Material Selection of Chair Frame

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Formulation of a need statement

Component selection

College chairs, one of the most common thing in our college life, have many types of material selection such as wood, metals and plastic. In our project, the product selected is one type of them which has steel frame and plastic seat. The component selected to analyse in this project is the steel frame of that chair. In this project, the main goal is finding the most suitable material of the frame for existed product.

Figure 1. The college chair

Function requirement

The function of a chair frame is clear which is supporting a human's weight. The bottom frame which contacted with the floor can be assumed fixed because of the high friction. The only force applied to system is the weight of human which is applied to the seat frames. The average weight of human being is 62 kg [1]. For the security concerns, we assume the person sitting on the chair is 150 kg and the force applied to the frame is around 1500 N. In addition, forces is distributed evenly among three seat frames. For the safety reasons, the chair frame needs to withstand as much pressure as possible. It requires the safety factor of material selected becomes as higher as possible.

Failure possibility

The types of loading will be compression and bending. This chair frame will fail if the stress applied is larger than ultimate strength. For more precise, we even don't want the stress applied exceed the yield strength. This is simply because the deformation happened when the stress is larger than yield strength which is not expected. The possible failure situations may be breaking or buckling. Therefore, the ultimate strength, yield strength, bulk modulus and flexural strength are all the important parameters in this project.

Objectives and Stakeholders

When selecting the material, we need to make sure the material selected won't fail when 1500 N force is applied. This security concern will be considered by all people including manufacturer, users and related authorities. To achieve this goal, the ultimate strength, yield strength, bulk modulus and flexural strength should be as high as possible.

For the commercial perspective, the cost will be considered after security factors by manufacturer. They want the price of material selected as low as possible in the case that the material can achieve goals.

From the sustainability aspects, recyclable materials are prioritize considered under same conditions.

Material comparison

Callister and Rethwisch [2] grouped solid materials into three major categories: metals, ceramics, polymers, and composites. These materials were further engineered to larger classes of advanced materials which are identified as semiconductor, biomaterials, smart materials, nanomaterials, glasses, elastomers, and hybrids [2], [3].

Through series of a material survey on the production of the chairs, the following materials were chosen: wood, tempered plastic, steel (iron). These sets of possible materials for the components were selected and compared as shown in Table 2 below. This section of the report compares the strengths and weaknesses of the top-ranked materials. In addition, other products using the materials in one application or the other are investigated to ascertain how environmentally friendly the materials can be to claim sustainability. Table 2 shows the list of the top selected materials.

Table 2. Top Material Selection for Chair

MATERIAL	M_1 $(GPa)^{1/2}/(kg/m^3)$	M_2 (GPa)	CRITERIA
Steel	0.004 – 0.009	150 – 1000	Outstanding M_1 and M_2. Cheap, modern, reliable, recyclable.

Woods	0.005 – 0.008	4 – 20	Outstanding M_1; poor M_2. Cheaper than Steel, traditional, reliable.
CFRP	0.004 – 0.008	30 – 200	Outstanding M_1 and M_2, but expensive
Ceramics	0.004 – 0.008	150 – 1000	Outstanding M_1 and M_2. Eliminated by brittleness.

For the selection of material, a high M_1 and E values are considered as the best material for the chair. Figure 2 shows the appropriate chart: Young's modulus E, plotted against density, ρ. The selection line is located at . Materials above this line have high M_1 values. Composites (especially CFRP) and some special engineering ceramics are not very comfortable. In addition, polymers are not strong enough to be used as the material for the chair.

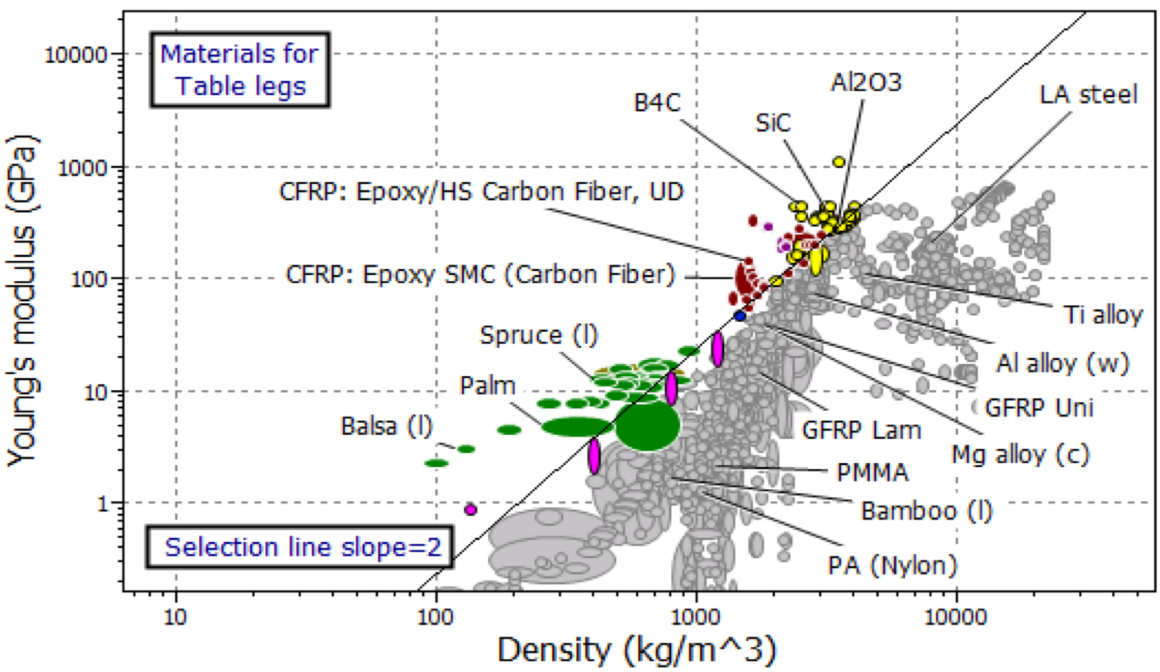


Figure 2. The E-ρ chart

Therefore, a more preferable material is the use of a metal with considerable high strength such as steel. This was validated using the chart in Figure 3 below for strength against the density of material.

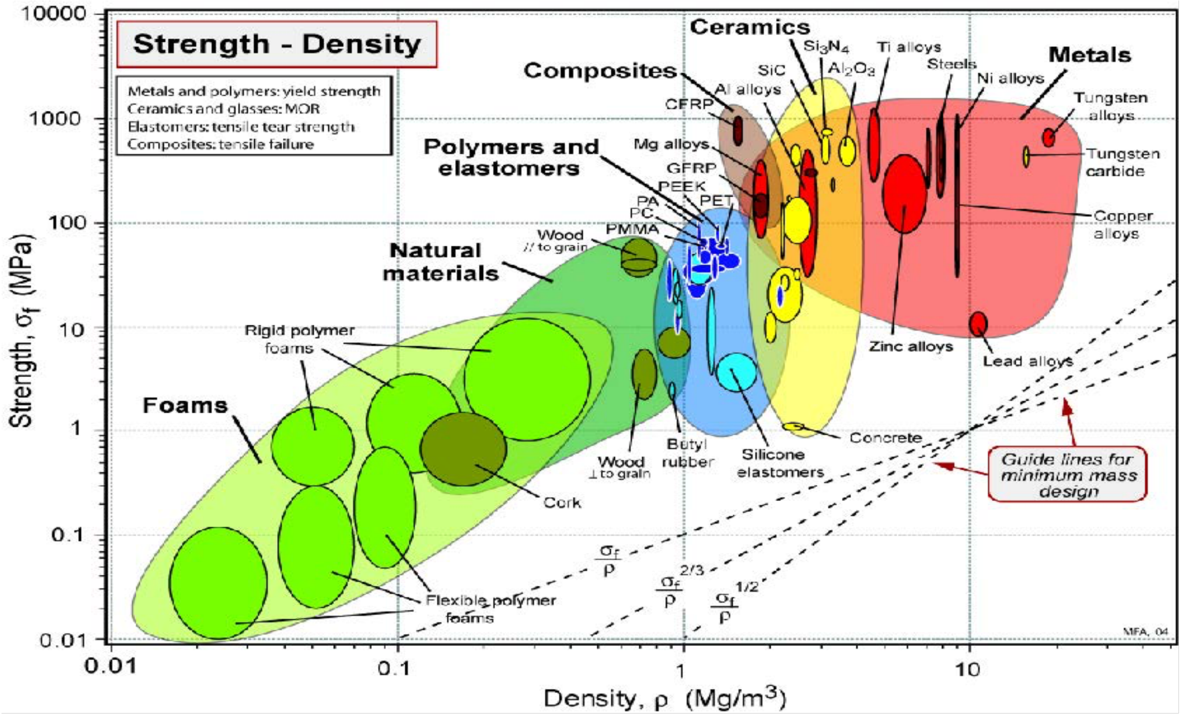


Figure 3. The Strength σ_f against density, ρ chart.

Ranking

The ranking of each of the selected material by screening to test for sustainability development of the product was conducted. This deals with the collection of quantitative information to identify materials that can achieve sustainability objectives. The properties of the materials are shown on Table 3 and Table 4. These safety factors for each of the selected materials were also included.

Table 3. Properties of Materials.

Material	Ultimate strength (MPa)	Safety factor	Percent	Recyclable	Compression Strength (MPa)	Percent	References
Alloy steel	760	3.88	0%	YES	1700	0%	[4]
Carbon fiber	1600	8.16	110%	NO	870	-49%	[5], [6]
Wood (Bamboo	350-500	1.78-2.55	34%-54%	NO	-	-	[7]

)							
PVC	52	0.265	FAIL	YES	-	-	
Ceramics	170-340	0.867-1.73	FAIL	NO	-	-	

Table 4. More properties of Materials.

Material	Bulk Modulus (GPa)	Percent	Density (g/cc)	Percent	Cost	Percent	References
Alloy steel	140	0%	7.77	0%	4.11	0%	[4]
Carbon fiber	13	-91%	1.43	82%	11.98	-191%	[5], [6]
Wood (Bamboo)	-	-	-	-	-	-	[7]
PVC	-	-	-	-	-	-	
Ceramics	-	-	-	-	-	-	

The approximate data are used on each phase of the product life. Table 5 shows the criteria for ranking the materials for sustainability. The list on the left side of the table shows the criteria used in ranking the materials.

Table 5. Criteria for ranking of materials for sustainability of product life.

Material Criteria	Steel (iron)	Wood (Bamboo)	CFRP	PVC	Ceramic
Abundance in Earth's crust (PPM)	51e3	-	-	-	-

World Production (Tonnes/year)	2.3e9	1.4e9	28,000	3e7	
Approximate Price ($/kg)	0.52	1.6	39	15	
Embodied energy Content (MJ/kg)	45	5	480		
Carbon generation ($CO_{2,eq}$(GWP) kg/kg)	3	0.31	35		
Water usage (L/kg)	50	57	1,400		
Recyclability	Recyclable	Non-recyclable	Non-recyclable	Recyclable	Non-recyclable
Availability of recycled stock	Available	Non-available	Non-available	Available	Non-Available

Note: CFRP: Carbon Fibre Reinforced Polymer, PVC: PolyVinyl Chloride.

Some materials are eliminated based on some criteria or goals of achieving sustainability. The purpose of using attribute limits and material indexing is to design technical and economic requirements [8]. These technical and economical requirements are based on what is currently available around the world.

In addition to the above, this problem was also analyzed based on two design goals: weight minimization and maximum length and the limiting case is resisting buckling. The best way was first to consider losing weight. The legs of the chair are elongated columns of material, density ρ and modulus E. Its length, and the maximum load P it must carry are fixed by design [9]. The radius r of the leg is a free variable, and finally, the mass m of the leg is minimized by the objective function (m). Where m can be defined as:

$$m = \pi r^2 l \rho \quad (1)$$

The material is also limited by its supporting load P without buckling. The elastic load Pcrit of a column of length and radius r is defined as:

$$P_{crit} = \frac{\pi^2 EI}{l^2} \quad (2)$$

where, I is the second moment area of the column. The load P must not exceed P_{crit}. Solving for the free variable, r, and substituting it into Equation 1 gives [10].

$$m \geq \left(\frac{4P}{\pi}\right)^{\frac{1}{2}} (l)^2 \left(\frac{\rho}{E^{\frac{1}{2}}}\right) \quad (3)$$

Materials are grouped in the last set of parentheses. The quality is obtained by selecting a subset of materials that have the highest performance index value. Thus, the goal of obtaining a sustainable material is achieved.

Material selection

Steel is composed of about 2% of iron-carbon and smaller amounts of chromium, manganese, nickel, phosphorus, sulphur, and silicon. From the ranking of material in Table 5above, it is clear that steel in the form of iron is more desirable in terms of sustainability for use as the chair frame material. The major considerations include the abundance of steel in the earth crust, the strength of steel against the density.

The annual production of steel is found to be higher than the rest materials on the list in Table 5 above. The annual production can also be found in the literature [11]. Materials that have lower availability are considered critical materials in terms of sustainability. Thus, they will not be used for the production of the chair framework.

Materials such as wood are usual materials of chairs. However, the strength of wood is lower than the strength of steel. Thus, wood is eliminated based on strength of material as the material for the chair frame.

Component design

The weight of the whole chair is about 3.5 kg which contains the steel frame and plastic. The steel frame takes the main percentage of weight because the density of plastic is relatively smaller than steels. However, there is an uncertainty in the material's weight as a result of the estimated values; thus the analysis may include some human errors. In general, the material selected is pretty light comparing with some metals such as copper, iron and zinc. Therefore, it can be assumed that the material of this steel frame maybe made by aluminum alloy.

By measuring the dimensions of the chair, the model can be easily built in SolidWorks for further study as shown on Figure 4. There is also a three-dimensional diagram of frame to indicate the dimension built in SolidWorks (see Figure 5). The unit used in three-dimensional diagram is centimeter and diameter of cylinder is 1 cm. For the model built, there are also some uncertainties when measuring the dimensions by rulers. In order to reduce the error, the best method is to measure them several times and use the mean value in the project.

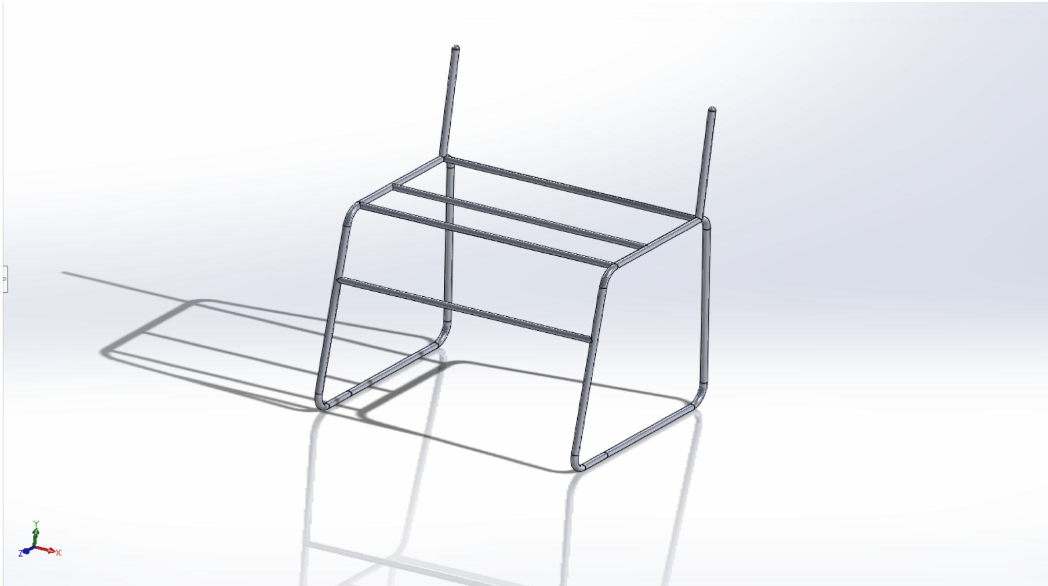


Figure 4. Frame Model in SolidWorks

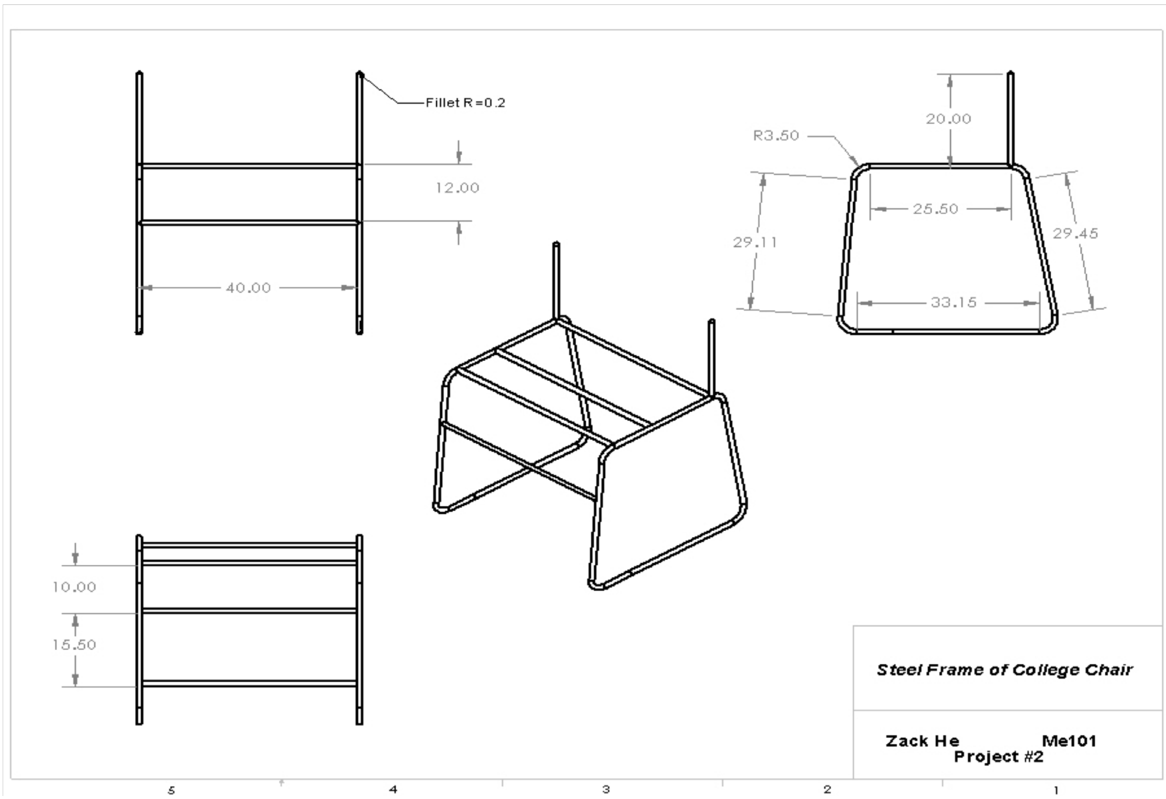


Figure 5. Three-Dimensional diagram of frame

The product can be manufactured using specific processes such as: hot-press, casting, hot rolling, cooling, strip, polish, etc. The output from the processes will be the finished product, heat, sound and some wastes [12].

Model information

By using alloy steel, the model information is shown as following figure. The mass is around 2.8 kg which has a little weight but also very suitable for handling.

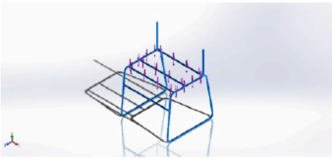
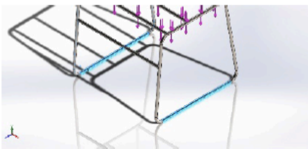
Model Reference	Properties		Volumetric Properties
	Name: Model type: Yield strength: Tensile strength: Elastic modulus: Poisson's ratio: Shear modulus: Thermal expansion	Alloy Steel Linear Elastic Isotropic Max von Mises Stress 6.20422e+08 N/m^2 7.23826e+08 N/m^2 2.1e+11 N/m^2 0.28 7.9e+10 N/m^2 1.3e-05 /Kelvin	Mass:2.82725 kg Volume:0.000367182 m^3 Density:7699.86 kg/m^3 Weight:27.707 N
Curve Data:N/A			

Figure 5. Model information of design

Loads and fixtures

As we discussed in function requirement, the bottom frame is fixed. 1500 N compression force is applied evenly and vertically to the seat frame. The information of loads and fixtures is looking like following figure.

Fixture name	Fixture Image	Fixture Details
Fixed-1		Entities: 2 face(s) Type: Fixed Geometry

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	0.0724316	1496.6	-1.56676	1496.6
Reaction Moment(N.m)	0	0	0	0

Figure 6. Fixture information of design

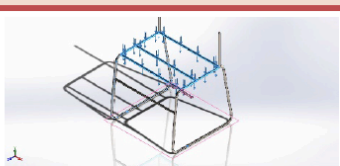
Load name	Load Image	Load Details
Force-1		Entities: 5 face(s), 1 plane(s) Reference: Top Plane Type: Apply force Values: ---, ---, -1500 N

Figure 7. Load information of design

Mesh information

For the mesh information, the mesher used is standard mesh and the element size is around 0.765 cm.

Mesh type	Solid Mesh
Mesher Used:	Standard mesh
Automatic Transition:	Off
Include Mesh Auto Loops:	Off
Jacobian points	4 Points
Element Size	0.764981 cm
Tolerance	0.038249 cm
Mesh Quality Plot	High
Total Nodes	24658
Total Elements	11707
Maximum Aspect Ratio	16.823
% of elements with Aspect Ratio < 3	98
% of elements with Aspect Ratio > 10	0.12
% of distorted elements(Jacobian)	0

Figure 8. Mesh information of design

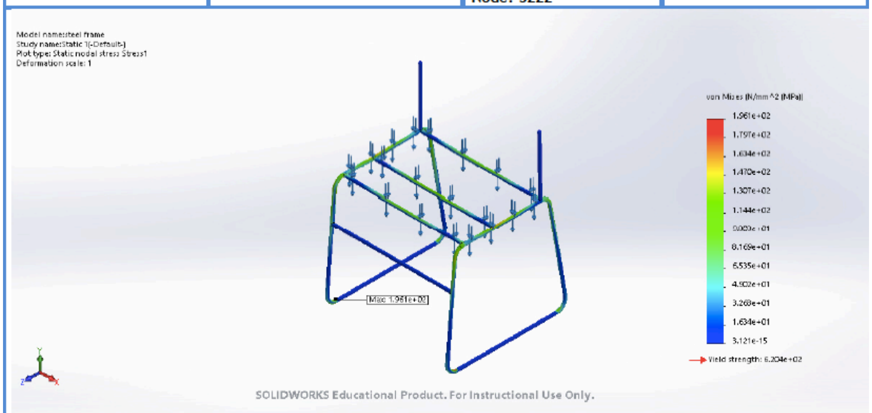
Stress result

By running this mesh, the final result of stress can be determined as following figure. The maximum stress appeared at the bottom corner and the magnitude of maximum stress is 196.1 MPa. The yield stress is 620.4 MPa, therefore, the safety factor can be calculated by following equation.

$$S.F = \frac{\sigma_y}{\sigma_{max}} = \frac{620.4MPa}{196.1MPa} = 3.16 \quad (4)$$

This safety factor has achieved our expected results.

Name	Type	Min	Max
Stress1	VON: von Mises Stress	3.121e-15 N/mm^2 (MPa) Node: 3222	1.961e+02 N/mm^2 (MPa) Node: 23597



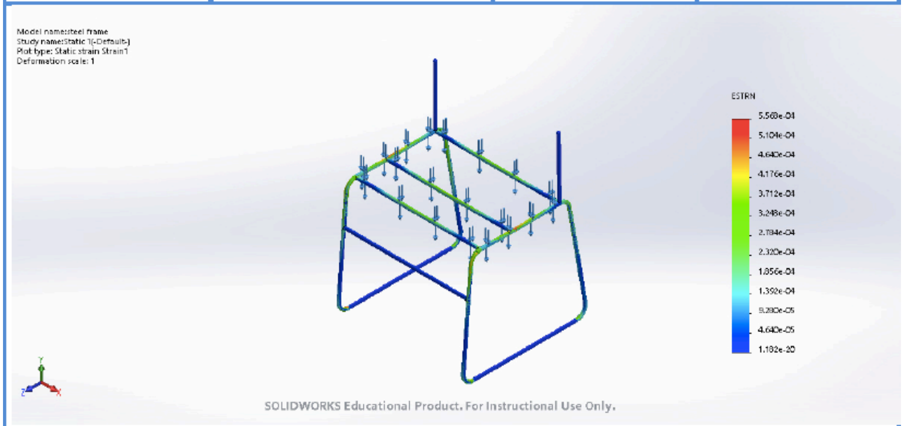
steel frame-Static 1-Stress-Stress1

Figure 9. Stress result of design

Strain result

The maximum strain is on the place where horizontal and vertical seat frames intersect each other. The magnitude of maximum strain is around 0.05% which is totally acceptable for a alloy steel.

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	1.182e-20 Element: 3076	5.568e-04 Element: 6505



steel frame-Static 1-Strain-Strain1

Figure 10. Stain result of design

Conclusion

The final selected material for this project is alloy steel which has highest cost-performance ratio. The safety factor of alloy steel is 3.16 and the maximum strain is 0.05% which has achieved our expected well. The scrap alloy steel also be recyclable and reused again which can save a lot resources and protect environments. However, with the advancement of science and the simplification of manufacturing process in the future, carbon fiber composites maybe recyclable and the price of them may decrease. At that time, carbon fiber composites can also be a good choice for the chair frame because of their high performances.

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