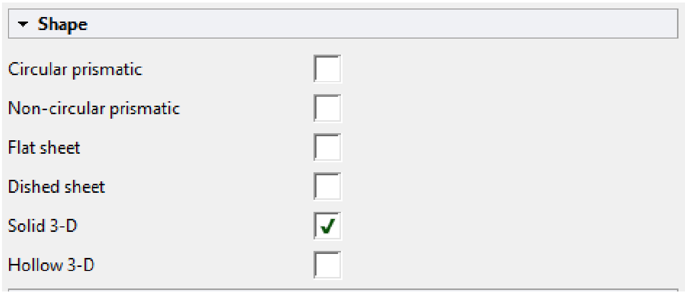


Figure I-2: Shape.

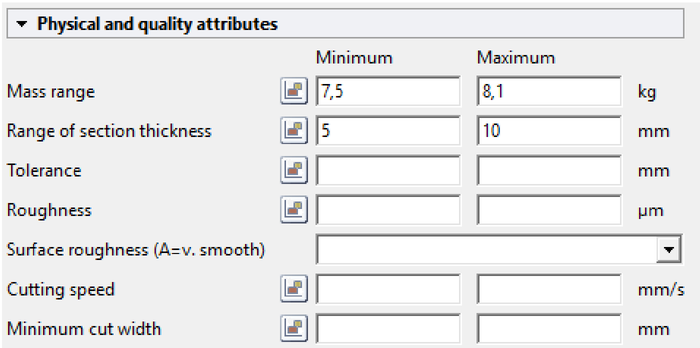


Figure I-3: Minimum and maximum value for mass and range of section thickness.

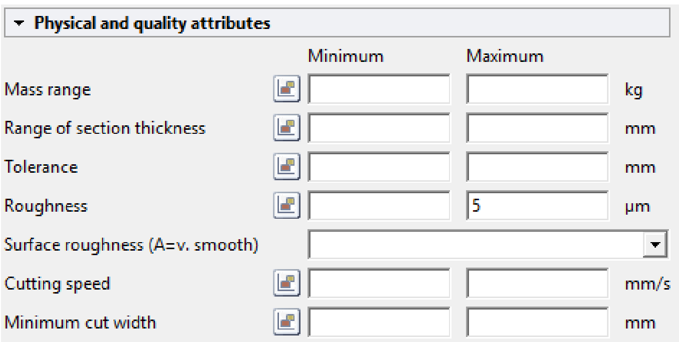


Figure I-4: Maximum roughness.

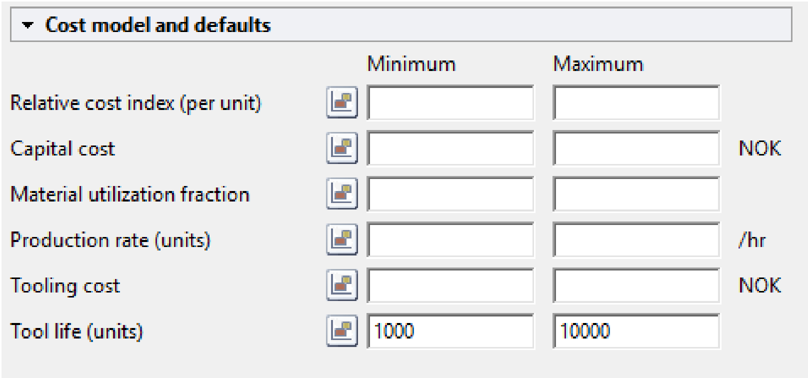


Figure I-5: Limits for tool life (units). The requirement is 500 – 5000 stretchers, and since the body consists of two units per product, the tool life must produce twice the units per stretcher.

Appendix J – Properties of Injection Molding (Process)

Description

Process schematic

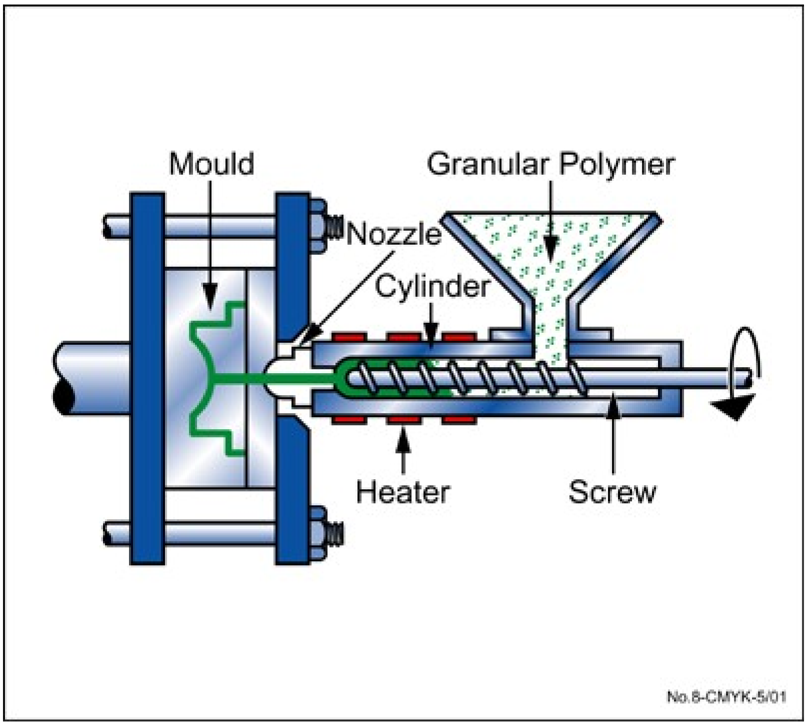


Figure caption

Injection molding: polymer granules are heated and forced by the screw through a nozzle into the die.

The process

No other process has changed product design more than INJECTION MOLDING. Injection molded products appear in every sector of product design: consumer products, business, industrial, computers, communication, medical and research products, toys, cosmetic packaging and sports equipment. The most common equipment for molding thermoplastics is the reciprocating screw machine, shown schematically in the figure. Polymer granules are fed into a spiral press where they mix and soften to a dough-like consistency that can be forced through one or more channels ('sprues') into the die. The polymer solidifies under pressure and the component is then ejected.
Thermoplastics, thermosets and elastomers can all be injection molded. Co-injection allows molding of components with different materials, colors and features. Injection foam molding allows economical production of large molded components by using inert gas or chemical blowing agents to make components that have a solid skin and a cellular inner structure.

Material compatibility

Polymers - thermoplastics	✓

Shape

Circular prismatic	✓
Non-circular prismatic	✓
Solid 3-D	✓
Hollow 3-D	✓

Economic compatibility

Relative tooling cost	very
Relative equipment cost	high

Labor intensity	low			
Economic batch size (units)	1e4	-	1e6	

Physical and quality attributes

Mass range	0,001	-	25	kg
Range of section thickness	0,4	-	6,3	mm
Tolerance	0,07	-	1	mm
Roughness	0,2	-	1,6	µm
Surface roughness (A=v. smooth	A			

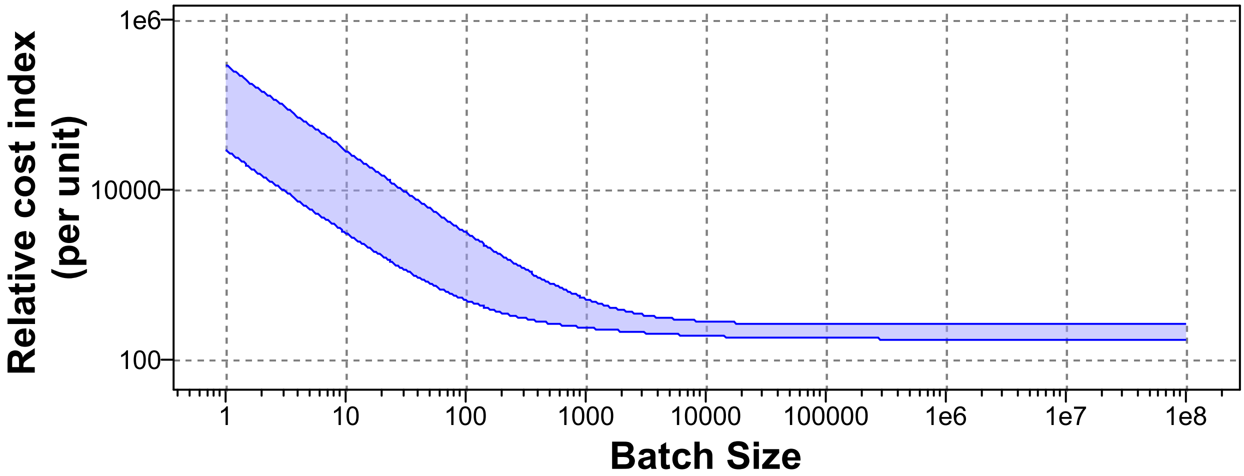
Process characteristics

Primary shaping processes	✓
Discrete	✓

Cost model and defaults

Relative cost index (per unit)	* 239	-	526

Parameters: Material Cost = 21,5NOK/kg, Component Mass = 7kg, Batch Size = 1e3, Overhead Rate = 500NOK/hr, Discount Rate = 5%, Capital Write-off Time = 10yrs, Load Factor = 0,5



Material Cost=21,5NOK/kg, Component Mass=7kg, Overhead Rate=500NOK/hr,

Capital cost	* 2,91e5	-	6,54e6	NOK
Material utilization fraction	* 0,6	-	0,9	
Production rate (units)	* 60	-	1e3	/hr
Tooling cost	* 2,91e4	-	2,91e5	NOK
Tool life (units)	* 1e4	-	1e6	

Supporting information

Design guidelines

Injection molding is the best way to mass-produce small, precise, polymer components with complex shapes. The surface finish is good; texture and pattern can be easily altered in the tool, and fine detail reproduces well. Decorative labels can be molded onto the surface of the component (see In-mold Decoration). The only finishing operation is the removal of the sprue.

Technical notes

Most thermoplastics can be injection molded, although those with high melting temperatures (e.g. PTFE) are difficult. Thermoplastic-based composites (short fiber and particulate filled) can be processed providing the filler-loading is not too large. Large changes in section area are not recommended. Small re-entrant angles and complex shapes are possible, though some features (e.g. undercuts, screw threads, inserts) may result in increased tooling costs. The process may also be used with thermosets and elastomers. The most common equipment for molding thermoplastics is the reciprocating screw machine, shown schematically in the figure. Polymer granules are fed into a spiral press where they mix and soften to a dough-like consistency that can be forced through one or more channels ('sprues') into the die. The polymer solidifies under pressure and the component is then ejected.

Typical uses

Extremely varied. Housings, containers, covers, knobs, tool handles, plumbing fittings, lenses,

The economics

Capital cost are medium to high, tooling costs are usually high - making injection molding economic only for large batch sizes. Production rate can be high particularly for small moldings. Multi-cavity molds are often used. Prototype moldings can be made using single cavity molds of cheaper materials. Typical products. Housings, containers, covers, knobs, tool handles, plumbing fittings, lenses.

The environment

Thermoplastic sprues can be recycled. Extraction fans may be required for volatile fumes. Significant dust exposures may occur in the formulation of the resins. Thermostatic controller malfunctions can be hazardous.

Links

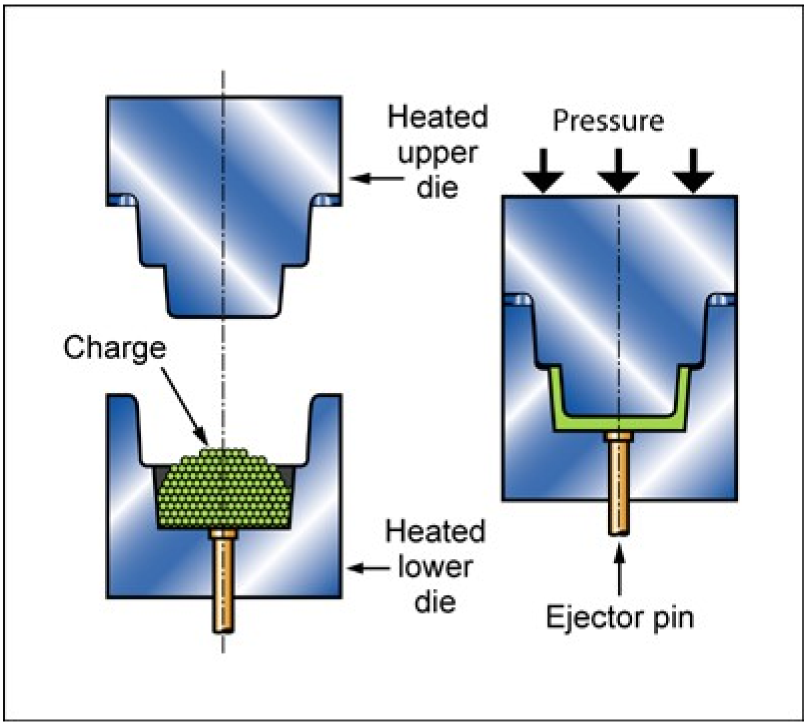
MaterialUniverse

Reference

Appendix K – Properties of Compression Molding (Process)

Description

Process schematic



The process

In COMPRESSION MOLDING a pre-measured quantity of polymer - usually a thermoset - in the form of granules or a pre-formed tablet containing resin and hardener is placed in a heated mold. The mold is closed creating sufficient pressure to force the polymer into the mold cavity. The polymer is allowed to cure, the mold is opened and the component removed. A variant, polymer forging, is used to form thermoplastics that are difficult to mold, such as ultra high molecular weight polyethylene, or shapes that have thick walls or large and abrupt changes in section area. Compression molding is widely used to shape the composites BMC and SMC. BMC (Bulk Molding Compound) and SMC (Sheet Molding Compound) differ in the shape and content of reinforcement and filler. BMC has less (15-25% of glass fiber) and it is the easiest to mold to 3-dimensional shapes. SMC has more (up to 35%) of glass fiber and is limited to sheet shapes. DMC (Dough Molding Compound) is the genesis - a dough-like mix of thermosetting polyester, polyurethane or epoxy with hardener, chopped glass fiber, filler and coloring agent. Two more - GMT (Glass Mat Thermoplastics) and TSC (Thermoplastic Sheet Compounds) - are the thermoplastic equivalent, based on nylon 6 or polypropylene. The word "dough" conveys well the way in which they are shaped: squeezed between a pair of dies, like a pie crust.

Material compatibility

Glasses	✓
Polymers - thermoplastics	✓
Polymers - thermosets	✓

Shape

Flat sheet	✓
Dished sheet	✓
Solid 3-D	✓

Economic compatibility

Relative tooling cost	high
Relative equipment cost	high

Labor intensity	low			
Economic batch size (units)	500	-	2e6	

Physical and quality attributes

Mass range	0,2	-	20	kg
Range of section thickness	1,5	-	25	mm
Tolerance	0,15	-	1	mm
Roughness	0,2	-	1,6	µm
Surface roughness (A=v. smooth)	A			

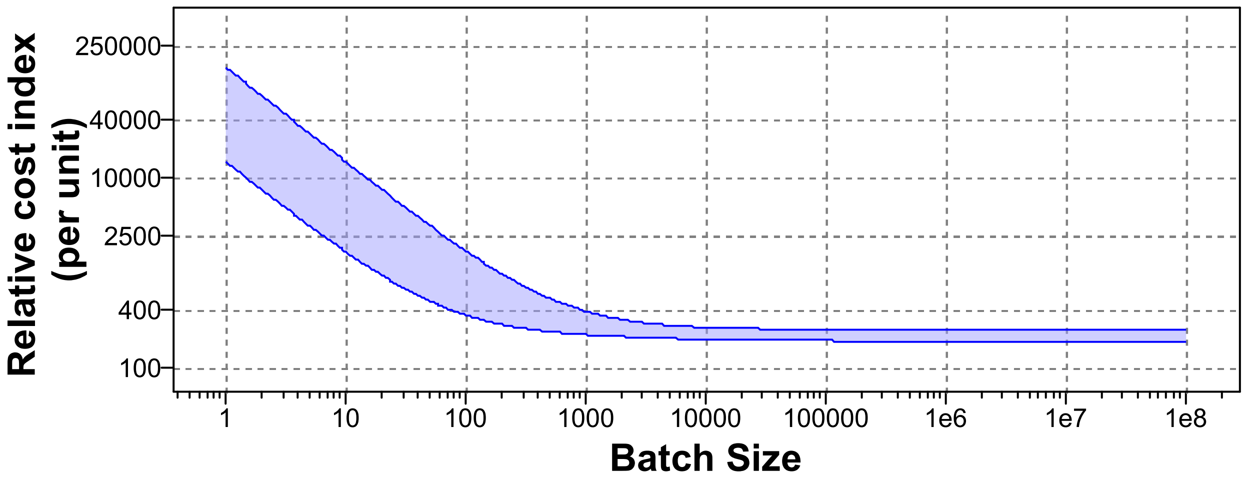
Process characteristics

Primary shaping processes	✓
Discrete	✓

Cost model and defaults

Relative cost index (per unit)	* 224	-	395	

Parameters: Material Cost = 19,6NOK/kg, Component Mass = 8,1kg, Batch Size = 1e3, Overhead Rate = 500NOK/hr, Discount Rate = 5%, Capital Write-off Time = 10yrs, Load Factor = 0,5



Material Cost=19,6NOK/kg, Component Mass=8,1kg, Overhead Rate=500NOK/hr,

Capital cost	* 1,45e5	-	8,72e5	NOK
Material utilization fraction	* 0,8	-	0,95	
Production rate (units)	* 10	-	100	/hr
Tooling cost	* 1,45e4	-	1,45e5	NOK
Tool life (units)	* 2e3	-	2e5	

Supporting information

Design guidelines

Compression molding is limited to simple shapes without undercuts. Complex shapes are more economically produced by injection molding or resin transfer molding. The components generally require some finishing to remove flash. BMC, SMC, etc. moldings have good surface finish and accurate dimensioning, good enough for auto manufacturers to use them for external body components. SMC moldings yield high quality panels and casings; shapes in which the sheet thickness is more or less uniform. BMC moldings yield simple 3-dimensional shapes with changes in section.

Technical notes

The process is mainly used with thermosets. Elastomers and thermoplastics can be processed but they require a long heating and cooling cycle, reducing the production rate. The process is frequently used for particle and short fiber-reinforced composites. Several different resin systems are used for BMC, SMC, etc. Among thermosets, polyester, vinyl ester and phenolic resins are best; among thermoplastics, polypropylene, nylon or PEEK (but this is expensive). The mold is made from aluminum, cast iron or steel, heated by steam or electricity to the curing or molding temperature (typically 140-160ºC). Typical cycle times are 2-4 minutes.

Typical uses

Electrical and electronic components, tableware, washing machine agitators, utensil handles, container caps, appliance housings; SMC: body panels and bumpers for cars and trucks, gas and electricity meter boxes, and electrical housings. BMC: more complicated shapes.

The economics

Although the tooling costs are high, they are not as high as injection molding or resin transfer molding; they depend, of course, on the size and complexity of the molds. Compression molding is most frequently used for large components where it is cheaper than injection molding or resin transfer molding; the upper size limit is set only by the press capacity. Tooling costs are relatively high for BMC, SMC molding, so it tends to be limited to large batch sizes.

The environment

The process itself does not damage the environment, but flash and scrap cannot be recycled for

Links

MaterialUniverse

Reference

Appendix L – Solid 187 (Element Type)

SOLID187 Element Description

SOLID187 element is a higher order 3-D, 10-node element. SOLID187 has a quadratic displacement behavior and is well suited to modeling irregular meshes (such as those produced from various CAD/CAM systems).

The element is defined by 10 nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element has plasticity, hyperelasticity, creep, stress stiffening, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elastoplastic materials, and fully incompressible hyperelastic materials. See SOLID187 in the *Mechanical APDL Theory Reference* for more details about this element.

Figure 187.1: SOLID187 Geometry

SOLID187 Input Data

The geometry, node locations, and the coordinate system for this element are shown in *Figure 187.1: SOLID187 Geometry*.

In addition to the nodes, the element input data includes the orthotropic or anisotropic material properties. Orthotropic and anisotropic material directions correspond to the element coordinate directions. The element coordinate system orientation is as described in *Linear Material Properties* in the *Material Reference*.

Element loads are described in *Nodal Loading*. Pressures may be input as surface loads on the element faces as shown by the circled numbers on *Figure 187.1: SOLID187 Geometry*. Positive pressures act into the element. Temperatures may be input as element body loads at the nodes. The node I temperature T(I) defaults to TUNIF. If all other temperatures are unspecified, they default to T(I). If all corner node temperatures are specified, each midside node temperature defaults to the average temperature of its adjacent corner nodes. For any other input temperature pattern, unspecified temperatures default to TUNIF.

As described in *Coordinate Systems*, you can use **ESYS** to orient the material properties and strain/stress output. Use **RSYS** to choose output that follows the material coordinate system or the global coordinate system. For the case of hyperelastic materials, the output of stress and strain is always with respect to the global Cartesian coordinate system rather than following the material/element coordinate system.

KEYOPT(6) = 1 or 2 sets the element for using mixed formulation. For details on the use of mixed formulation, see *Applications of Mixed u-P Formulations* in the *Element Reference*.

KEYOPT(15) = 1 sets the element for perfectly matched layers (PML). For more information, see *Perfectly Matched Layers (PML) in Elastic Media* in the *Mechanical APDL Theory Reference*.

KEYOPT(16) = 1 activates steady state analysis (defined via the **SSTATE** command). For more information, see *Steady State Rolling* in the *Mechanical APDL Theory Reference*.

You can apply an initial stress state to this element via the **INISTATE** command. For more information, see the **INISTATE** command, and also Initial Stress Loading in the *Basic Analysis Guide*.

The effects of pressure load stiffness are automatically included for this element. If an unsymmetric matrix is needed for pressure load stiffness effects, use **NROPT**,UNSYM.

The next table summarizes the element input. *Element Input* gives a general description of element input.

SOLID187 Input Summary

Nodes

I, J, K, L, M, N, O, P, Q, R

Degrees of Freedom

UX, UY, UZ

Real Constants

None

Material Properties

TB command: See *Element Support for Material Models* for this element.

MP command: EX, EY, EZ, ALPX, ALPY, ALPZ (or CTEX, CTEY, CTEZ *or* THSX, THSY, THSZ), PRXY, PRYZ, PRXZ (or NUXY, NUYZ, NUXZ), DENS, GXY, GYZ, GXZ, ALPD, BETD

Surface Loads

Pressures --

face 1 (J-I-K), face 2 (I-J-L), face 3 (J-K-L), face 4 (K-I-L)

Body Loads

Temperatures --

T(I), T(J), T(K), T(L), T(M), T(N), T(O), T(P), T(Q), T(R)

Body force densities --

The element values in the global X, Y, and Z directions.

Special Features

Birth and death

Element technology autoselect

Fracture parameter calculation

Initial stress import

Large deflection

Large strain

Linear perturbation

Material force evaluation

Nonlinear stabilization

Steady state

Stress stiffening

KEYOPT(6)

Element formulation:

0 --

Use pure displacement formulation (default)

1 --

Use mixed formulation, hydrostatic pressure is constant in an element (recommended for hyperelastic materials)

2 --

Use mixed formulation, hydrostatic pressure is interpolated linearly in an element (recommended for nearly incompressible elastoplastic materials)

KEYOPT(15)

PML absorbing condition:

0 --

Do not include PML absorbing condition (default)

1 --

Include PML absorbing condition

KEYOPT(16)

Steady state analysis flag:

0 --

Steady state analysis disabled (default)

1 --

Enable steady state analysis

SOLID187 Output Data

The solution output associated with the element is in two forms:

- Nodal displacements included in the overall nodal solution
- Additional element output as shown in *Table 187.1: SOLID187 Element Output Definitions*

Several items are illustrated in *Figure 187.2: SOLID187 Stress Output*. The element stress directions are parallel to the element coordinate system. A general description of solution output is given in *The Item and Sequence Number Table*. See the *Basic Analysis Guide* for ways to view results.

Figure 187.2: SOLID187 Stress Output

The Element Output Definitions table uses the following notation:

A colon (:) in the Name column indicates that the item can be accessed by the Component Name method (**ETABLE**, **ESOL**). The O column indicates the availability of the items in the file`Jobname.OUT`. The R column indicates the availability of the items in the results file.

In either the O or R columns, "Y" indicates that the item is *always* available, a number refers to a table footnote that describes when the item is *conditionally* available, and "-" indicates that the item is *not* available.

Table 187.1: SOLID187 Element Output Definitions

Name	Definition	O	R
EL	Element Number	-	Y
NODES	Nodes - I, J, K, L	-	Y
MAT	Material number	-	Y
VOLU:	Volume	-	Y
XC, YC, ZC	Location where results are reported	Y	3
PRES	Pressures P1 at nodes J, I, K; P2 at I, J, L; P3 at J, K, L; P4 at K, I, L	-	Y
TEMP	Temperatures T(I), T(J), T(K), T(L)	-	Y
S:X, Y, Z, XY, YZ, XZ	Stresses	Y	Y
S:1, 2, 3	Principal stresses	-	Y
S:INT	Stress intensity	-	Y
S:EQV	Equivalent stress	-	Y
EPEL:X, Y, Z, XY, YZ, XZ	Elastic strains	Y	Y
EPEL:EQV	Equivalent elastic strains [6]	-	Y
EPTH:X, Y, Z, XY, YZ, XZ	Thermal strains	1	1
EPTH: EQV	Equivalent thermal strains [6]	1	1
EPPL:X, Y, Z, XY, YZ, XZ	Plastic strains [7]	1	1
EPPL:EQV	Equivalent plastic strains [6]	1	1
EPCR:X, Y, Z, XY, YZ, XZ	Creep strains	1	1
EPCR:EQV	Equivalent creep strains [6]	1	1
EPTO:X, Y, Z, XY, YZ, XZ	Total mechanical strains (EPEL + EPPL + EPCR)	Y	-

Name	Definition	O	R
EPTO:EQV	Total equivalent mechanical strains (EPEL + EPPL + EPCR)	Y	-
NL:SEPL	Plastic yield stress	1	1
NL:EPEQ	Accumulated equivalent plastic strain	1	1
NL:CREQ	Accumulated equivalent creep strain	1	1
NL:SRAT	Plastic yielding (1 = actively yielding, 0 = not yielding)	1	1
NL:HPRES	Hydrostatic pressure	1	1
SEND: ELASTIC, PLASTIC, CREEP	Strain energy density	-	1
LOCI:X, Y, Z	Integration point locations	-	4
SVAR:1, 2, ... , N	State variables	-	5

1. Nonlinear solution, output only if the element has a nonlinear material, or if large-deflection effects are enabled (**NLGEOM**,ON) for SEND.
2. Output only if element has a thermal load
3. Available only at centroid as a ***GET** item.
4. Available only if **OUTRES**,LOCI is used.
5. Available only if the `UserMat` subroutine and **TB**,STATE command are used.
6. The equivalent strains use an effective Poisson's ratio: for elastic and thermal this value is set by the user (**MP**,PRXY); for plastic and creep this value is set at 0.5.
7. For the shape memory alloy material model, transformation strains are reported as plasticity strain EPPL.

Table 187.2: SOLID187 Item and Sequence Numbers lists output available through **ETABLE** using the Sequence Number method. See The General Postprocessor (POST1) in the *Basic Analysis Guide* and *The Item and Sequence Number Table* in this reference for more information. The following notation is used in *Table 187.2: SOLID187 Item and Sequence Numbers*:

Name

output quantity as defined in *Table 187.1: SOLID187 Element Output Definitions*

Item

predetermined Item label for **ETABLE** command

I,J,...,R

sequence number for data at nodes I, J, ..., R

Table 187.2: SOLID187 Item and Sequence Numbers

Output Quantity Name	ETABLE and ESOL Command Input					
	Item	I	J	K	L	M,...,R
P1	SMISC	2	1	3	-	-
P2	SMISC	4	5	-	6	-
P3	SMISC	-	7	8	9	-
P4	SMISC	11	-	10	12	-

SOLID187 Assumptions and Restrictions

- The element must not have a zero volume.
- Elements may be numbered either as shown in *Figure 187.1: SOLID187 Geometry* or may have node L below the I, J, K plane.
- An edge with a removed midside node implies that the displacement varies linearly, rather than parabolically, along that edge. See Quadratic Elements (Midside Nodes) in the *Modeling and Meshing Guide* for information about using midside nodes.
- When mixed formulation is used (KEYOPT(6) = 1 or 2), no midside nodes can be missed.
- If you use the mixed formulation (KEYOPT(6) = 1 or 2), the damped eigensolver is not supported. You must use the sparse solver (default).
- Stress stiffening is always included in geometrically nonlinear analyses (**NLGEOM**,ON). Prestress effects can be activated by the **PSTRES** command.

SOLID187 Product Restrictions

When used in the product(s) listed below, the stated product-specific restrictions apply to this element in addition to the general assumptions and restrictions given in the previous section.

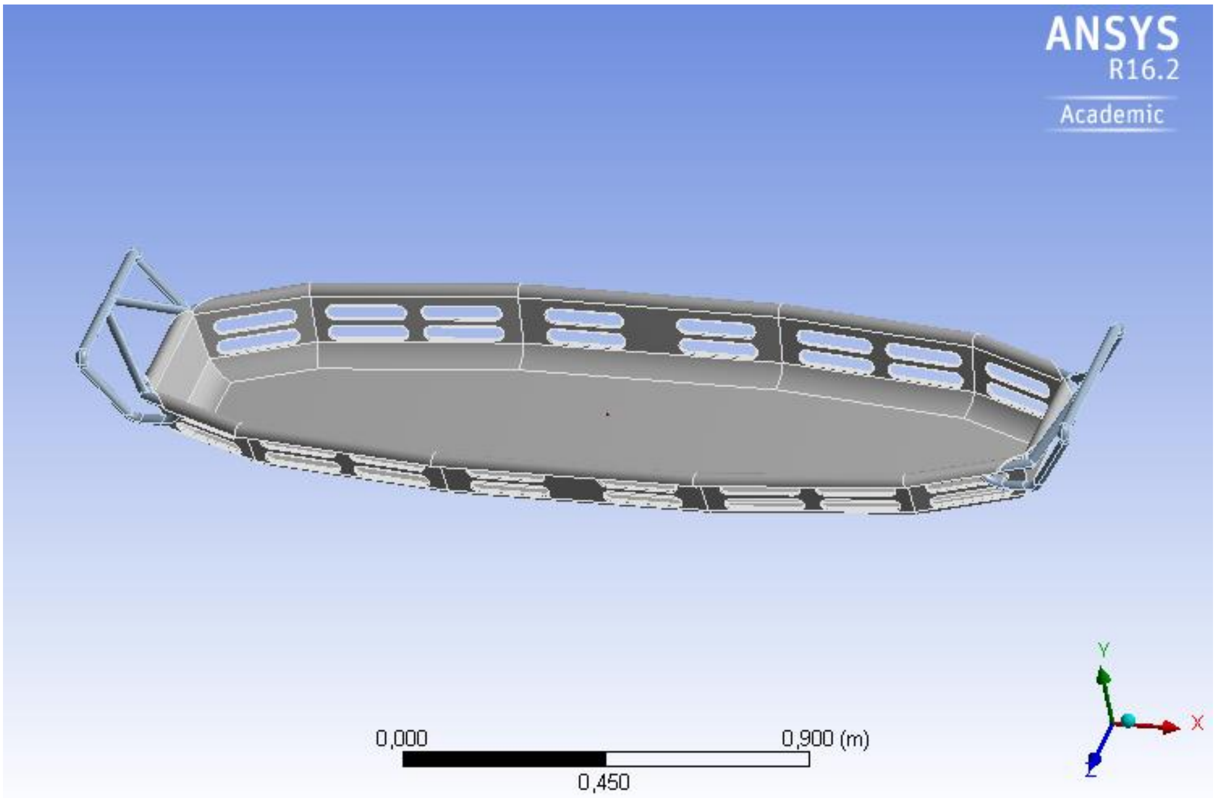
ANSYS Professional

- The only special feature allowed is stress stiffening.

Appendix M – ANSYS Project File for Case 1

Project

First Saved	Tuesday, May 30, 2017
Last Saved	Tuesday, May 30, 2017
Product Version	16.2 Release
Save Project Before Solution	No
Save Project After Solution	No



Contents

Units

TABLE 1

Unit System	Metric (m, kg, N, s, V, A) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model (A4)

Geometry

TABLE 2
Model (A4) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	E:\Mater thesis\wholeass2.STEP
Type	Step
Length Unit	Meters
Element Control	Program Controlled
Display Style	Body Color
Bounding Box	
Length X	2,357 m
Length Y	0,31101 m
Length Z	0,63767 m
Properties	
Volume	1,7785e-002 m^3
Mass	19,571 kg
Scale Factor Value	1,

Statistics	
Bodies	2
Active Bodies	2
Nodes	64387
Elements	33875
Mesh Metric	None
Basic Geometry Options	
Solid Bodies	Yes
Surface Bodies	Yes
Line Bodies	No
Parameters	Yes
Parameter Key	DS
Attributes	No
Named Selections	No
Material Properties	No
Advanced Geometry Options	
Use Associativity	Yes
Coordinate Systems	No
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	No
Compare Parts On Update	No
Attach File Via Temp File	Yes
Temporary Directory	C:\Users\kbr059\AppData\Local\Temp
Analysis Type	3-D
Mixed Import Resolution	None
Decompose Disjoint Geometry	Yes
Enclosure and Symmetry Processing	Yes

TABLE 3
Model (A4) > Geometry > Parts

Object Name	*wholebody*	*wholeframe_Default<As Machined>*
State	Meshed	
Graphics Properties		
Visible	Yes	
Transparency	1	
Definition		
Suppressed	No	
Stiffness Behavior	Flexible	
Coordinate System	Default Coordinate System	
Reference Temperature	By Environment	
Material		
Assignment	Polyethylene	AL 6061-T6
Nonlinear Effects	Yes	
Thermal Strain Effects	Yes	
Bounding Box		
Length X	2,1375 m	2,357 m
Length Y	0,18619 m	0,18875 m
Length Z	0,63767 m	0,625 m
Properties		
Volume	1,6258e-002 m³	1,5262e-003 m³
Mass	15,445 kg	4,1252 kg

Centroid X	0,73525 m	0,73772 m
Centroid Y	1,1491 m	1,2917 m
Centroid Z	1,8554 m	1,8571 m
Moment of Inertia Ip1	0,42854 kg·m²	0,20969 kg·m²
Moment of Inertia Ip2	5,1179 kg·m²	3,1658 kg·m²
Moment of Inertia Ip3	4,7652 kg·m²	2,9749 kg·m²
Statistics		
Nodes	36914	27473
Elements	19192	14683
Mesh Metric	None	

Coordinate Systems

TABLE 4
Model (A4) > Coordinate Systems > Coordinate System

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Coordinate System ID	0,
Origin	
Origin X	0, m
Origin Y	0, m
Origin Z	0, m
Directional Vectors	
X Axis Data	[1, 0, 0,]
Y Axis Data	[0, 1, 0,]
Z Axis Data	[0, 0, 1,]

Connections

TABLE 5
Model (A4) > Connections

Object Name	*Connections*
State	Fully Defined
Auto Detection	
Generate Automatic Connection On Refresh	Yes
Transparency	
Enabled	Yes

TABLE 6
Model (A4) > Connections > Contacts

Object Name	*Contacts*
State	Fully Defined
Definition	
Connection Type	Contact
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Auto Detection	
Tolerance Type	Slider
Tolerance Slider	0,

Tolerance Value	6,1536e-003 m
Use Range	No
Face/Face	Yes
Face/Edge	No
Edge/Edge	No
Priority	Include All
Group By	Bodies
Search Across	Bodies
Statistics	
Connections	1
Active Connections	1

TABLE 7
Model (A4) > Connections > Contacts > Contact Regions

Object Name	*Contact Region*
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Contact	25 Faces
Target	29 Faces
Contact Bodies	wholebody
Target Bodies	wholeframe_Default<As Machined>
Definition	
Type	Bonded
Scope Mode	Automatic
Behavior	Program Controlled
Trim Contact	Program Controlled
Trim Tolerance	6,1536e-003 m
Suppressed	No
Advanced	
Formulation	Program Controlled
Detection Method	Program Controlled
Penetration Tolerance	Program Controlled
Elastic Slip Tolerance	Program Controlled
Normal Stiffness	Program Controlled
Update Stiffness	Program Controlled
Pinball Region	Program Controlled
Geometric Modification	
Contact Geometry Correction	None
Target Geometry Correction	None

Mesh

TABLE 8
Model (A4) > Mesh

Object Name	*Mesh*
State	Solved
Display	
Display Style	Body Color
Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	Off
Relevance Center	Coarse
Element Size	Default
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Fast
Span Angle Center	Coarse
Minimum Edge Length	6,9599e-007 m
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0,272
Maximum Layers	5
Growth Rate	1,2
Inflation Algorithm	Pre
View Advanced Options	No
Patch Conforming Options	
Triangle Surface Mesher	Program Controlled
Patch Independent Options	
Topology Checking	No
Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled
Shape Checking	Standard Mechanical
Element Midside Nodes	Program Controlled
Straight Sided Elements	No
Number of Retries	Default (4)
Extra Retries For Assembly	Yes
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Defeaturing	
Pinch Tolerance	Please Define
Generate Pinch on Refresh	No
Automatic Mesh Based Defeaturing	On
Defeaturing Tolerance	Default
Statistics	
Nodes	64387
Elements	33875
Mesh Metric	None

Static Structural (A5)

TABLE 9
Model (A4) > Analysis

Object Name	*Static Structural (A5)*
State	Solved
Definition	
Physics Type	Structural
Analysis Type	Static Structural
Solver Target	Mechanical APDL
Options	
Environment Temperature	22, °C
Generate Input Only	No

TABLE 10
Model (A4) > Static Structural (A5) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Step Controls	
Number Of Steps	1,
Current Step Number	1,
Step End Time	1, s
Auto Time Stepping	Program Controlled
Solver Controls	
Solver Type	Program Controlled
Weak Springs	Program Controlled
Solver Pivot Checking	Program Controlled
Large Deflection	Off
Inertia Relief	Off
Restart Controls	
Generate Restart Points	Program Controlled
Retain Files After Full Solve	No
Nonlinear Controls	
Newton-Raphson Option	Program Controlled
Force Convergence	Program Controlled
Moment Convergence	Program Controlled
Displacement Convergence	Program Controlled
Rotation Convergence	Program Controlled
Line Search	Program Controlled
Stabilization	Off
Output Controls	
Stress	Yes
Strain	Yes
Nodal Forces	No
Contact Miscellaneous	No
General Miscellaneous	No
Store Results At	All Time Points
Analysis Data Management	
Solver Files Directory	E:\Mater thesis\ANSYS\whoassimpstudy_files\dp0\SYS\MECH\
Future Analysis	None
Scratch Solver Files Directory	
Save MAPDL db	No

Delete Unneeded Files	Yes
Nonlinear Solution	No
Solver Units	Active System
Solver Unit System	mks

TABLE 11
Model (A4) > Static Structural (A5) > Loads

Object Name	*Roller A (imp) Y free*	*Roller B (imp)*	*Pressure*	*Roller A, X free*	*Fixed C*	*Moment*
State	Suppressed		Fully Defined			
Scope						
Scoping Method	Geometry Selection					
Geometry	1 Face					
Definition						
Type	Displacement		Pressure	Displacement		Moment
Define By	Components		Normal To	Components		Vector
Coordinate System	Global Coordinate System			Global Coordinate System		
X Component	0, m (ramped)	Free		Free	0, m (ramped)	
Y Component	Free	0, m (ramped)		0, m (ramped)		
Z Component	0, m (ramped)			0, m (ramped)		
Suppressed	Yes		No			
Magnitude			2300, Pa (ramped)			6300, N·m (ramped)
Direction						Defined
Behavior						Deformable
Advanced						
Pinball Region						All

FIGURE 1
Model (A4) > Static Structural (A5) > Roller A (imp) Y free

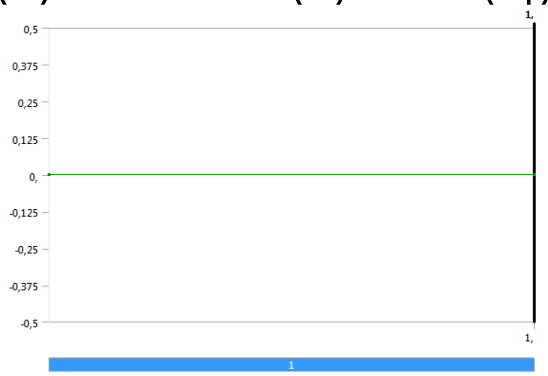


FIGURE 2
Model (A4) > Static Structural (A5) > Roller B (imp)

FIGURE 3
Model (A4) > Static Structural (A5) > Pressure

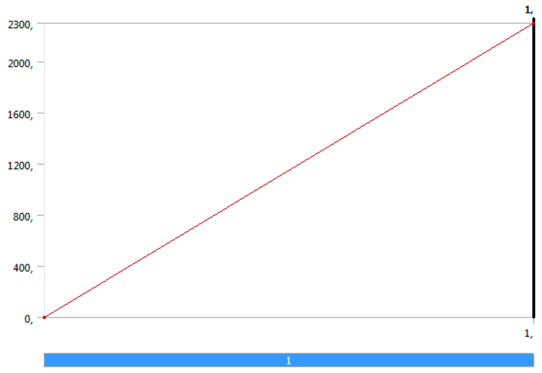


FIGURE 4
Model (A4) > Static Structural (A5) > Roller A, X free

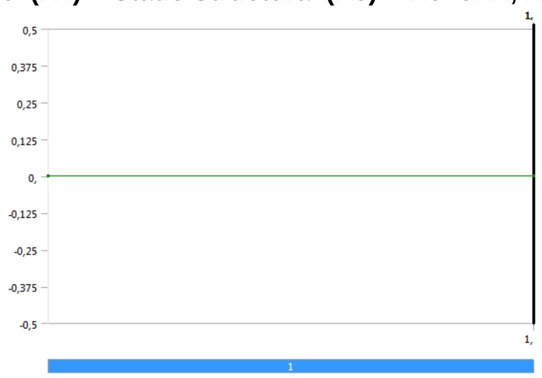


FIGURE 5
Model (A4) > Static Structural (A5) > Fixed C

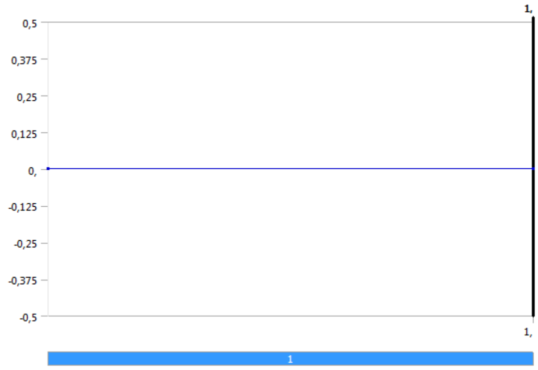
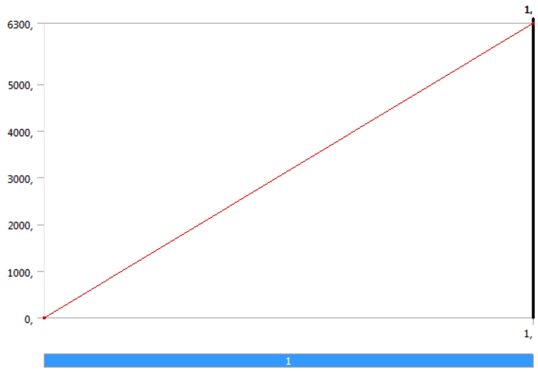


FIGURE 6
Model (A4) > Static Structural (A5) > Moment



Solution (A6)

TABLE 12
Model (A4) > Static Structural (A5) > Solution

Object Name	*Solution (A6)*
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1,
Refinement Depth	2,
Information	
Status	Done
Post Processing	
Calculate Beam Section Results	No

TABLE 13
Model (A4) > Static Structural (A5) > Solution (A6) > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output
Newton-Raphson Residuals	0
Update Interval	2,5 s
Display Points	All
FE Connection Visibility	
Activate Visibility	Yes
Display	All FE Connectors

Draw Connections Attached To	All Nodes
Line Color	Connection Type
Visible on Results	No
Line Thickness	Single
Display Type	Lines

TABLE 14
Model (A4) > Static Structural (A5) > Solution (A6) > Results

Object Name	*Total Deformation*	*Equivalent Stress*	*Shear Stress*
State	Solved		
Scope			
Scoping Method	Geometry Selection		
Geometry	All Bodies		
Definition			
Type	Total Deformation	Equivalent (von-Mises) Stress	Shear Stress
By	Time		
Display Time	Last		
Calculate Time History	Yes		
Identifier			
Suppressed	No		
Orientation			XY Plane
Coordinate System			Global Coordinate System
Results			
Minimum	0, m	40452 Pa	-3,4448e+008 Pa
Maximum	1,592e-002 m	1,116e+009 Pa	2,5886e+008 Pa
Minimum Occurs On	wholeframe_Default<As Machined>	wholebody	wholeframe_Default<As Machined>
Maximum Occurs On	wholebody	wholeframe_Default<As Machined>	
Information			
Time	1, s		
Load Step	1		
Substep	1		
Iteration Number	1		
Integration Point Results			
Display Option		Averaged	
Average Across Bodies		No	

FIGURE 7
Model (A4) > Static Structural (A5) > Solution (A6) > Total Deformation

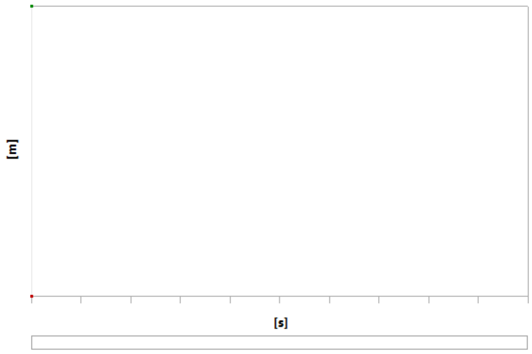


TABLE 15
Model (A4) > Static Structural (A5) > Solution (A6) > Total Deformation

Time [s]	Minimum [m]	Maximum [m]
1,	0,	1,592e-002

FIGURE 8
Model (A4) > Static Structural (A5) > Solution (A6) > Equivalent Stress

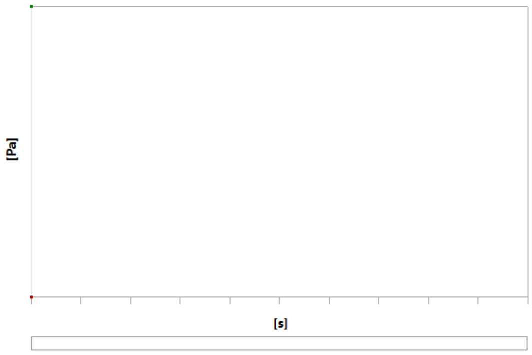


TABLE 16
Model (A4) > Static Structural (A5) > Solution (A6) > Equivalent Stress

Time [s]	Minimum [Pa]	Maximum [Pa]
1,	40452	1,116e+009

FIGURE 9
Model (A4) > Static Structural (A5) > Solution (A6) > Shear Stress

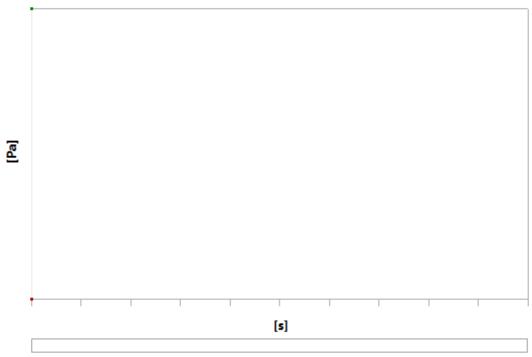


TABLE 17
Model (A4) > Static Structural (A5) > Solution (A6) > Shear Stress

Time [s]	Minimum [Pa]	Maximum [Pa]
1,	-3,4448e+008	2,5886e+008

Material Data

Polyethylene

TABLE 18
Polyethylene > Constants

Density	950, kg m^-3
Coefficient of Thermal Expansion	2,3e-004 C^-1
Specific Heat	296, J kg^-1 C^-1
Thermal Conductivity	0,28 W m^-1 C^-1

TABLE 19
Polyethylene > Compressive Ultimate Strength

Compressive Ultimate Strength Pa
0,

TABLE 20
Polyethylene > Compressive Yield Strength

Compressive Yield Strength Pa
0,

TABLE 21
Polyethylene > Tensile Yield Strength

Tensile Yield Strength Pa
2,5e+007

TABLE 22
Polyethylene > Tensile Ultimate Strength

Tensile Ultimate Strength Pa
3,3e+007

TABLE 23
Polyethylene > Isotropic Secant Coefficient of Thermal Expansion

Reference Temperature C
22,

TABLE 24
Polyethylene > Isotropic Elasticity

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
	1,1e+009	0,42	2,2917e+009	3,8732e+008

AL 6061-T6

TABLE 25
AL 6061-T6 > Constants

Density	2703, kg m^-3
Specific Heat	885, J kg^-1 C^-1

TABLE 26
AL 6061-T6 > Shock EOS Linear

Gruneisen Coefficient	Parameter C1 m s^-1	Parameter S1	Parameter Quadratic S2 s m^-1
1,97	5240,	1,4	0,

TABLE 27
AL 6061-T6 > Steinberg Guinan Strength

Initial Yield Stress Y Pa	Maximum Yield Stress Ymax Pa	Hardening Constant B	Hardening Exponent n	Derivative dG/dP G'P	Derivative dG/dT G'T Pa C^-1	Derivative dY/dP Y'P	Melting Temperature Tmelt C
2,9e+008	6,8e+008	125,	0,1	1,8	-1,7e+007	1,8908e-002	946,85

TABLE 28
AL 6061-T6 > Shear Modulus

Shear Modulus Pa
2,76e+010

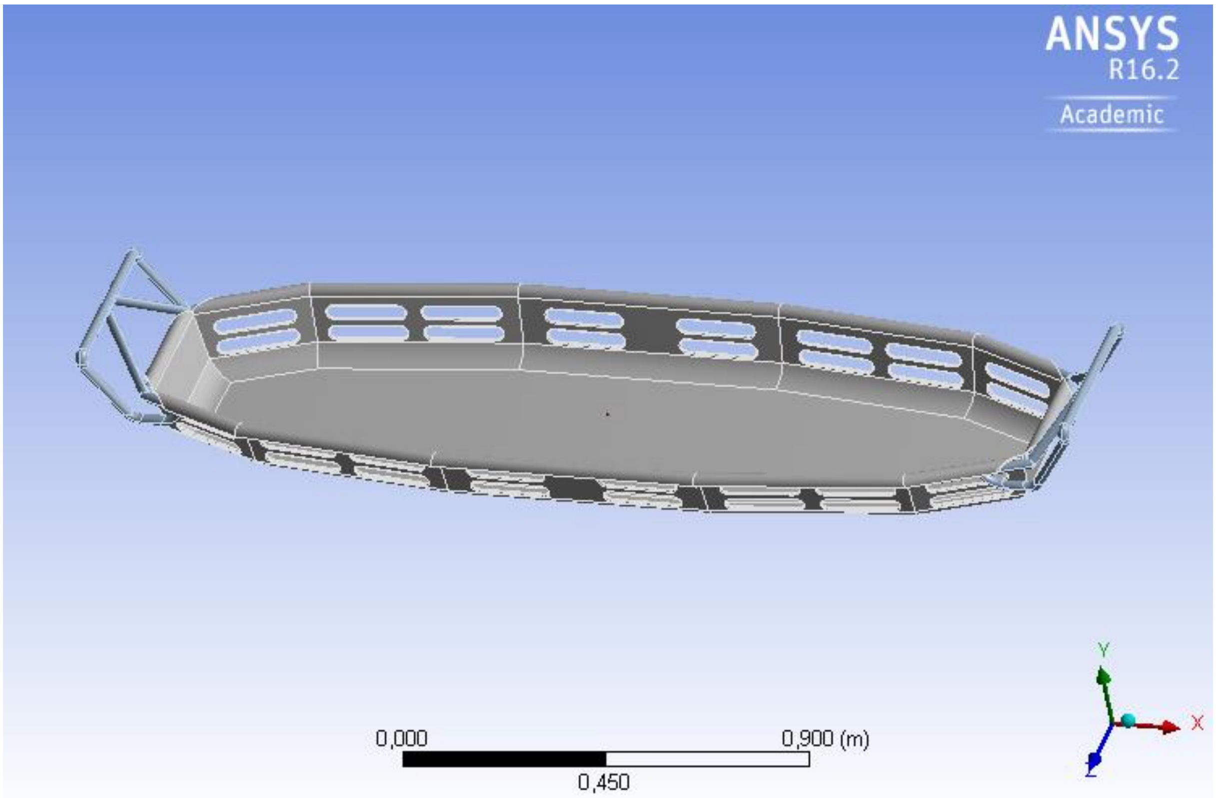
TABLE 29
AL 6061-T6 > Isotropic Elasticity

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
	7,1e+010	0,33	6,9608e+010	2,6692e+010

Appendix N – ANSYS Project File for Case 2 and Case 3

Project

First Saved	Tuesday, May 30, 2017
Last Saved	Tuesday, May 30, 2017
Product Version	16.2 Release
Save Project Before Solution	No
Save Project After Solution	No



Contents

Units

TABLE 1

Unit System	Metric (m, kg, N, s, V, A) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model (A4)

Geometry

TABLE 2
Model (A4) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	E:\Mater thesis\wholeass2.STEP
Type	Step
Length Unit	Meters
Element Control	Program Controlled
Display Style	Body Color
Bounding Box	
Length X	2,357 m
Length Y	0,31101 m
Length Z	0,63767 m
Properties	
Volume	1,7785e-002 m^3
Mass	19,571 kg
Scale Factor Value	1,

Statistics	
Bodies	2
Active Bodies	2
Nodes	64387
Elements	33875
Mesh Metric	None
Basic Geometry Options	
Solid Bodies	Yes
Surface Bodies	Yes
Line Bodies	No
Parameters	Yes
Parameter Key	DS
Attributes	No
Named Selections	No
Material Properties	No
Advanced Geometry Options	
Use Associativity	Yes
Coordinate Systems	No
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	No
Compare Parts On Update	No
Attach File Via Temp File	Yes
Temporary Directory	C:\Users\kbr059\AppData\Local\Temp
Analysis Type	3-D
Mixed Import Resolution	None
Decompose Disjoint Geometry	Yes
Enclosure and Symmetry Processing	Yes

TABLE 3
Model (A4) > Geometry > Parts

Object Name	*wholebody*	*wholeframe_Default<As Machined>*
State	Meshed	
Graphics Properties		
Visible	Yes	
Transparency	1	
Definition		
Suppressed	No	
Stiffness Behavior	Flexible	
Coordinate System	Default Coordinate System	
Reference Temperature	By Environment	
Material		
Assignment	Polyethylene	AL 6061-T6
Nonlinear Effects	Yes	
Thermal Strain Effects	Yes	
Bounding Box		
Length X	2,1375 m	2,357 m
Length Y	0,18619 m	0,18875 m
Length Z	0,63767 m	0,625 m
Properties		
Volume	1,6258e-002 m³	1,5262e-003 m³
Mass	15,445 kg	4,1252 kg

Centroid X	0,73525 m	0,73772 m
Centroid Y	1,1491 m	1,2917 m
Centroid Z	1,8554 m	1,8571 m
Moment of Inertia Ip1	0,42854 kg·m²	0,20969 kg·m²
Moment of Inertia Ip2	5,1179 kg·m²	3,1658 kg·m²
Moment of Inertia Ip3	4,7652 kg·m²	2,9749 kg·m²
Statistics		
Nodes	36914	27473
Elements	19192	14683
Mesh Metric	None	

Coordinate Systems

TABLE 4
Model (A4) > Coordinate Systems > Coordinate System

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Coordinate System ID	0,
Origin	
Origin X	0, m
Origin Y	0, m
Origin Z	0, m
Directional Vectors	
X Axis Data	[1, 0, 0,]
Y Axis Data	[0, 1, 0,]
Z Axis Data	[0, 0, 1,]

Connections

TABLE 5
Model (A4) > Connections

Object Name	*Connections*
State	Fully Defined
Auto Detection	
Generate Automatic Connection On Refresh	Yes
Transparency	
Enabled	Yes

TABLE 6
Model (A4) > Connections > Contacts

Object Name	*Contacts*
State	Fully Defined
Definition	
Connection Type	Contact
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Auto Detection	
Tolerance Type	Slider
Tolerance Slider	0,

Tolerance Value	6,1536e-003 m
Use Range	No
Face/Face	Yes
Face/Edge	No
Edge/Edge	No
Priority	Include All
Group By	Bodies
Search Across	Bodies
Statistics	
Connections	1
Active Connections	1

TABLE 7
Model (A4) > Connections > Contacts > Contact Regions

Object Name	*Contact Region*
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Contact	25 Faces
Target	29 Faces
Contact Bodies	wholebody
Target Bodies	wholeframe_Default<As Machined>
Definition	
Type	Bonded
Scope Mode	Automatic
Behavior	Program Controlled
Trim Contact	Program Controlled
Trim Tolerance	6,1536e-003 m
Suppressed	No
Advanced	
Formulation	Program Controlled
Detection Method	Program Controlled
Penetration Tolerance	Program Controlled
Elastic Slip Tolerance	Program Controlled
Normal Stiffness	Program Controlled
Update Stiffness	Program Controlled
Pinball Region	Program Controlled
Geometric Modification	
Contact Geometry Correction	None
Target Geometry Correction	None

Mesh

TABLE 8
Model (A4) > Mesh

Object Name	*Mesh*
State	Solved
Display	
Display Style	Body Color
Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	Off
Relevance Center	Coarse
Element Size	Default
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Fast
Span Angle Center	Coarse
Minimum Edge Length	6,9599e-007 m
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0,272
Maximum Layers	5
Growth Rate	1,2
Inflation Algorithm	Pre
View Advanced Options	No
Patch Conforming Options	
Triangle Surface Mesher	Program Controlled
Patch Independent Options	
Topology Checking	No
Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled
Shape Checking	Standard Mechanical
Element Midside Nodes	Program Controlled
Straight Sided Elements	No
Number of Retries	Default (4)
Extra Retries For Assembly	Yes
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Defeaturing	
Pinch Tolerance	Please Define
Generate Pinch on Refresh	No
Automatic Mesh Based Defeaturing	On
Defeaturing Tolerance	Default
Statistics	
Nodes	64387
Elements	33875
Mesh Metric	None

Static Structural (A5)

TABLE 9
Model (A4) > Analysis

Object Name	*Static Structural (A5)*
State	Solved
Definition	
Physics Type	Structural
Analysis Type	Static Structural
Solver Target	Mechanical APDL
Options	
Environment Temperature	22, °C
Generate Input Only	No

TABLE 10
Model (A4) > Static Structural (A5) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Step Controls	
Number Of Steps	1,
Current Step Number	1,
Step End Time	1, s
Auto Time Stepping	Program Controlled
Solver Controls	
Solver Type	Program Controlled
Weak Springs	Program Controlled
Solver Pivot Checking	Program Controlled
Large Deflection	Off
Inertia Relief	Off
Restart Controls	
Generate Restart Points	Program Controlled
Retain Files After Full Solve	No
Nonlinear Controls	
Newton-Raphson Option	Program Controlled
Force Convergence	Program Controlled
Moment Convergence	Program Controlled
Displacement Convergence	Program Controlled
Rotation Convergence	Program Controlled
Line Search	Program Controlled
Stabilization	Off
Output Controls	
Stress	Yes
Strain	Yes
Nodal Forces	No
Contact Miscellaneous	No
General Miscellaneous	No
Store Results At	All Time Points
Analysis Data Management	
Solver Files Directory	E:\Mater thesis\ANSYS\whoassimpstudy_files\dp0\SYS\MECH\
Future Analysis	None
Scratch Solver Files Directory	
Save MAPDL db	No

Delete Unneeded Files	Yes
Nonlinear Solution	No
Solver Units	Active System
Solver Unit System	mks

TABLE 11
Model (A4) > Static Structural (A5) > Loads

Object Name	*Roller A (imp) Y free*	*Roller B (imp)*	*Pressure*	*Roller A, X free*	*Fixed C*	*Moment*
State	Suppressed		Fully Defined			
Scope						
Scoping Method	Geometry Selection					
Geometry	1 Face					
Definition						
Type	Displacement		Pressure	Displacement		Moment
Define By	Components		Normal To	Components		Vector
Coordinate System	Global Coordinate System			Global Coordinate System		
X Component	0, m (ramped)	Free		Free	0, m (ramped)	
Y Component	Free	0, m (ramped)		0, m (ramped)		
Z Component	0, m (ramped)			0, m (ramped)		
Suppressed	Yes		No			
Magnitude			2300, Pa (ramped)			6300, N·m (ramped)
Direction						Defined
Behavior						Deformable
Advanced						
Pinball Region						All

FIGURE 1
Model (A4) > Static Structural (A5) > Roller A (imp) Y free

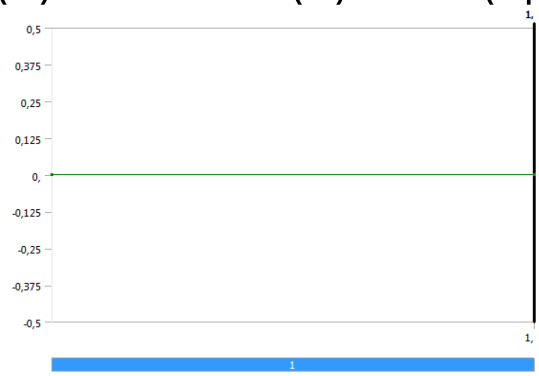


FIGURE 2
Model (A4) > Static Structural (A5) > Roller B (imp)

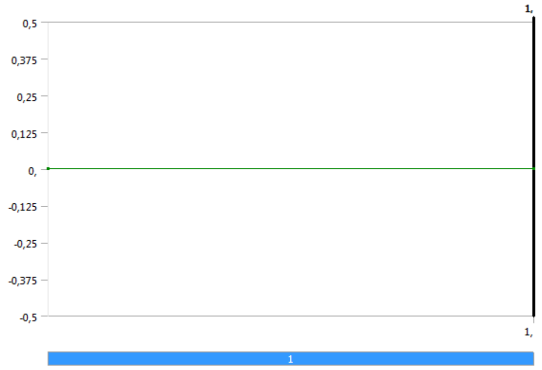


FIGURE 3
Model (A4) > Static Structural (A5) > Pressure

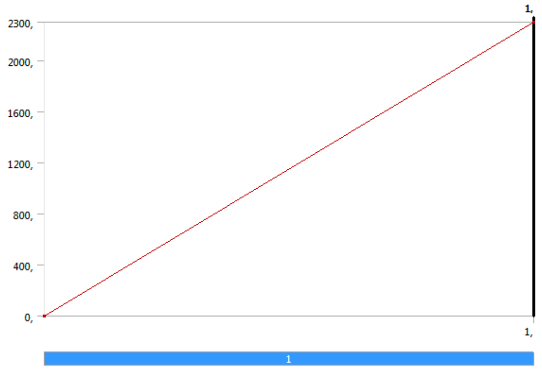


FIGURE 4
Model (A4) > Static Structural (A5) > Roller A, X free

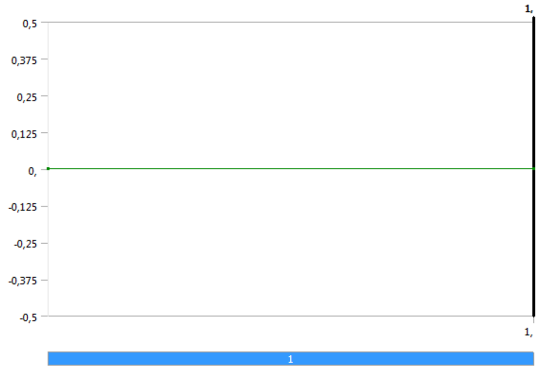


FIGURE 5
Model (A4) > Static Structural (A5) > Fixed C

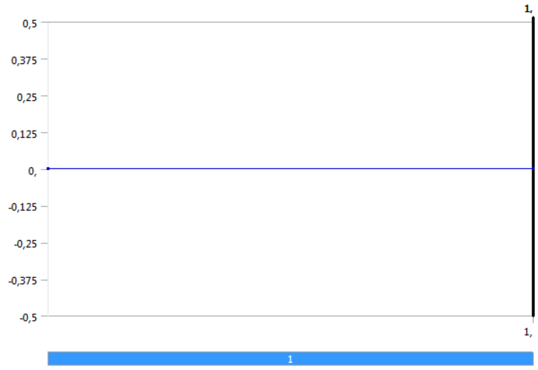
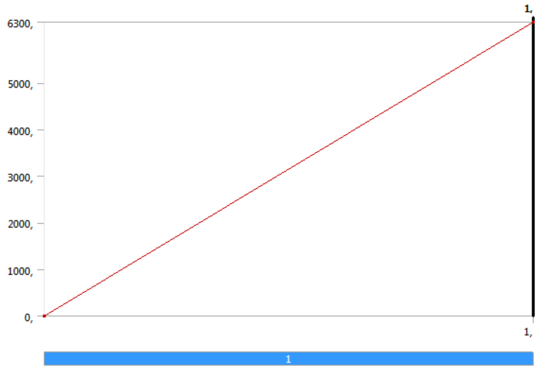


FIGURE 6
Model (A4) > Static Structural (A5) > Moment



Solution (A6)

TABLE 12
Model (A4) > Static Structural (A5) > Solution

Object Name	*Solution (A6)*
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1,
Refinement Depth	2,
Information	
Status	Done
Post Processing	
Calculate Beam Section Results	No

TABLE 13
Model (A4) > Static Structural (A5) > Solution (A6) > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output
Newton-Raphson Residuals	0
Update Interval	2,5 s
Display Points	All
FE Connection Visibility	
Activate Visibility	Yes
Display	All FE Connectors

Draw Connections Attached To	All Nodes
Line Color	Connection Type
Visible on Results	No
Line Thickness	Single
Display Type	Lines

TABLE 14
Model (A4) > Static Structural (A5) > Solution (A6) > Results

Object Name	*Total Deformation*	*Equivalent Stress*	*Shear Stress*
State	Solved		
Scope			
Scoping Method	Geometry Selection		
Geometry	All Bodies		
Definition			
Type	Total Deformation	Equivalent (von-Mises) Stress	Shear Stress
By	Time		
Display Time	Last		
Calculate Time History	Yes		
Identifier			
Suppressed	No		
Orientation			XY Plane
Coordinate System			Global Coordinate System
Results			
Minimum	0, m	40452 Pa	-3,4448e+008 Pa
Maximum	1,592e-002 m	1,116e+009 Pa	2,5886e+008 Pa
Minimum Occurs On	wholeframe_Default<As Machined>	wholebody	wholeframe_Default<As Machined>
Maximum Occurs On	wholebody	wholeframe_Default<As Machined>	
Information			
Time	1, s		
Load Step	1		
Substep	1		
Iteration Number	1		
Integration Point Results			
Display Option		Averaged	
Average Across Bodies		No	

FIGURE 7
Model (A4) > Static Structural (A5) > Solution (A6) > Total Deformation

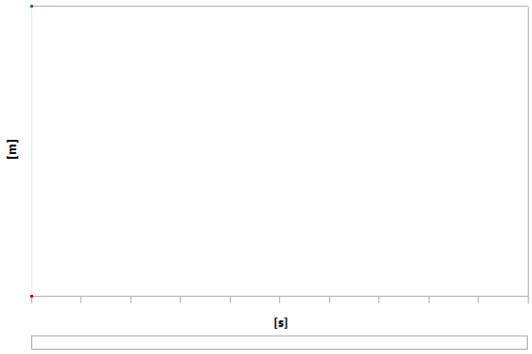


TABLE 15
Model (A4) > Static Structural (A5) > Solution (A6) > Total Deformation

Time [s]	Minimum [m]	Maximum [m]
1,	0,	1,592e-002

FIGURE 8
Model (A4) > Static Structural (A5) > Solution (A6) > Equivalent Stress

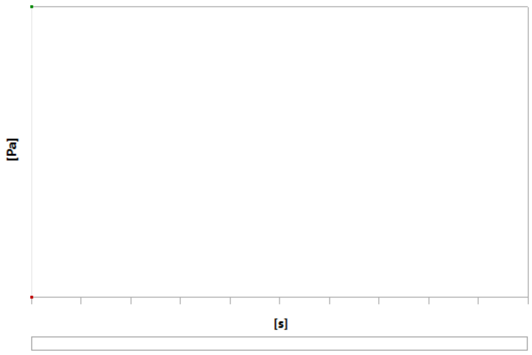


TABLE 16
Model (A4) > Static Structural (A5) > Solution (A6) > Equivalent Stress

Time [s]	Minimum [Pa]	Maximum [Pa]
1,	40452	1,116e+009

FIGURE 9
Model (A4) > Static Structural (A5) > Solution (A6) > Shear Stress

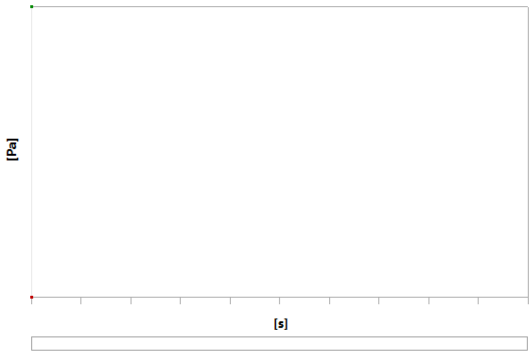


TABLE 17
Model (A4) > Static Structural (A5) > Solution (A6) > Shear Stress

Time [s]	Minimum [Pa]	Maximum [Pa]
1,	-3,4448e+008	2,5886e+008

Material Data

Polyethylene

TABLE 18
Polyethylene > Constants

Density	950, kg m^-3
Coefficient of Thermal Expansion	2,3e-004 C^-1
Specific Heat	296, J kg^-1 C^-1
Thermal Conductivity	0,28 W m^-1 C^-1

TABLE 19
Polyethylene > Compressive Ultimate Strength

Compressive Ultimate Strength Pa
0,

TABLE 20
Polyethylene > Compressive Yield Strength

Compressive Yield Strength Pa
0,

TABLE 21
Polyethylene > Tensile Yield Strength

Tensile Yield Strength Pa
2,5e+007

TABLE 22
Polyethylene > Tensile Ultimate Strength

Tensile Ultimate Strength Pa
3,3e+007

TABLE 23
Polyethylene > Isotropic Secant Coefficient of Thermal Expansion

Reference Temperature C
22,

TABLE 24
Polyethylene > Isotropic Elasticity

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
	1,1e+009	0,42	2,2917e+009	3,8732e+008

AL 6061-T6

TABLE 25
AL 6061-T6 > Constants

Density	2703, kg m^-3
Specific Heat	885, J kg^-1 C^-1

TABLE 26
AL 6061-T6 > Shock EOS Linear

Gruneisen Coefficient	Parameter C1 m s^-1	Parameter S1	Parameter Quadratic S2 s m^-1
1,97	5240,	1,4	0,

TABLE 27
AL 6061-T6 > Steinberg Guinan Strength

Initial Yield Stress Y Pa	Maximum Yield Stress Ymax Pa	Hardening Constant B	Hardening Exponent n	Derivative dG/dP G'P	Derivative dG/dT G'T Pa C^-1	Derivative dY/dP Y'P	Melting Temperature Tmelt C
2,9e+008	6,8e+008	125,	0,1	1,8	-1,7e+007	1,8908e-002	946,85

TABLE 28
AL 6061-T6 > Shear Modulus

Shear Modulus Pa
2,76e+010

TABLE 29
AL 6061-T6 > Isotropic Elasticity

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
	7,1e+010	0,33	6,9608e+010	2,6692e+010