Numerical Simulation of a Composite Rod with ANSYS (1. Ansysaufgabe)

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1. Introduction

This report presents a numerical simulation study of a composite rod using ANSYS Workbench. The rod has a total length of 1.20 m and a square cross-section of 10 mm $\times$ 10 mm. It is divided into four equal segments (each 0.3 m), made of different materials: Bronze, Copper, Steel, and Aluminum.

2. Simulation Setup

Geometry and Materials

The rod consists of four segments:

- Bronze (0.3 m)
- Copper (0.3 m)
- Steel (0.3 m)
- Aluminum (0.3 m)

Material properties were defined using the thermal material database in ANSYS.

Boundary Conditions

Two types of boundary conditions were considered:

- **Case 1 (Fixed Temperatures):** Left end at 10 °C, right end at 100 °C.

- **Case 2 (Convection):** Left end exposed to ambient temperature of 10 °C, right end to 100 °C, with heat transfer coefficient α varied as 5, 25, 50, 75, and 100 W/(m²·K).

3. Results

Case 1: Fixed Temperatures

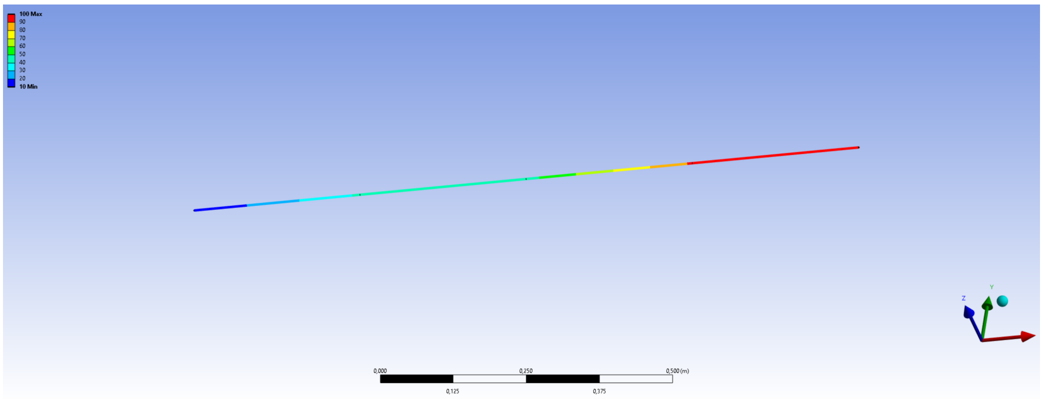


Figure 1: Temperature distribution in the 1D rod model with fixed temperatures.

The 1D simulation shows a continuous temperature gradient from 10 °C to 100 °C, with distinct slope changes at material interfaces due to differences in thermal conductivity.

	Zeit [s]	Brone-Kupfer-Grenztemperatur [°C]
1	1,	41,56

	Zeit [s]	Kupfer-Stahl-Grenztemperatur [°C]
1	1,	46,61

	Zeit [s]	Stahl-Aluminimum-Grenztemperatur [°C]
1	1,	91,495

Figure 2: Interface temperatures in the 1D model.

The interface temperatures obtained are:

- Bronze–Copper: 41.56 °C
- Copper–Steel: 46.61 °C
- Steel–Aluminum: 91.495 °C

Tabellarische Daten

	Zeit [s]	Minimum [°C]	Maximum [°C]	Mittelwert [°C]
1	1,	10,	100,	57,933

Figure 3: Minimum, maximum, and mean temperatures (1D model).

The 3D model shows similar overall behavior, confirming the 1D results.

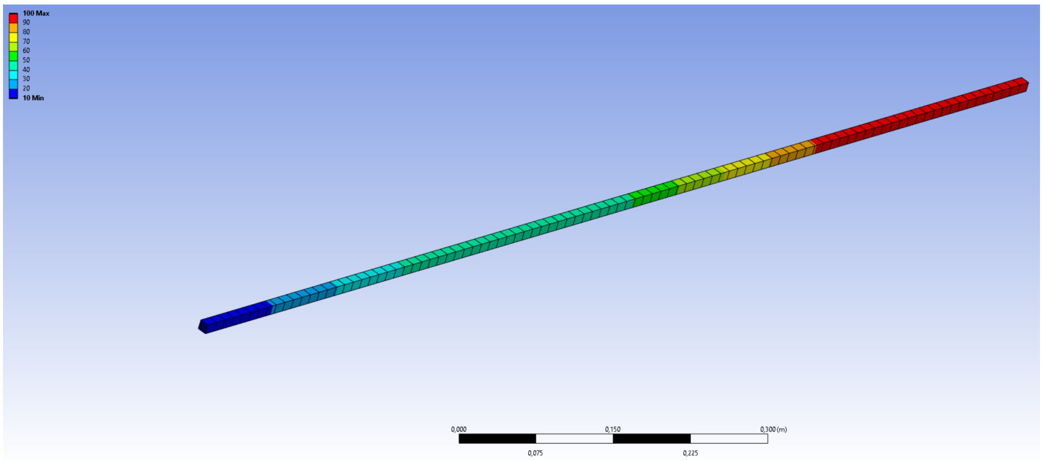


Figure 4: Temperature distribution in the 3D model with fixed temperatures.

	Zeit [s]	Bronze-Kupfer-Grenztemperatur [°C]
1	1,	41,56

	Zeit [s]	Kupfer-Stahl-Grenztemperatur [°C]
1	1,	46,61

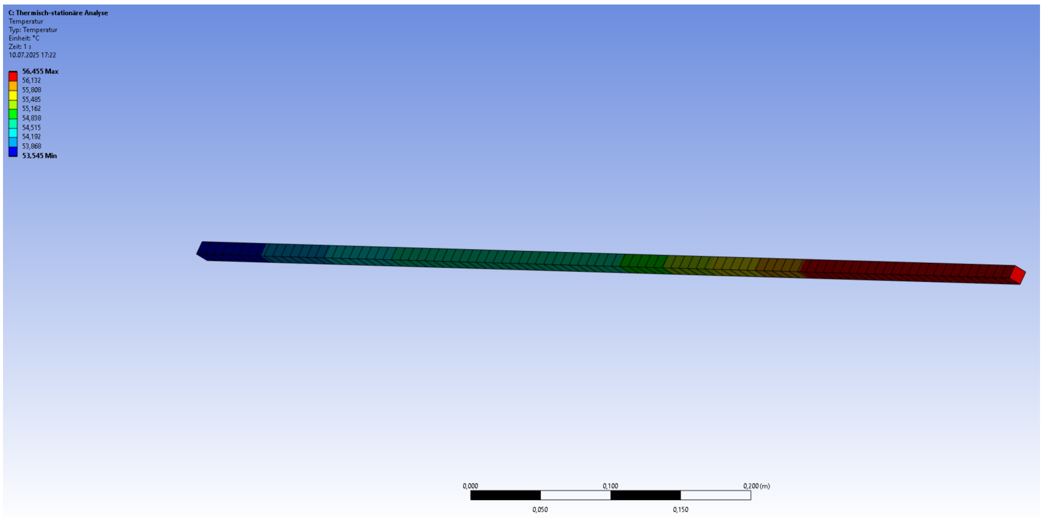
	Zeit [s]	Stahl-Aluminium-Grenztemperatur [°C]
1	1,	91,495

Figure 5: Interface temperatures in the 3D model.

	Zeit [s]	Minimum [°C]	Maximum [°C]	Mittelwert [°C]
1	1,	10,	100,	58,641

Figure 6: Minimum, maximum, and mean temperatures (3D model).

Case 2: Convection



	Zeit [s]	Minimum [°C]	Maximum [°C]	Mittelwert [°C]
1	1,	53,545	56,455	55,118

Figure 7: Detailed result for $\alpha = 5$ W/(m²·K): (Top) temperature distribution, (Bottom) min, max, and mean temperatures.

Übersicht von Alle Parameter

	A	B	C	D
1	ID	Parametername	Wert	Einheit
2	Eingabeparameter			
3	Thermisch-stationäre Analyse (C1)			
4	P3	Konvektion Wärmeübergangskoeffizient	5	W m^-2 C^-1
5	P4	Konvektion 2 Wärmeübergangskoeffizient	5	W m^-2 C^-1
*	Neuer Eingabeparameter	Neuer Name	Neuer Ausdruck	
7	Ausgabeparameter			
8	Thermisch-stationäre Analyse (C1)			
9	P1	Temperatur Minimum	53,545	C
10	P2	Temperatur Maximum	56,455	C
*	Neuer Ausgabeparameter		Neuer Ausdruck	
12	Diagramme			

Tabelle von Design Points

	A	B	C	D	E	F	G	H
1	Name	P3 - Konvektion Wärmeübergangskoeffizient	P4 - Konvektion 2 Wärmeübergangskoeffizient	P1 - Temperatur Minimum	P2 - Temperatur Maximum	Beh...	Beibehaltene Daten	Hinweis
2	Einheit	W m^-2 C^-1	W m^-2 C^-1	C	C			
3	DP 0 (aktuell)	5	5	53,545	56,455	☑	✓	
4	DP 2	25	25	48,557	61,443	☐		
5	DP 3	50	50	43,729	66,271	☐		
6	DP 4	75	75	39,975	70,025	☐		
7	DP 1	100	100	36,972	73,028	☐		
*						☐		

Figure 8: Overview of heat transfer coefficients and corresponding results.

Table summarizing the minimum and maximum temperatures for different α values:

Table 1: Minimum and maximum temperatures for each heat transfer coefficient α.

α [W/(m²·K)]	Minimum [°C]	Maximum [°C]
5	53.545	56.455
25	48.557	61.443
50	43.729	66.271
75	39.975	70.025
100	36.972	73.028

4. Physical Interpretation

Case 1 uses fixed temperature boundary conditions, where the ends are strictly maintained at 10 °C and 100 °C, creating a stable and enforced temperature gradient along the rod. In contrast, Case 2 employs convection boundary conditions, exposing the ends to ambient temperatures of 10 °C and 100 °C. Here, the actual end temperatures depend on the heat transfer coefficient , which determines how effectively the rod exchanges heat with the environment. As a result, the temperature distribution in Case 2 is influenced both by material properties and the convection strength, leading to different gradient profiles compared to Case 1.

In Case 1, within each material segment, the gradient is constant due to uniform thermal conductivity, but the gradient changes at the interfaces because of different conductivities. Copper and aluminum, having higher thermal conductivities, transfer heat more easily, resulting in smaller temperature differences within these segments. Bronze and steel segments have low thermal conductivities. As a result, the temperatures near the ends partially follow the boundary conditions, but inside the segments, heat transfer is less effective and temperature variations are smaller, leading to a larger overall temperature difference within these segments.

Additionally, the mean (Mittelwert) temperatures obtained from the 1D and 3D models are slightly different. This is because the 1D model only looks at heat conduction along the rod's length, while the 3D model takes into account the real shape and possible small surface effects. As a result, there are slight differences in the overall temperature distribution and mean temperature.

In Case 2, as α increases, the ends of the rod become more strongly coupled to the ambient temperatures. With low α, heat exchange is inefficient, and the rod retains more uniform internal temperatures. As α rises, the temperatures at the ends approach the ambient values (10 °C and 100 °C), leading to a steeper overall temperature gradient.

5. Conclusion

This study illustrates the strong influence of material properties and boundary conditions on thermal behavior. The simulation results highlight how interface temperatures and gradients depend on thermal conductivities and how varying the heat transfer coefficient affects the interaction with the environment.