CAE Simulation #6	**Heat Transfer and Thermal Stress (Turbine Blade)**	*21900416 Gyeonheal An*

1. Introduction

In this simulation report, we analyze the deformation and stress concentrated on a turbine blade(1/4) due to heat, convection, and radiative heat using Ansys. Furthermore, we investigate variations in heat distribution based on different materials and compare the maximum stress based on heat coefficients. Additionally, we compare the results between transient heat transfer conditions and steady-state thermal situations for the turbine blade.

2. Geometry Design (DesignModeler)

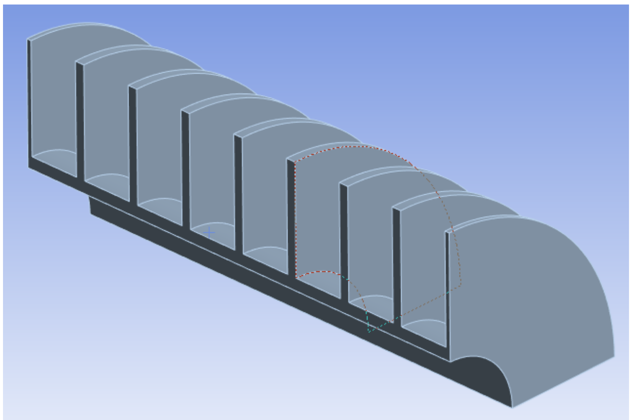


Figure 1. Model of Turbine Blade

3. Material (Aluminum Alloy)

Properties of Outline Row 3: Aluminum Alloy

	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variables	Table			
3	Density	2770	kg m^-3		
4	Isotropic Secant Coefficient of Thermal Expansion				
6	Isotropic Elasticity				
7	Derive from	Young's Modulus and Poisson...			
8	Young's Modulus	7.1E+10	Pa		
9	Poisson's Ratio	0.33			
10	Bulk Modulus	6.9608E+10	Pa		
11	Shear Modulus	2.6692E+10	Pa		
12	S-N Curve	Tabular			
13	Interpolation	Semi-Log			
14	Scale	1			
15	Offset	0	Pa		
16	Tensile Yield Strength	2.8E+08	Pa		
17	Compressive Yield Strength	2.8E+08	Pa		
18	Tensile Ultimate Strength	3.1E+08	Pa		
19	Compressive Ultimate Strength	0	Pa		
20	Isotropic Thermal Conductivity	Tabular			

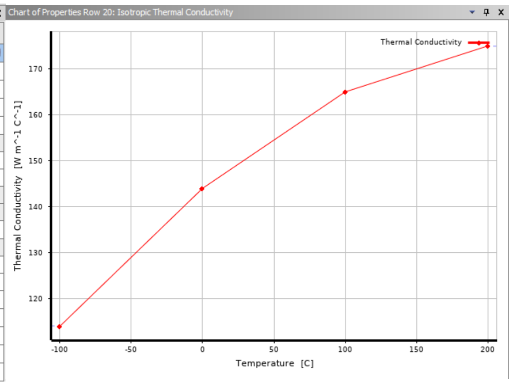


Table 1. Material Properties

4. Experimental Condition

Used Material	Aluminum Alloy	
Mesh	Multizone(Hexa), 2mm	
Thermal Conditions	Convection	$30°, \mathit{Tabular\ Data}$
	Radiation	30°, 1 emissivity
	Temperature	$200 - 0.25 \times y$
Solution	Temperature	
	Total Deformation	
	Equivalent Stress	

Table 2. Simulation Conditions

5. Boundary Conditions & Load Conditions

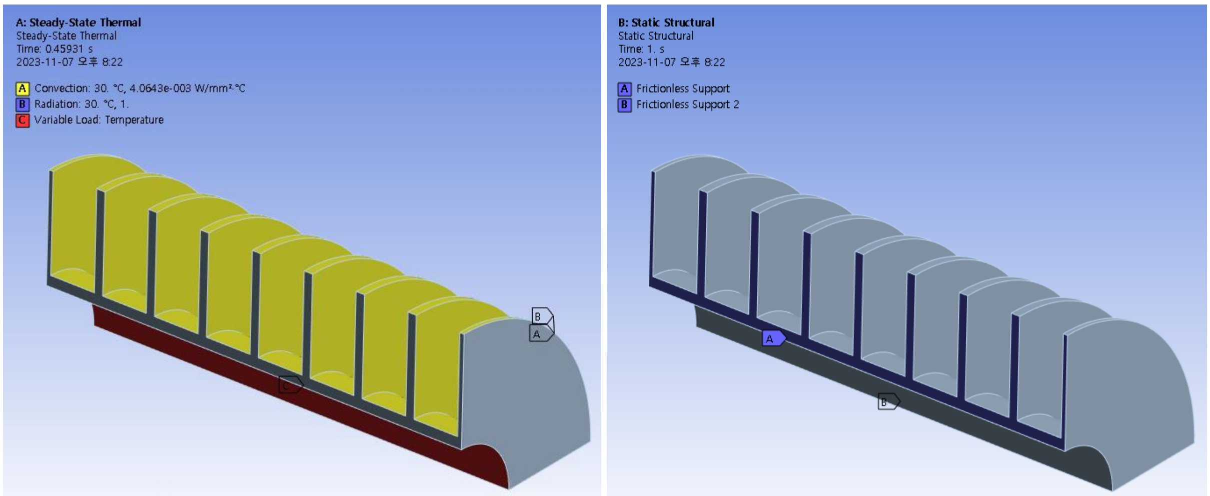


Figure 2. Thermal Conditions and Boundary Conditions

6. Result of Symmetry Model

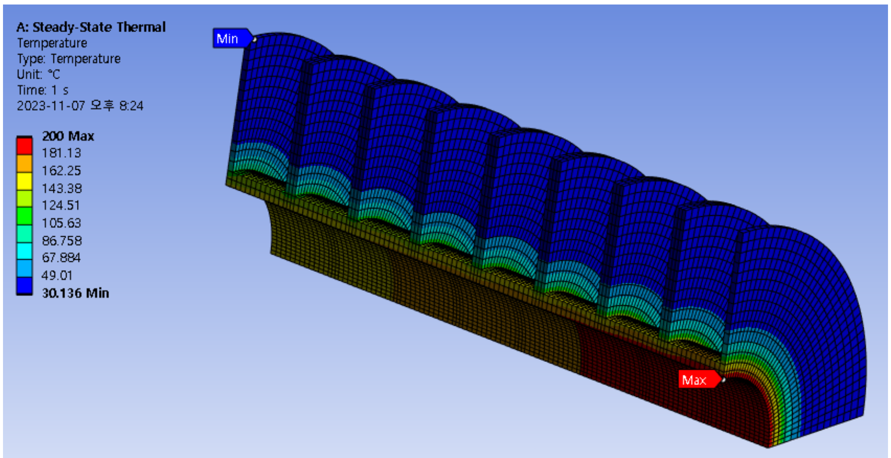


Figure 3. Temperature (Aluminum Alloy)

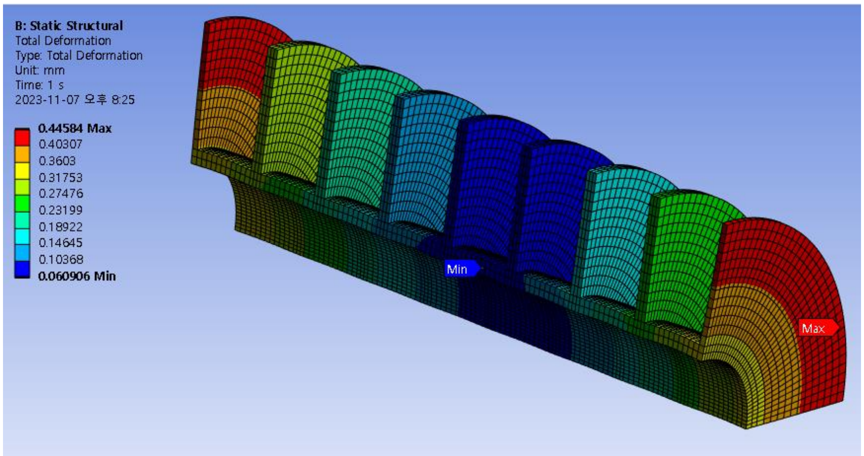


Figure 4. Total Deformation (Aluminum Alloy)

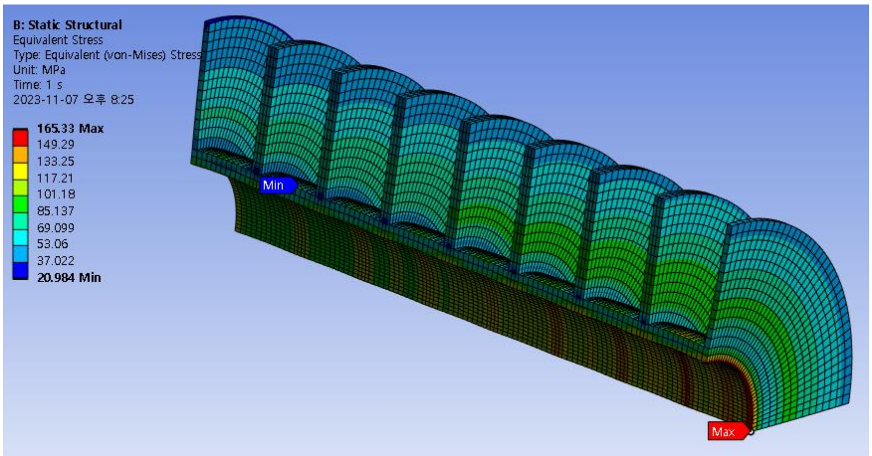


Figure 5. Equivalent Stress (Aluminum Alloy)

8. Analysis

① **Change material from aluminum alloy to structural steel.**
Explain differences in the temperature distribution and maximum stress with values of thermal conductivity(k), thermal expansion coef.(α), and elastic modulus(E).

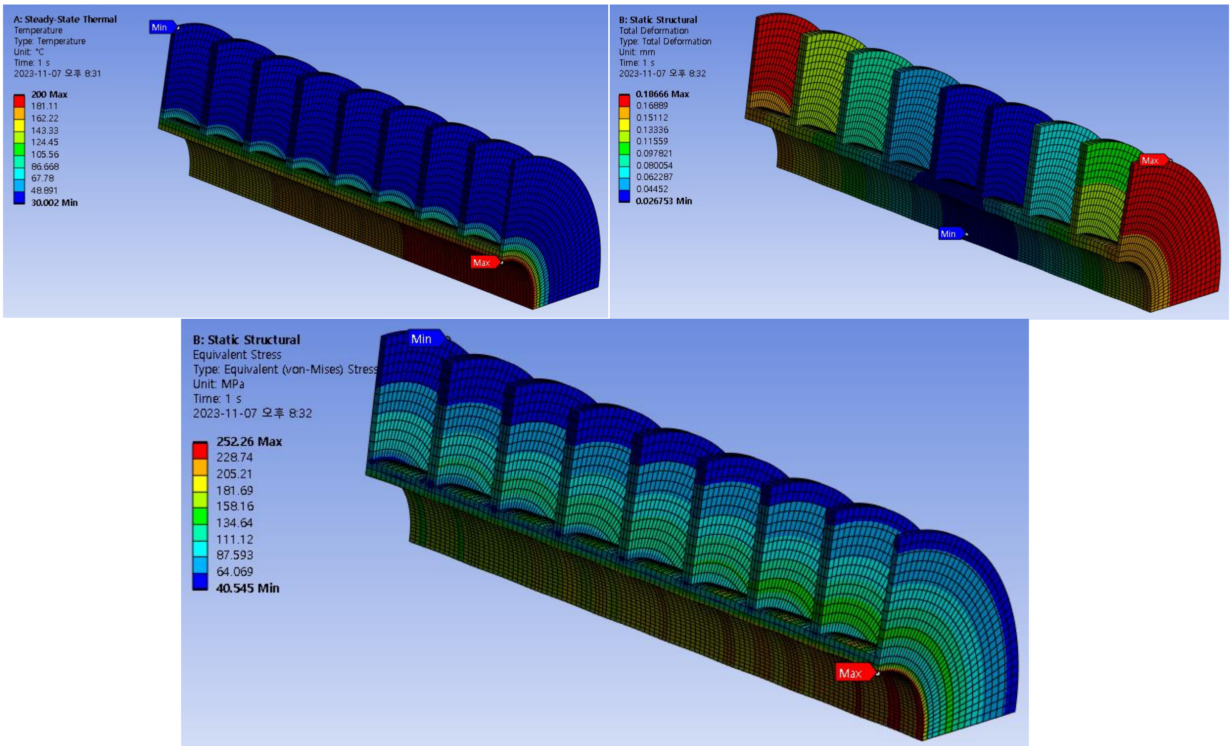


Figure 6. Ansys Simulation Results (Structural Steel)

Solutions	Equivalent Stress [Mpa]		Temperature [$c°$]		Total Deformation[mm]	
	Max	Min	Max	Min	Max	Min
Aluminum Alloy	165.33	20.984	200	30.136	0.446	0.061
Structural Steel	252.26	40.545	200	30.002	0.187	0.027

Table 3. Simulation Results

Material Property	Structural Steel	Aluminum Alloy
Thermal expansion coefficient (α)	1.2×10^{-5} °C^{-1}	2.3×10^{-5} °C^{-1}
Thermal conductivity (k)	60.5 W. m^{-1}. °C^{-1}	Temperature dependent
Elastic Modulus (E)	200 [Gpa]	71 [Gpa]

Table 4. Thermal Coefficients

Conduction formula is below,

$$\frac{\partial q}{\partial x} = k\frac{dT}{dx}$$

The thermal conductivity values for Structural Steel and Aluminum Alloy are as shown in Table 4. According to Table 1, Aluminum Alloy exhibits a thermal conductivity that varies between 114 and 175 depending on temperature, which means it conducts heat more rapidly and disperses it more efficiently compared to Structural Steel.

The stress with temperature variation is as follows:

$$\Delta L = \alpha L \Delta T$$

$$\sigma = E\varepsilon = E\alpha\Delta T$$

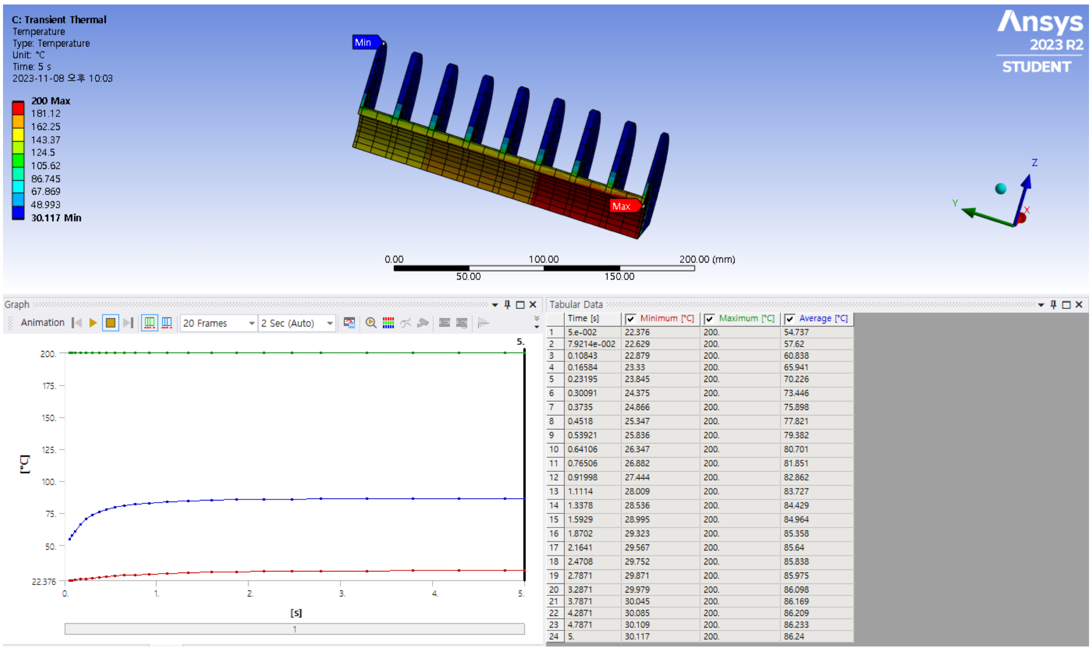
For both Structural Steel and Aluminum Alloy, the coefficients of thermal expansion (α) and Elastic Modulus are as listed in Table 4. When we substitute these values into the equations mentioned above, we arrive at the following conclusions:

$$\sigma_{steel} = 200 \times 10^9 \times 1.2 \times 10^{-5} \times \Delta T = 2.4 \times \Delta T \ [Mpa]$$

$$\sigma_{al} = 71 \times 10^9 \times 2.3 \times 10^{-5} \times \Delta T = 1.633 \times \Delta T \ [Mpa]$$

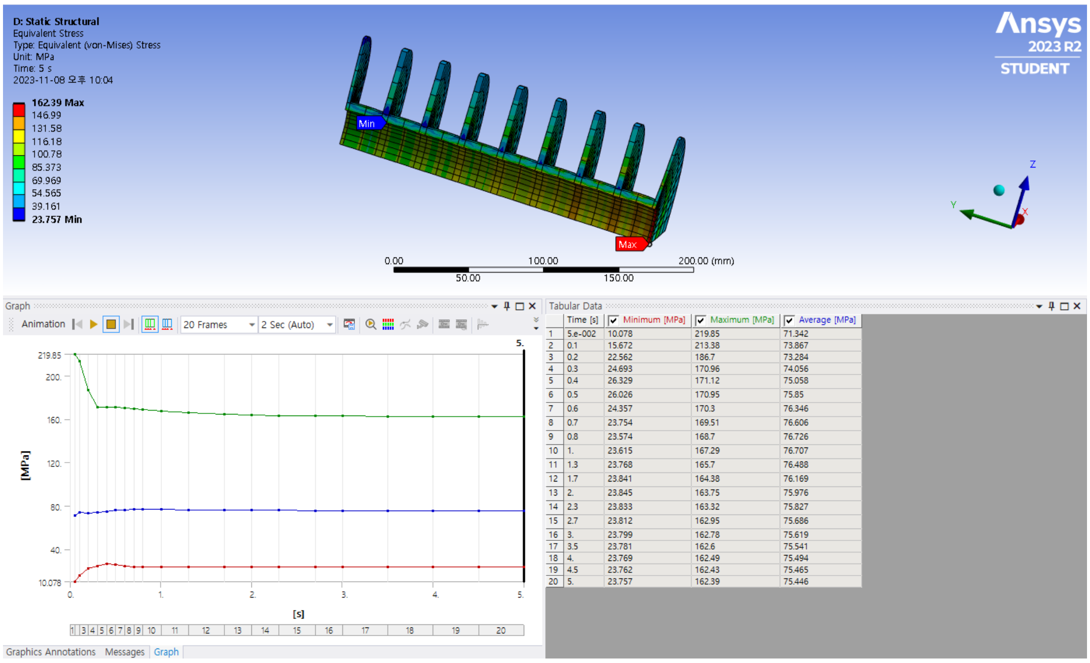
Hence, it can be determined that the stress induced by heat is greater when the material is Structural Steel as compared to Aluminum Alloy. This observation is consistent with the results presented in the simulation data in Table 3.

② **Try a transient heat transfer (initial temperature of 22°C) and transient structural analysis. Discuss on the difference between the steady and transient analysis.**



	Time [s]	Minimum [°C]	Maximum [°C]	Average [°C]
1	5.e-002	22.376	200.	54.737
2	7.9214e-002	22.629	200.	57.62
3	0.10843	22.879	200.	60.838
4	0.16584	23.33	200.	65.941
5	0.23195	23.845	200.	70.226
6	0.30091	24.375	200.	73.446
7	0.3735	24.866	200.	75.898
8	0.4518	25.347	200.	77.821
9	0.53921	25.836	200.	79.382
10	0.64106	26.347	200.	80.701
11	0.76506	26.882	200.	81.851
12	0.91998	27.444	200.	82.862
13	1.1114	28.009	200.	83.727
14	1.3378	28.536	200.	84.429
15	1.5929	28.995	200.	84.964
16	1.8702	29.323	200.	85.358
17	2.1641	29.567	200.	85.64
18	2.4708	29.752	200.	85.838
19	2.7871	29.871	200.	85.975
20	3.2871	29.979	200.	86.098
21	3.7871	30.045	200.	86.169
22	4.2871	30.085	200.	86.209
23	4.7871	30.109	200.	86.233
24	5.	30.117	200.	86.24

Figure 7. Transient Thermal Temperature (Aluminum Alloy)



	Time [s]	Minimum [MPa]	Maximum [MPa]	Average [MPa]
1	5.e-002	10.078	219.85	71.342
2	0.1	15.672	213.38	73.867
3	0.2	22.562	186.7	73.284
4	0.3	24.693	170.96	74.056
5	0.4	26.329	171.12	75.058
6	0.5	26.026	170.95	75.85
7	0.6	24.357	170.3	76.346
8	0.7	23.754	169.51	76.606
9	0.8	23.574	168.7	76.726
10	1.	23.615	167.29	76.707
11	1.3	23.768	165.7	76.488
12	1.7	23.841	164.38	76.169
13	2.	23.845	163.75	75.976
14	2.3	23.833	163.32	75.827
15	2.7	23.812	162.95	75.686
16	3.	23.799	162.78	75.619
17	3.5	23.781	162.6	75.541
18	4.	23.769	162.49	75.494
19	4.5	23.762	162.43	75.465
20	5.	23.757	162.39	75.446

Figure 8. Transient Thermal Equivalent Stress (Aluminum Alloy)

Transient Thermal Analysis

- Transient thermal analysis models the changes in temperature and heat distribution over time.
- This method is useful for situations where temperature changes occur over time, such as when an initial temperature distribution is given, and the changes in temperature due to heat transfer and storage need to be tracked over time.
- It can account for the effects of time-dependent heat transfer and heat storage and model both long-term and short-term thermal variations.

Steady-State Thermal Analysis

- Steady-state thermal analysis examines the temperature distribution resulting from given conditions where the temperature distribution no longer changes.
- This approach models the state where the temperature has stabilized over time, and the temperature and heat distribution remain constant.
- It is primarily used for evaluating thermal designs and performance after a system has reached a stable temperature state.

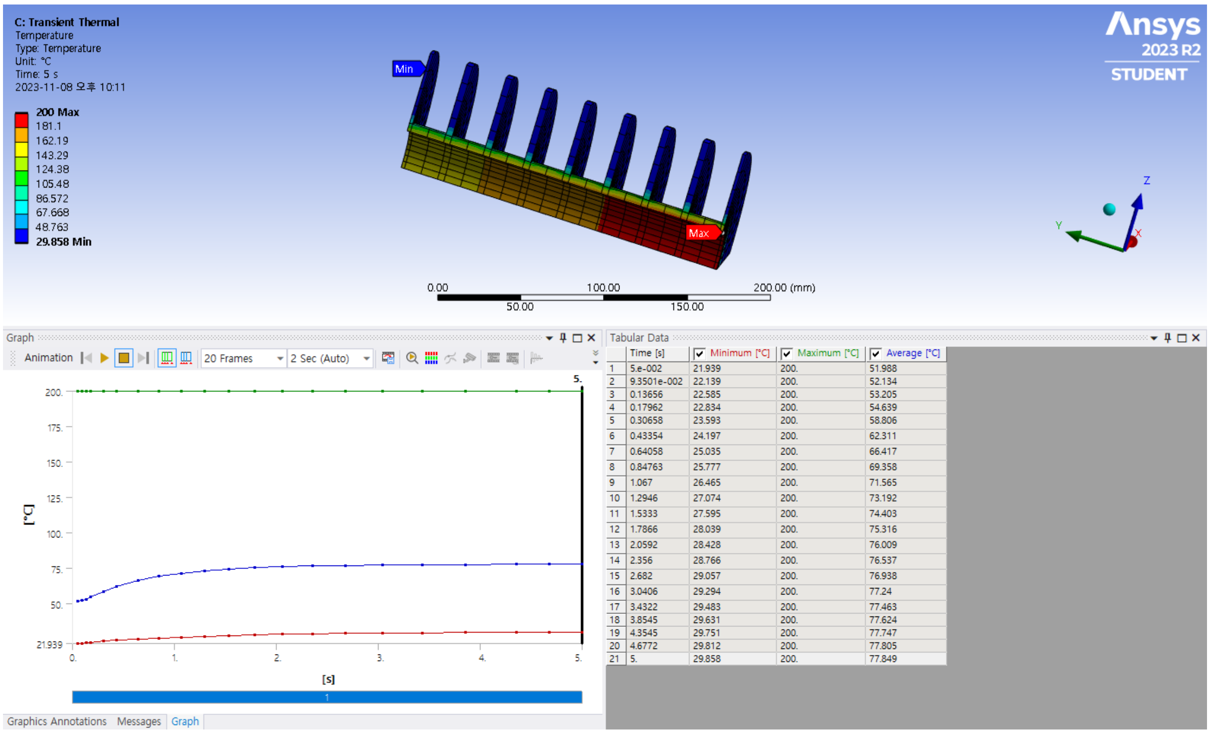


Figure 9. Transient Thermal Temperature (Structural Steel)

As evident from the above figure, it can be observed that Aluminum Alloy, which has higher thermal conductivity, exhibits a faster temperature convergence rate compared to Structural Steel.