Composites Design Project Report

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Introduction

For this project, our task was to design a composite sandwich structure for use in an electric vertical take-off and landing aircraft. Specifically, we designed a portion of the wing, with dimensions 0.15m wide and 1m long. It was given that this structure was subject to a F_x = 50 kN, F_y = 50 kN, and N_{xy} = 50 kN*m. The design safety factor was 1.5. Figure 1 below shows this structure with loads applied.

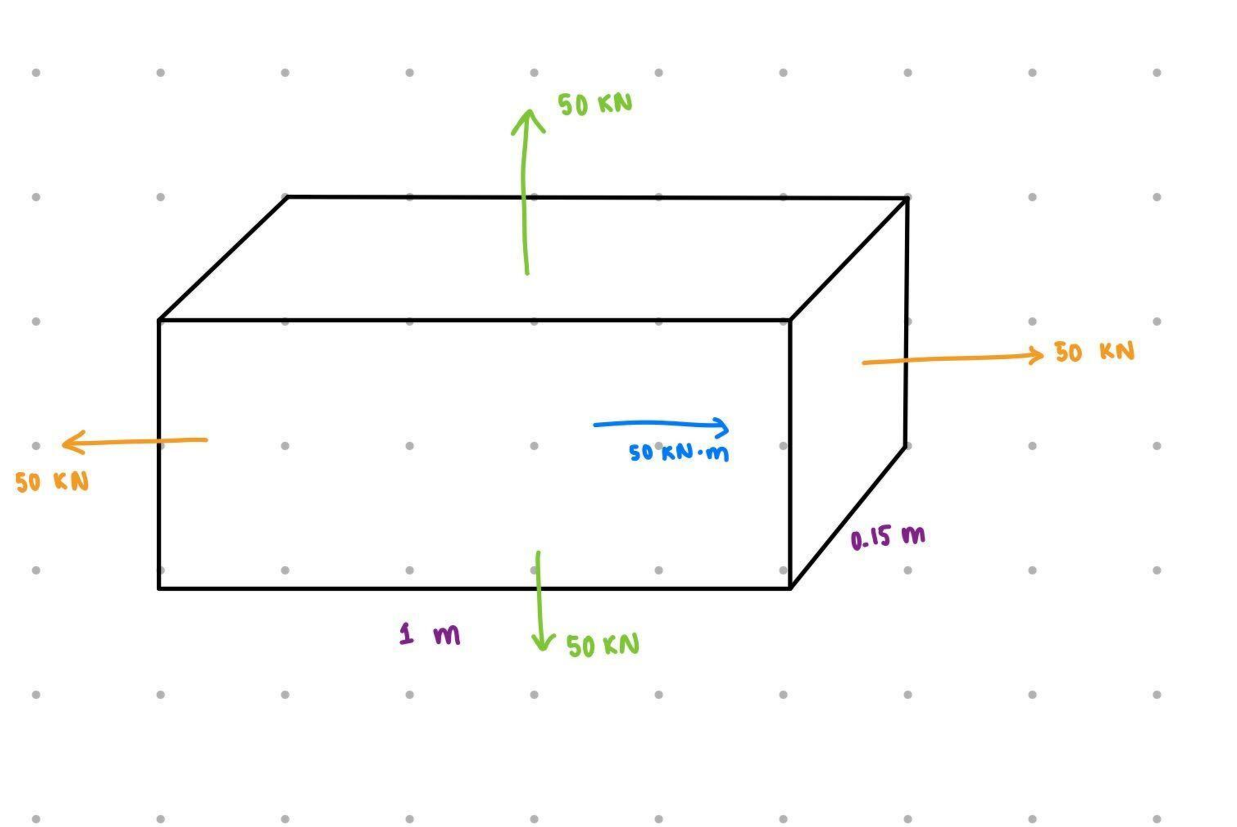

Figure 1: Applied Loads on Wing

Design Methodology

To determine which structure would be the best for our application, we computed the required number of plies, laminate thickness, weight, and cost for each of our stacking sequences and each material. The composite materials used were S-glass/Epoxy, Kevlar(Aramid49)/Epoxy, and Carbon(IM7)/Epoxy. We also compared these to aluminum, to determine whether that was a better option instead of the composites.

The stacking sequences we chose were $[0_m/90_n]_s$, $[+-\theta]_{ns}$, $[90/+-\theta]_{ns}$, and $[0/+-\theta]_{ns}$, as shown in Table 1 below. In choosing these stacking sequences, we referenced best practices for designing composites, such as trying to use balance and symmetry, stacking +/- θ plies in pairs, and avoiding stacking many plies at one angle. These design practices helped to minimize bending and twisting effects, better handle shear loads, and reduce residual stresses.

Table 1: Stacking Sequences and Materials Used

Stacking Sequence	**Material**
$[0_m/90_n]_s$	S-glass/Epoxy
$[0_m/90_n]_s$	Kevlar(Aramid49)/Epoxy
$[0_m/90_n]_s$	Carbon(IM7)/Epoxy
$[+-\theta]_{ns}$	S-glass/Epoxy
$[+-\theta]_{ns}$	Kevlar(Aramid49)/Epoxy
$[+-\theta]_{ns}$	Carbon(IM7)/Epoxy
$[90/+-\theta]_{ns}$	S-glass/Epoxy
$[90/+-\theta]_{ns}$	Kevlar(Aramid49)/Epoxy
$[90/+-\theta]_{ns}$	Carbon(IM7)/Epoxy
$[0/+-\theta]_{ns}$	S-glass/Epoxy
$[0/+-\theta]_{ns}$	Kevlar(Aramid49)/Epoxy
$[0/+-\theta]_{ns}$	Carbon(IM7)/Epoxy

To determine the optimal layup for each of the stacking sequences and materials, we ran a CLT code which took into account material properties, loads, and our required safety factor (of 1.5). We used ply thicknesses for each sequence as given in the textbook tables. The code then calculated the Tsai-Wu safety factors for each stacking sequence, and appended the sequence based on whether the safety factor was at least 1.5. Once that criterion was satisfied, the code output the required m and n values for the optimal layup, and computed that laminate's thickness, weight, and cost.

The failure criteria we chose to use was Tsai-Wu, because it is an interactive failure theory that most accurately captures the failure envelope, as compared to other theories like Maximum Strain and Tsai-Hill. Figure 2 below shows this comparison. Note that the Tsai-Wu criteria encompass more of the experimental points than the other theories.

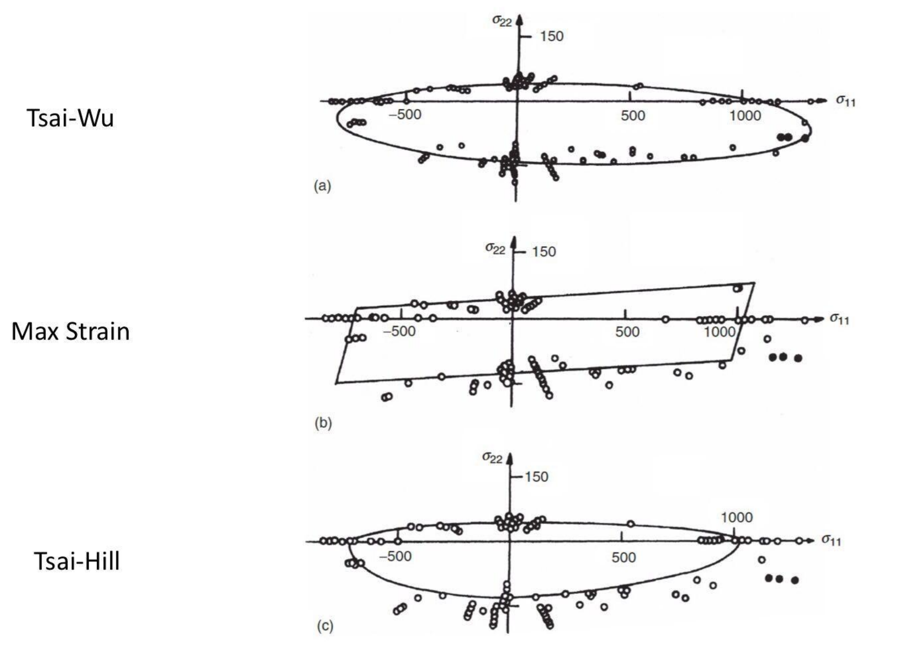

Figure 2: Comparison of Tsai-Wu and other failure theories

Results

As mentioned previously and shown in Tables 2-7 below, we computed the number of required plies, laminate thickness, weight, and cost for each stacking sequence.

Table 2: Results for $[0_m/90_n]_s$ stacking sequence

$[0_m/90_n]_s$	**Material**	**S-Glass**	**Kevlar**	**Carbon**
	Ply Thickness (mm)	0.165	0.127	0.127
	m	24	39	25
	n	1	2	2
	Safety Factor	1.50896	1.5149	1.5135
	Optimum Layup	$[0_{24}/90_1]$	$[0_{39}/90_2]$	$[0_{25}/90_2]$
	Laminate Thickness (mm)	8.25	10.414	6.858
	Weight (kg)	2.475	2.1557	1.656
	Cost ($)	24.75	75.4495	99.36

Table 3: Results for [+-θ]$_{ns}$ stacking sequence

[+-θ]$_{ns}$	**Material**	**S-Glass**	**Kevlar**	**Carbon**
	Ply Thickness (mm)	0.165	0.127	0.127
	n	9	14	4
	Theta	31	45	28
	Safety Factor	1.608	1.58	1.609
	Density (kg/m^3)	2000	1380	1610
	Optimum Layup	[+-31]$_{9s}$	[+-45]$_{14s}$	[+-28]$_{4s}$
	Laminate Thickness (mm)	5.94	7.112	2.032
	Weight (kg)	1.782	1.4722	0.49073
	Cost ($)	17.82	51.527	29.4438

Table 4: Results for [90/+-θ]$_{ns}$ stacking sequence

[90/+-θ]$_{ns}$	**Material**	**S-Glass**	**Kevlar**	**Carbon**
	Ply Thickness (mm)	0.165	0.127	0.127
	n	8	10	4
	Theta	29	43	33
	Safety Factor	1.626	1.606	1.969
	Density (kg/m^3)	2000	1380	1610
	Optimum Layup	[90/+-29]$_{8s}$	[90/+-43]$_{10s}$	[90/+-33]$_{4s}$
	Laminate Thickness (mm)	7.92	7.62	3.048
	Weight (kg)	2.376	1.577	0.7361
	Cost ($)	23.76	55.195	44.166

Table 5: Results for $[0/\pm\theta]_{ns}$ stacking sequence

$[0/+-\theta]_{ns}$	**Material**	**S-Glass**	**Kevlar**	**Carbon**
	Ply Thickness (mm)	0.165	0.127	0.127
	n	7	9	3
	Theta	34	45	43
	Safety Factor	1.55	1.686	1.827
	Density (kg/m^3)	2000	1380	1610
	Optimum Layup	$[0/+-34]_{7s}$	$[0/+-45]_{9s}$	$[0/+-43]_{3s}$
	Laminate Thickness (mm)	6.93	6.858	2.286
	Weight (kg)	2.079	1.42	0.5521
	Cost ($)	20.79	49.7	33.126

Table 6: Results for $[0/+-45/90]_{ns}$ stacking sequence

$[0/+-45/90]_{ns}$	**Material**	**S-Glass**	**Kevlar**	**Carbon**
	Ply Thickness (mm)	0.165	0.127	0.127
	n	7	8	3
	Safety Factor	1.63	1.58	1.951
	Density (kg/m^3)	2000	1380	1610
	Optimum Layup	$[0/+-45/90]_{7s}$	$[0/+-45/90]_{8s}$	$[0/+-45/90]_{3s}$
	Laminate Thickness (mm)	9.24	8.13	3.05
	Weight (kg)	2.77	1.68	0.7361
	Cost ($)	27.7	58.8	44.166

Table 7: Results for Aluminum

Aluminum	
Yield Strength	242 MPa
Thickness	4.066 mm
Weight	1.708 kg
Cost	$4.27

A visual representation of the information above is shown below. Figures 3 and 4 compare the weight and cost for each material and stacking sequence.

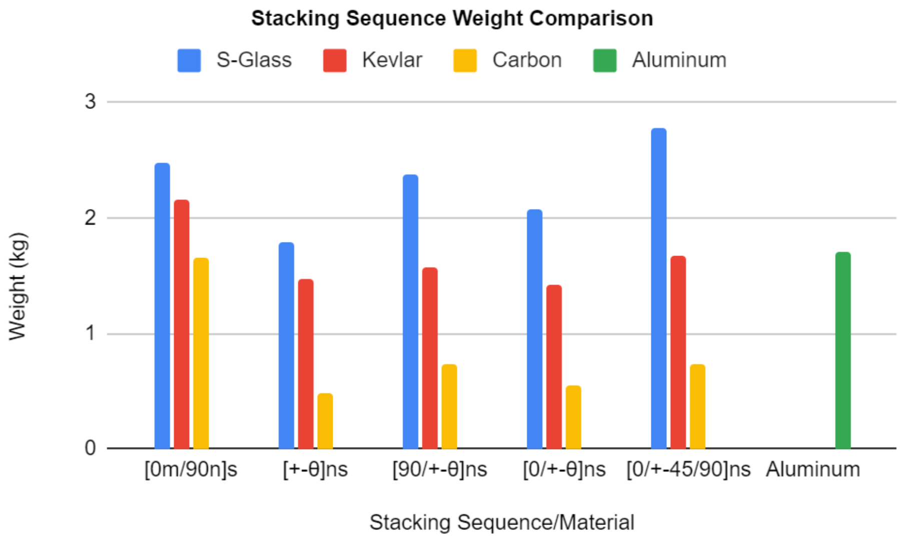

Figure 3: Weight Comparison for each Stacking Sequence

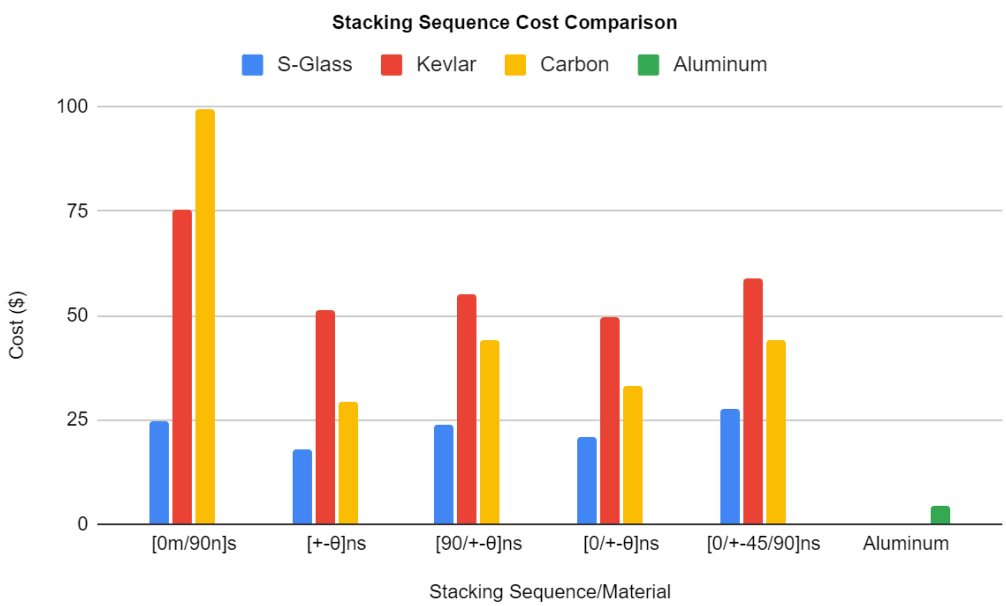

Figure 4: Cost Comparison for each Stacking Sequence

Discussions

Based on the results above, we can see that the Carbon(IM7)/Epoxy material with stacking sequence $[\pm 28]_{4s}$ is the best choice in terms of weight, with a weight of 0.49703 kg. However, based on cost, the S-glass/Epoxy was the best, with a $[\pm 31]_{9s}$ stacking sequence and $17.82. There were also some materials which were not good options. For example, the S-glass/Epoxy $[0/\pm 45/90]_{7s}$ sequence had a very high weight, at 2.77kg. For cost, the worst option was the Carbon(IM7)/Epoxy material, with stacking sequence $[0_{25}/90_2]$. This had a cost of $99.36. Compared with the aluminum option, we can see that the weight of aluminum is comparable with the majority of the composite structures, at 1.708 kg. However, the aluminum option is significantly cheaper than all the composites, at $4.27.

Therefore, the ultimate design decision would depend on whether we view cost or weight as a larger factor. Since this is for an aerospace application and the design criterion states that structural weight should be minimized, we can assume that low weight is more important than low cost, which makes the Carbon(IM7)/Epoxy with stacking sequence $[\pm 28]_{4s}$ the best option.

FEA Analysis

We also used ANSYS to do FEA of our leading designs. These were the Carbon(IM7)/Epoxy $[\pm 28]_{4s}$, Kevlar(Aramid49)/Epoxy $[0/\pm 45]_{9s}$, and S-glass $[\pm 31]_{9s}$, and the aluminum option. As shown in Figures 5-7 below, our maximum safety factors are 5.3914 for carbon fiber, 14.276 for Kevlar, 10.565 for S-glass, and 15 for aluminum.

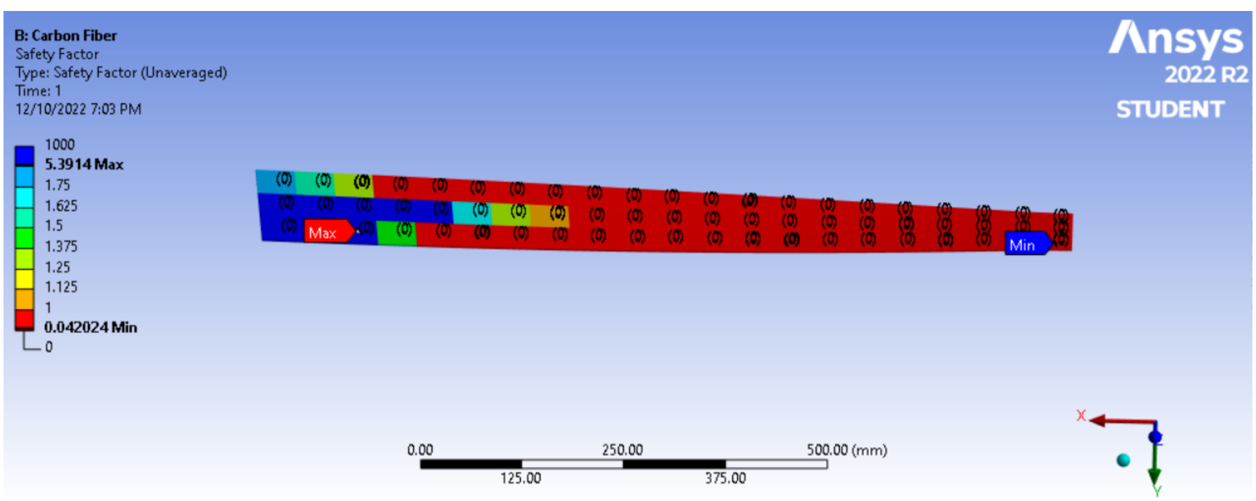

Figure 5: ANSYS Result for Carbon Fiber $[\pm 28]_{4s}$

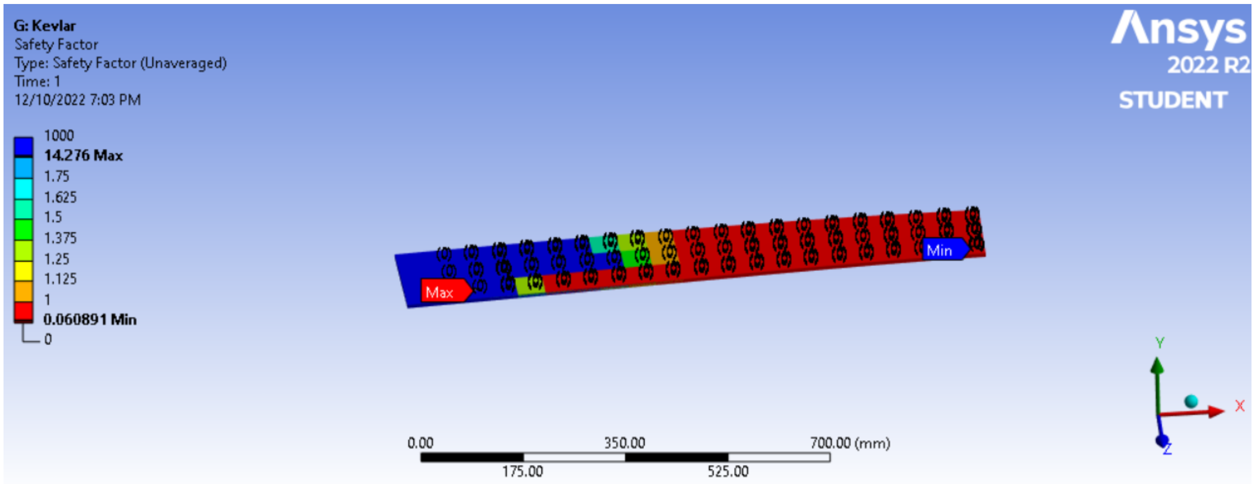

Figure 6: ANSYS Result for Kevlar [0/+-45]$_{9s}$

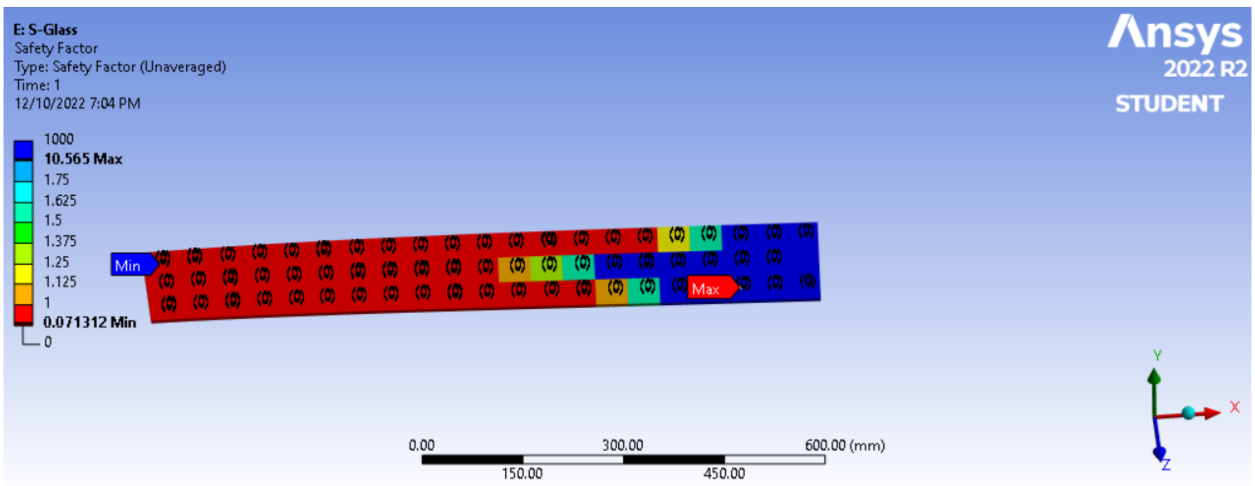

Figure 7: ANSYS Result for S-glass [+-31]$_{9s}$

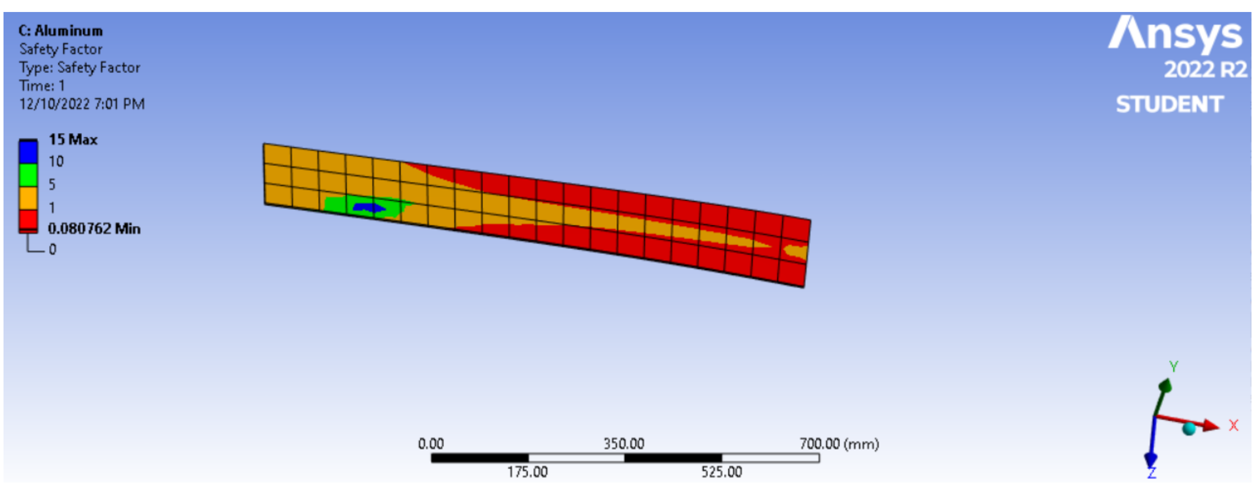

Figure 8: ANSYS Result for Aluminum

References

Daniel, I. M., & Ishai, O. (2006). *Engineering mechanics of Composite Materials* (2nd ed.). Oxford University Press.