

**LAMPIRAN A**  
**CONTOH PERHITUNGAN**

## Lampiran A. Contoh Perhitungan

### A.1 Perhitungan kriteria

$$hL/k \leq 0,1$$

$$0,5 \cdot 1,5 / 45 \leq 0,1$$

$$0,0167 \leq 0,1$$

### A. 2 Perhitungan Entalpi Reaksi

- Pembentukan  $\text{Al}_2\text{O}_3$

$$\Delta H = \Delta G + T \Delta S$$

- a) Temperatur  $750^\circ\text{C}$

$$\Delta H = -1353,325\text{kJ} + (1023\text{ K} - 332,408\text{ J/K})$$

$$\Delta H = -1693,428\text{ kJ}$$

- b) Temperatur  $850^\circ\text{C}$

$$\Delta H = -1320,130\text{ kJ} + (1123\text{ K} - 331,486\text{ J/K})$$

$$\Delta H = -1692,438\text{ kJ}$$

- c) Temperatur  $950^\circ\text{C}$

$$\Delta H = -1287,028\text{ kJ} + (1223\text{ K} - 330,548\text{ J/K})$$

$$\Delta H = -1691,339\text{kJ}$$

- Pembentukan  $\text{MgO}$

$$\Delta H = \Delta G + T \Delta S$$

- a) Temperatur  $750^\circ\text{C}$

$$\Delta H = -490,821 + (1023\text{ K} - 115,452\text{ J/K})$$

$$\Delta H = -608,946\text{ kJ}$$

b) Temperatur 850°C

$$\Delta H = -479.272 \text{ kJ} + (1123 \text{ K} - 115.512 \text{ J/K})$$

$$\Delta H = -609.010 \text{ kJ}$$

c) Temperatur 950°C

$$\Delta H = -467,719 \text{ kJ} + (1223 \text{ K} - 115,536 \text{ J/K})$$

$$\Delta H = -609,037 \text{ kJ}$$

• Pembentukan  $\text{MgAl}_2\text{O}_4$

$$\Delta H = \Delta G + T \Delta S$$

a) Temperatur 750°C

$$\Delta H = -1516,063 \text{ kJ} + (993 \text{ K} - 940,110 \text{ J/K})$$

$$\Delta H = -2477,937 \text{ kJ}$$

b) Temperatur 850°C

$$\Delta H = -1421,257 \text{ kJ} + (1123 \text{ K} - 955,795 \text{ J/K})$$

$$\Delta H = -2494,758 \text{ kJ}$$

c) Temperatur 950°C

$$\Delta H = -1324,947 \text{ kJ} + (1153 \text{ K} - 970,206 \text{ J/K})$$

$$\Delta H = -2511,655 \text{ kJ}$$

### A3. Perhitungan Nilai Koefisien Perpindahan Panas Fluida

• Temperatur 750°C

a) Perhitungan Grasshof Number

$$Gr = \frac{\beta \cdot g \cdot \Delta T \cdot L^3}{\mu^2}$$

$$Gr = \frac{1/303 \times 9.81 \times (1023 - 303) \times 0.12^3}{(1.6 \times 10^{-5})^2}$$

$$Gr = 1.57 \times 10^8$$

b) Perhitungan Prandtl Number

$$Pr = \frac{C_p \cdot \mu}{k}$$

$$Pr = \frac{1005 \times (1.86 \times 10^{-5})}{0.024}$$

$$Pr = 0.77875$$

c) Perhitungan Rayleigh Number

$$Ra = Gr \cdot Pr$$

$$Ra = 1.57 \times 10^8 (0.77875)$$

$$Ra = 1.22 \times 10^8$$

d) Perhitungan Nusselt Number

$$Nu = a \cdot Ra^3$$

$$Nu = 0.525 (1.22 \times 10^8)^3$$

$$Nu = 64$$

e) Perhitungan koefisien perpindahan panas fluida

$$h = Nu \cdot k / L$$

$$h = \frac{64 \times 0.024}{0.12}$$

$$h = 12,8$$

• Temperatur 850°C

a) Perhitungan Grasshof Number

$$Gr = \frac{\beta \cdot g \cdot \Delta T \cdot L^3}{\mu^2}$$

$$Gr = \frac{1/303 \times 9.81 \times (1123 - 303) \times 0.12^3}{(1.6 \times 10^{-5})^2}$$

$$Gr = 1.79 \times 10^8$$

b) Perhitungan Prandtl Number

$$Pr = \frac{C_p \cdot \mu}{k}$$

$$Pr = \frac{1005 \times (1.86 \times 10^{-5})}{0.024}$$

$$Pr = 0.77875$$

c) Perhitungan Rayleigh Number

$$Ra = Gr \cdot Pr$$

$$Ra = 1.73 \times 10^8 (0.77875)$$

$$Ra = 1.4 \times 10^8$$

d) Perhitungan Nusselt Number

$$Nu = a \cdot Ra^3$$

$$Nu = 0.525(1.4 \times 10^8)^3$$

$$Nu = 40$$

e) Perhitungan koefisien perpindahan panas fluida

$$h = Nu \cdot k / L$$

$$h = \frac{40 \times 0.024}{0.12}$$

$$h = 8$$

• Temperatur 950°C

a) Perhitungan Grasshof Number

$$Gr = \frac{\beta \cdot g \cdot \Delta T \cdot L^3}{\mu^2}$$

$$Gr = \frac{1/303 \times 9.81 \times (1223 - 303) \times 0.12^3}{(1.6 \times 10^{-5})^2}$$

$$Gr = 2.01 \times 10^8$$

b) Perhitungan Prandtl Number

$$Pr = \frac{C_p \cdot \mu}{k}$$

$$Pr = \frac{1005 \times (1.86 \times 10^{-5})}{0.024}$$

$$Pr = 0.77875$$

c) Perhitungan Rayleigh Number

$$Ra = Gr \cdot Pr$$

$$Ra = (2.01 \times 10^8) \times 0.77875$$

$$Ra = 1,57 \times 10^8$$

d) Perhitungan Nusselt Number

$$Nu = a \cdot Ra^3$$

$$Nu = 0.525(1,57 \times 10^8)^3$$

$$Nu = 56$$

e) Perhitungan koefisien perpindahan panas fluida

$$h = Nu \cdot k L$$

$$h = \frac{56 \times 0.024}{0.12}$$

$$h = 11.2$$

#### A.4 Perhitungan Volume Pori-pori

a) Tekanan 166 MPa

$$\bullet \rho = \frac{M}{V}$$

$$V = \frac{M}{\rho}$$

$$V = 1,936 \ 1,548 = 1,251 \text{ cm}^3$$

$$\blacklozenge \text{ Volume bulk} = 1,251 \text{ cm}^3$$

$$\bullet \phi = V_{\text{pori-pori}} / V_{\text{bulk}} \times 100\%$$

$$V_{\text{pori-pori}} = \phi \cdot V_{\text{bulk}}$$

$$V_{\text{pori-pori}} = 0,198 \cdot 1,251 = 0,248 \text{ cm}^3$$

$$V = \frac{M}{\rho} \ 2,032 \ 1,622 = 1,253 \text{ cm}^3$$

$$\blacklozenge \text{ Volume bulk} = 1,253 \text{ cm}^3$$

$$\bullet \phi = \frac{V_{\text{pori-pori}}}{V_{\text{bulk}}} \times 100\%$$

$$V_{\text{pori-pori}} = \phi \cdot V_{\text{bulk}}$$

$$V_{\text{pori-pori}} = 0,311 \cdot 1,253 = 0,220 \text{ cm}^3$$

b) Tekanan 171 MPa

$$\bullet \rho = M / V$$

$$V = M / \rho$$

$$V = 2,051 \cdot 1,615 = 1,270 \text{ cm}^3$$

$$\diamond \text{ Volume bulk} = 1,270 \text{ cm}^3$$

$$\bullet \phi = \frac{V_{\text{pori-pori}}}{V_{\text{bulk}}} \times 100\%$$

$$V_{\text{pori-pori}} = \phi \cdot V_{\text{bulk}}$$

$$V_{\text{pori-pori}} = 0,286 \cdot 1,270 = 0,23 \text{ cm}^3$$

c) Tekanan 176 MPa

$$\bullet \rho = \frac{M}{V}$$

$$V = \frac{M}{\rho}$$

$$V = \frac{2,032}{1,622} = 1,253 \text{ cm}^3$$

$$\diamond \text{ Volume bulk} = 1,253 \text{ cm}^3$$

$$\bullet \phi = \frac{V_{\text{pori-pori}}}{V_{\text{bulk}}} \times 100\%$$

$$V_{\text{pori-pori}} = \phi \cdot V_{\text{bulk}}$$

$$V_{\text{pori-pori}} = 0,311 \cdot 1,253 = 0,220 \text{ cm}^3$$

**LAMPIRAN B**  
**DATA HASIL PENELITIAN**



## Lampiran B. Data Hasil Penelitian

**Tabel B.1** Data hasil Penekanan

Geometri	Penekanan	Porositas	Volume Pori-pori ( $m^3$ )
	(Mpa)	(%)	kerapatan
1	166	29,1	$2,4 \times 10^{-9}$
	171	28,22	$2,3 \times 10^{-9}$
	176	27,3	$2,2 \times 10^{-9}$
2	166	30,1	$2,5 \times 10^{-9}$
	171	29,5	$2,4 \times 10^{-9}$
	176	28,4	$2,3 \times 10^{-9}$
3	166	28	$2,44 \times 10^{-9}$
	171	27	$2,37 \times 10^{-9}$
	176	26	$2,3 \times 10^{-9}$
4	166	26,45	$2,53 \times 10^{-9}$
	171	25,70	$2,46 \times 10^{-9}$
	176	24,95	$2,2 \times 10^{-9}$

**Tabel B.2** Data Perubahan Temperatur dan *Heat flux* dengan temperatur Pemanasan 750°C

Geometri	Waktu (Detik)	Tempertur (°C)		Heat Fllux ( $W/m^2$ )	
		Minimum	Maksimum	Minimum	Maksimum
1	3600	701,01	702,2	0,00037244	20986
	7200	721,74	724,83	0,00037196	9793
	10800	733,1	733,04	0,00037205	6597
2	3600	690,78	691,04	0,00016154	29186
	7200	724,88	724,96	0,00016154	12109
	10800	733,1	733,04	0,00016176	8936

3	3600	687,64	687,96	0,00010532	23299
	7200	717,59	717,76	0,00010572	12109
	10800	728,11	728,22	0,00010576	8179
4	3600	697,81	688,22	0,000073708	25574
	7200	717,82	718,04	0,000073584	13231
	10800	728,27	728,41	0,000073545	8936

**Tabel B.3** Data Perubahan Temperatur dan *Heat flux* dengan temperatur Pemanasan 850°C

Geometri	Waktu (Detik)	Tempertur (°C)		Heat Fllux (W/m <sup>2</sup> )	
		Minimum	Maksimum	Minimum	Maksimum
1	3600	795	796,05	0,00042242	18986
	7200	822	822,23	0,00042244	10801
	10800	831,27	831,31	0,00042069	7271
2	3600	701,44	796,32	0,00018339	22449
	7200	822,28	822,37	0,00018332	13247
	10800	831,34	831,4	0,00018316	9769
3	3600	781,57	781,92	0,00011955	25139
	7200	814,54	814,73	0,00011961	13247
	10800	826,08	826,2	0,0001197	8939
4	3600	782,02	728,47	0,000083345	27955
	7200	814,78	815,02	0,000082523	14481
	10800	826,24	826,4	0,000083275	9769

**Tabel B.4** Data Perubahan Temperatur dan *Heat flux* dengan temperatur Pemanasan 950°C

Geometri	Waktu (Detik)	Tempertur (°C)		Heat Fllux (W/m <sup>2</sup> )	
		Minimum	Maksimum	Minimum	Maksimum
1	3600	891,4	891,52	0,00047135	22742
	7200	919,9	919,96	0,00047112	11681

	10800	929	929,79	0,00047201	7857
2	3600	879,89	880,19	0,00020472	34538
	7200	920,02	920,11	0,00020493	14195
	10800	929,75	929,89	0,0002051	10462
3	3600	883,18	876,81	0,00013357	27483
	7200	912	921,2	0,00013352	14195
	10800	929,83	924,52	0,00013341	9566
4	3600	876,9	877,38	0,000092974	30062
	7200	903,19	903,31	0,000093694	19243
	10800	924,56	924,73	0,000093045	10462

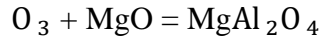
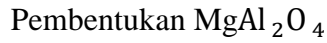
**Tabel B.5** Data Hasil Entalpi, Entropi, dan Energi Bebas Gibbs Reaksi Pembentukan  $\text{Al}_2\text{O}_3$

$2\text{Al} + 3/2\text{O}_2 (\text{g}) = \text{Al}_2\text{O}_3$			
T (°C)	$\Delta\text{H}$ (kJ)	$\Delta\text{S}$ (J/K)	$\Delta\text{G}$ (kJ)
750	-1693,428	-332,408	-1353,325
850	-1692,438	-331,486	-1320,130
950	-1691,339	-330,548	-1287,028

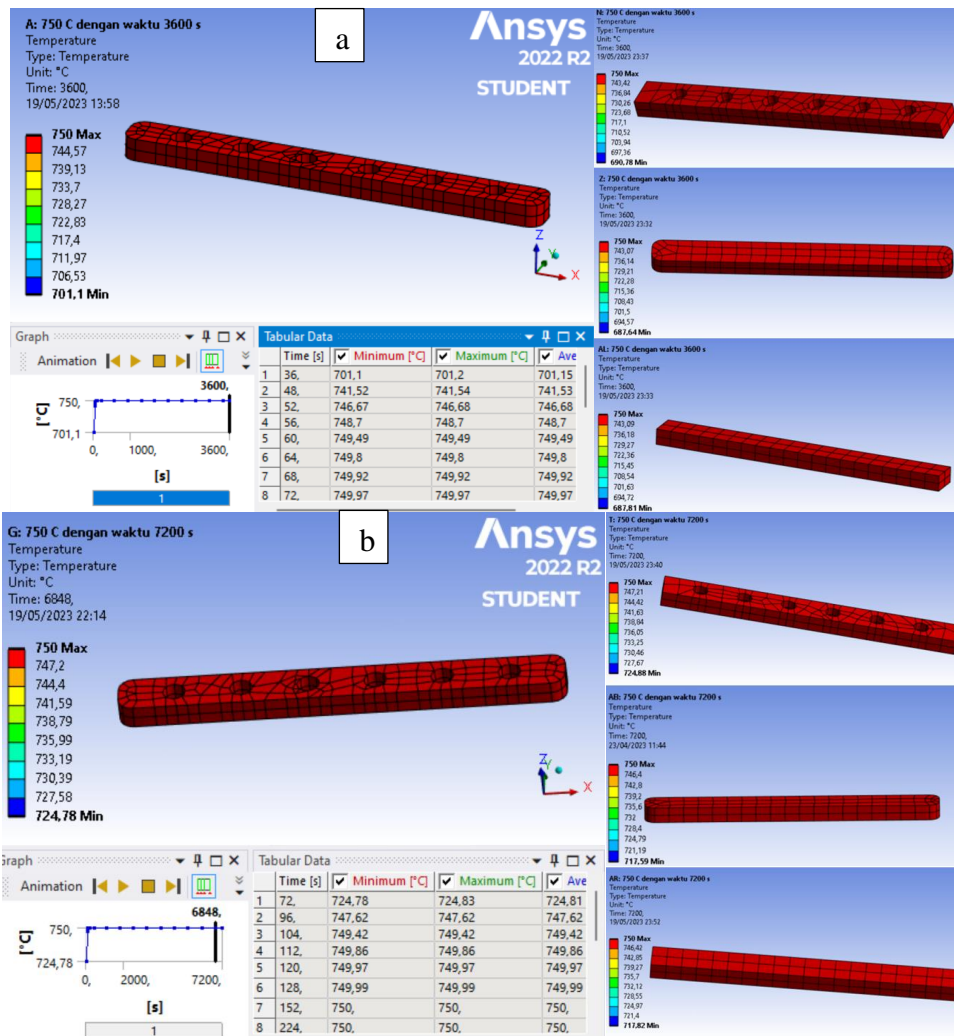
**Tabel B.6** Data Hasil Entalpi, Entropi, dan Energi Bebas Gibbs Reaksi Pembentukan MgO

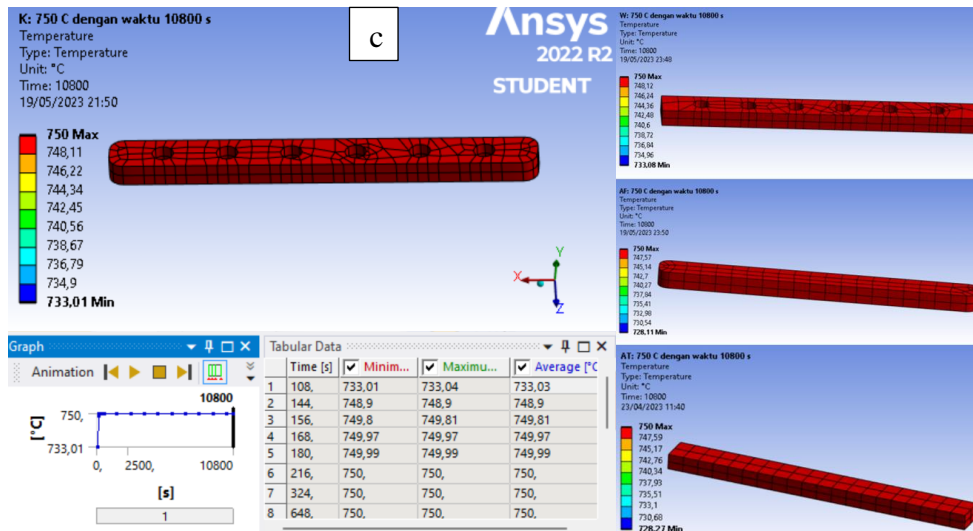
$\text{Mg} + 1/2 \text{O}_2(\text{g}) = \text{MgO}$			
T (°C)	$\Delta\text{H}$ (kJ)	$\Delta\text{S}$ (J/K)	$\Delta\text{G}$ (kJ)
750	-608,946	-115,452	-490,821
850	-609,010	-115,512	-479,272
950	-609,037	-115,536	-467,719

**Tabel B.7** Data Hasil Entalpi, Entropi, dan Energi Bebas Gibbs Reaksi

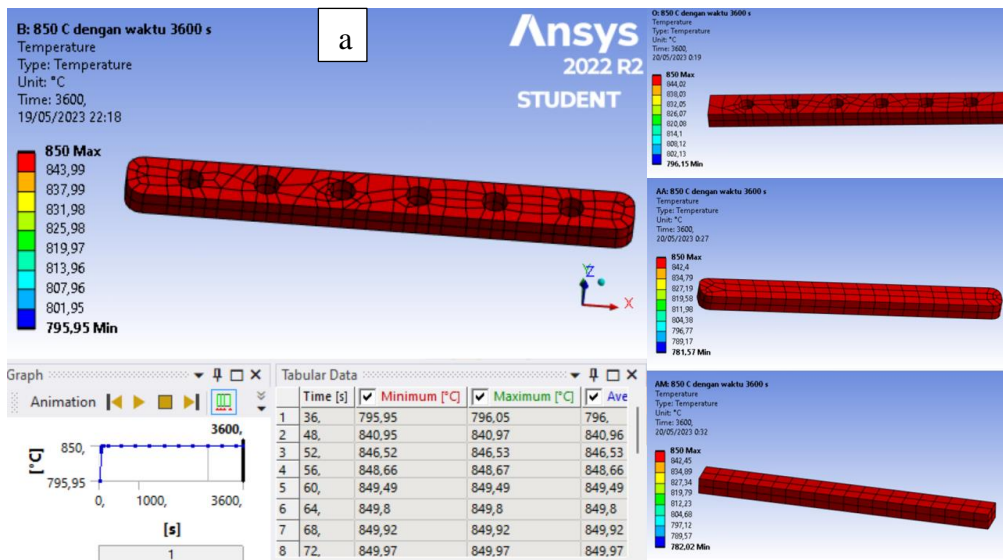


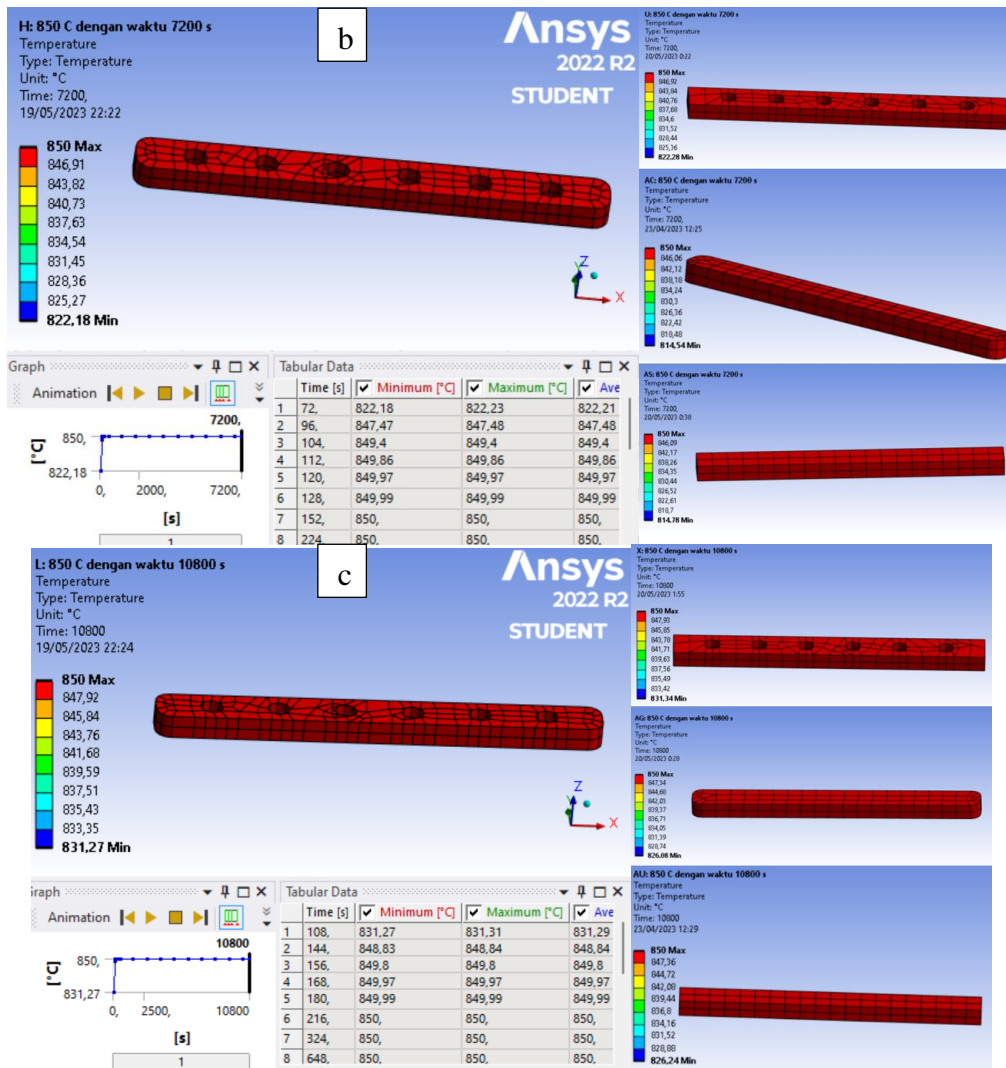
T (°C)	$\Delta H$ (kJ)	$\Delta S$ (J/K)	$\Delta G$ (kJ)
750	-2477,937	-940,110	-1516,063
850	-2494,758	-955,795	-1421,257
950	-2511,655	-970,206	-1324,947



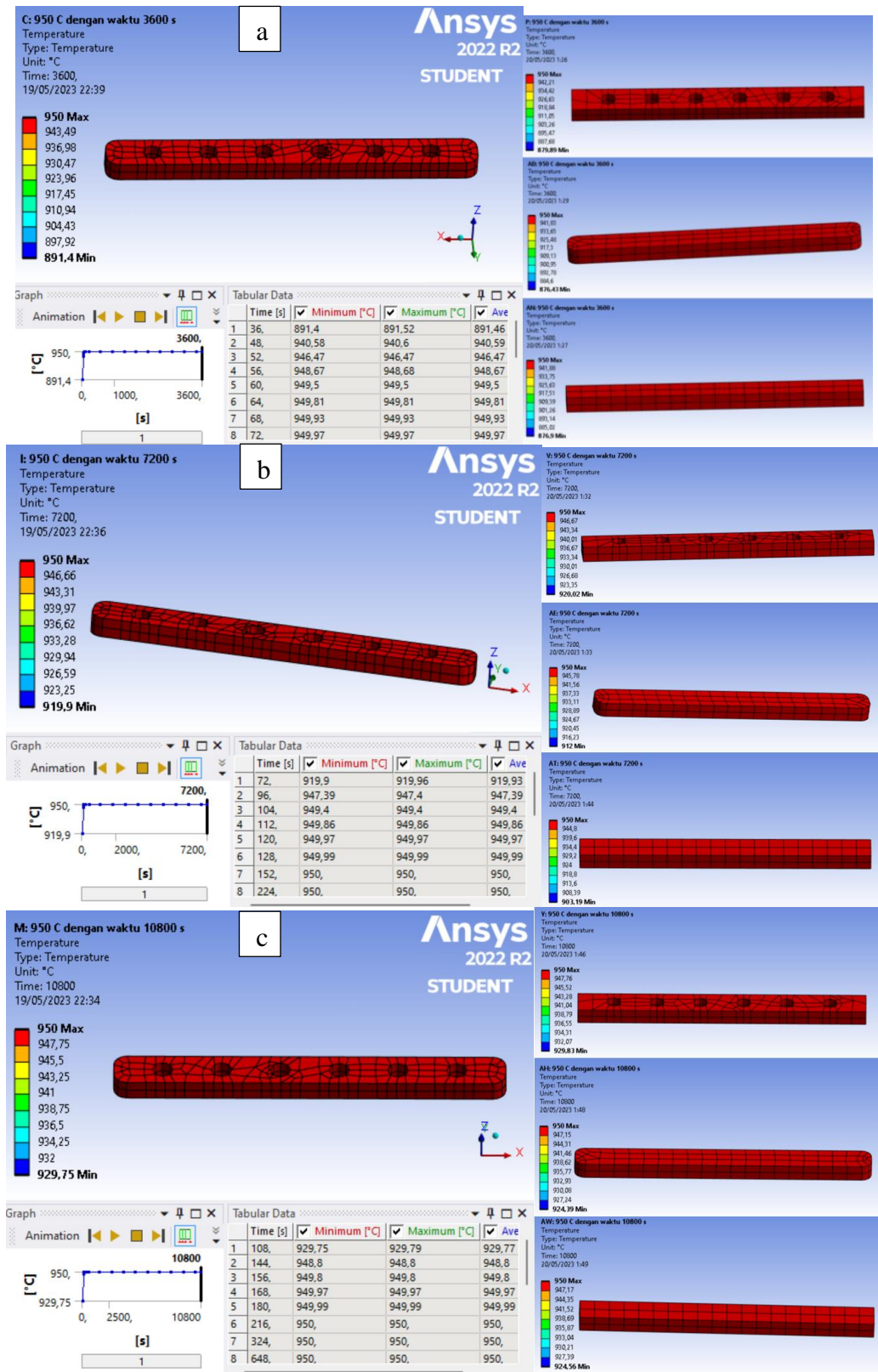


**Gambar B.2** Distribusi Temperatur dengan Pemanasan 750°C pada Waktu  
 a)3600 detik, b)7200 detik, dan c)10800 detik



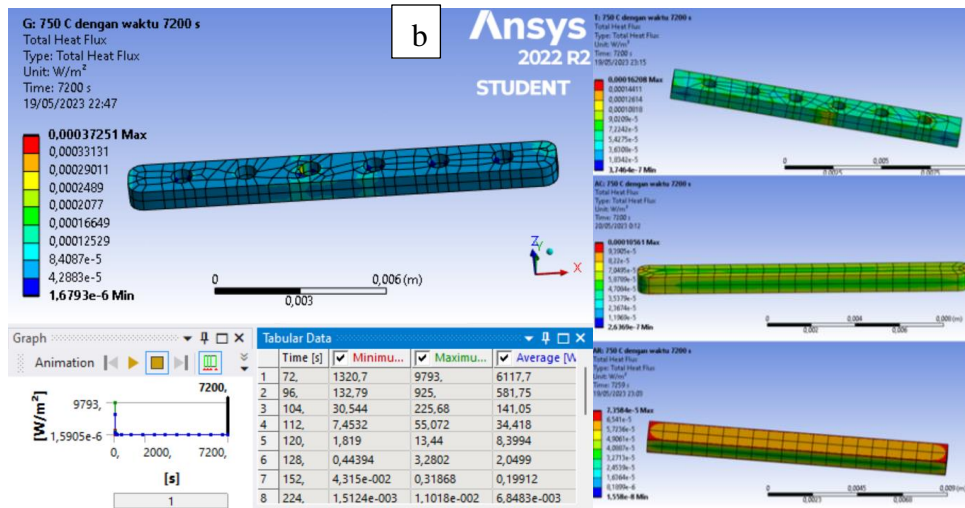
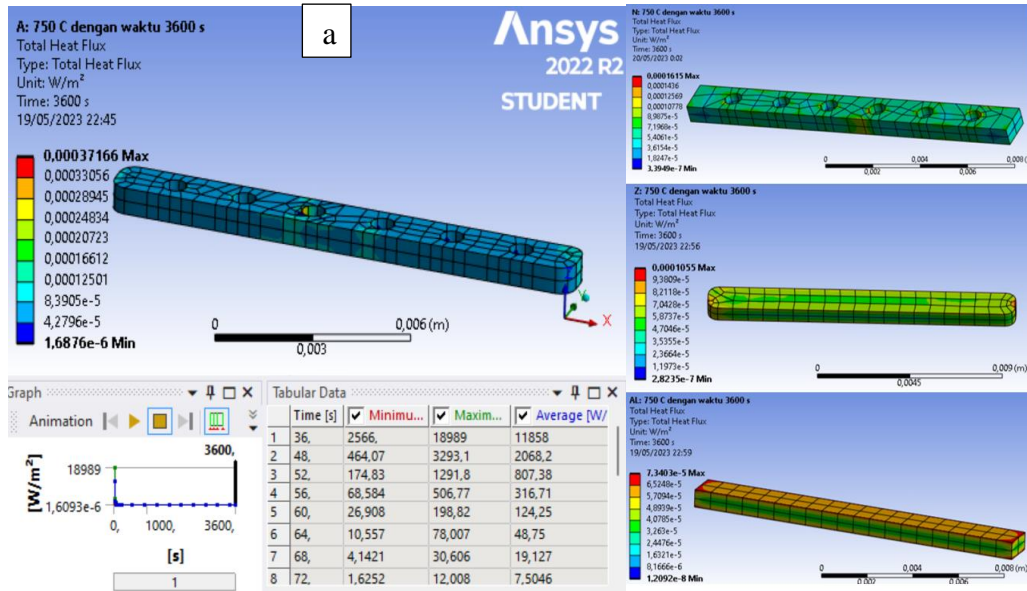


**Gambar B.2** Distribusi Temperatur dengan Pemanasan 850°C pada Waktu  
 a)3600 detik, b)7200 detik, dan c)10800 detik

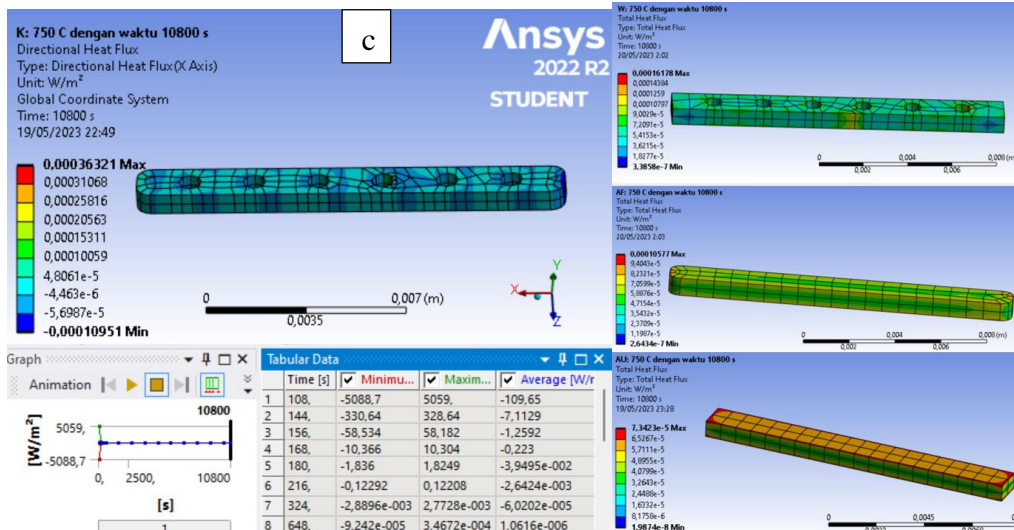


**Gambar B.3** Distribusi Temperatur dengan Pemanasan 950°C pada Waktu  
 a)3600 detik, b)7200 detik, dan c)10800 detik

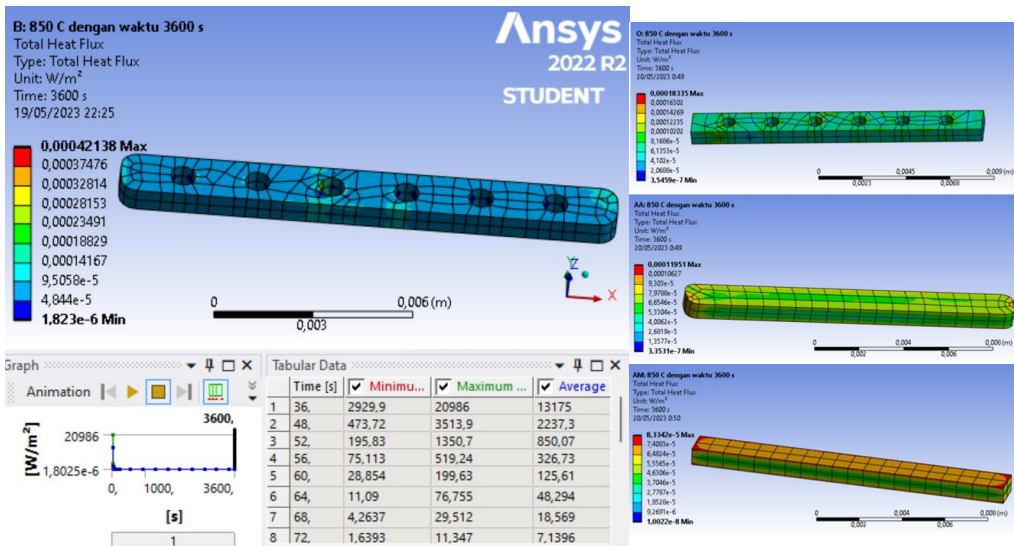
## Heat Flux

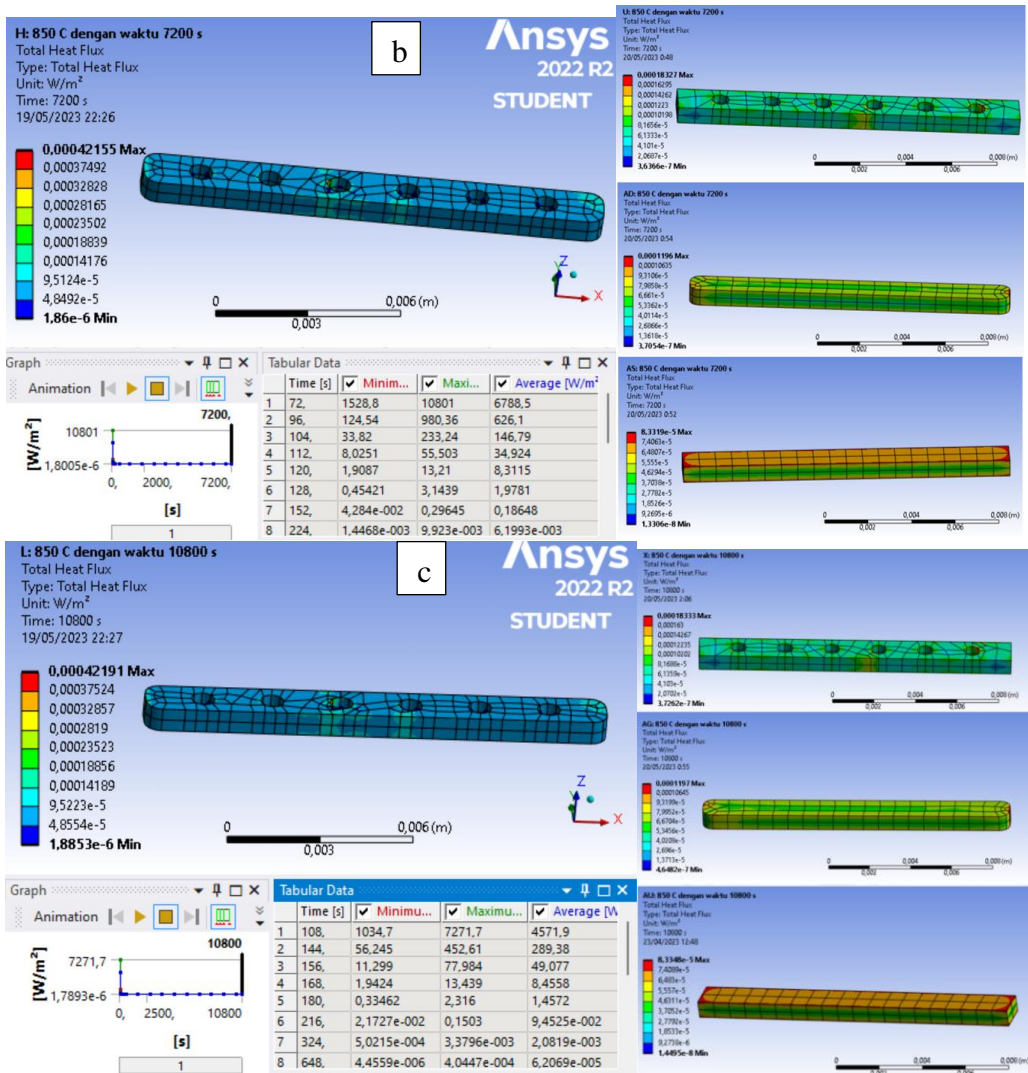




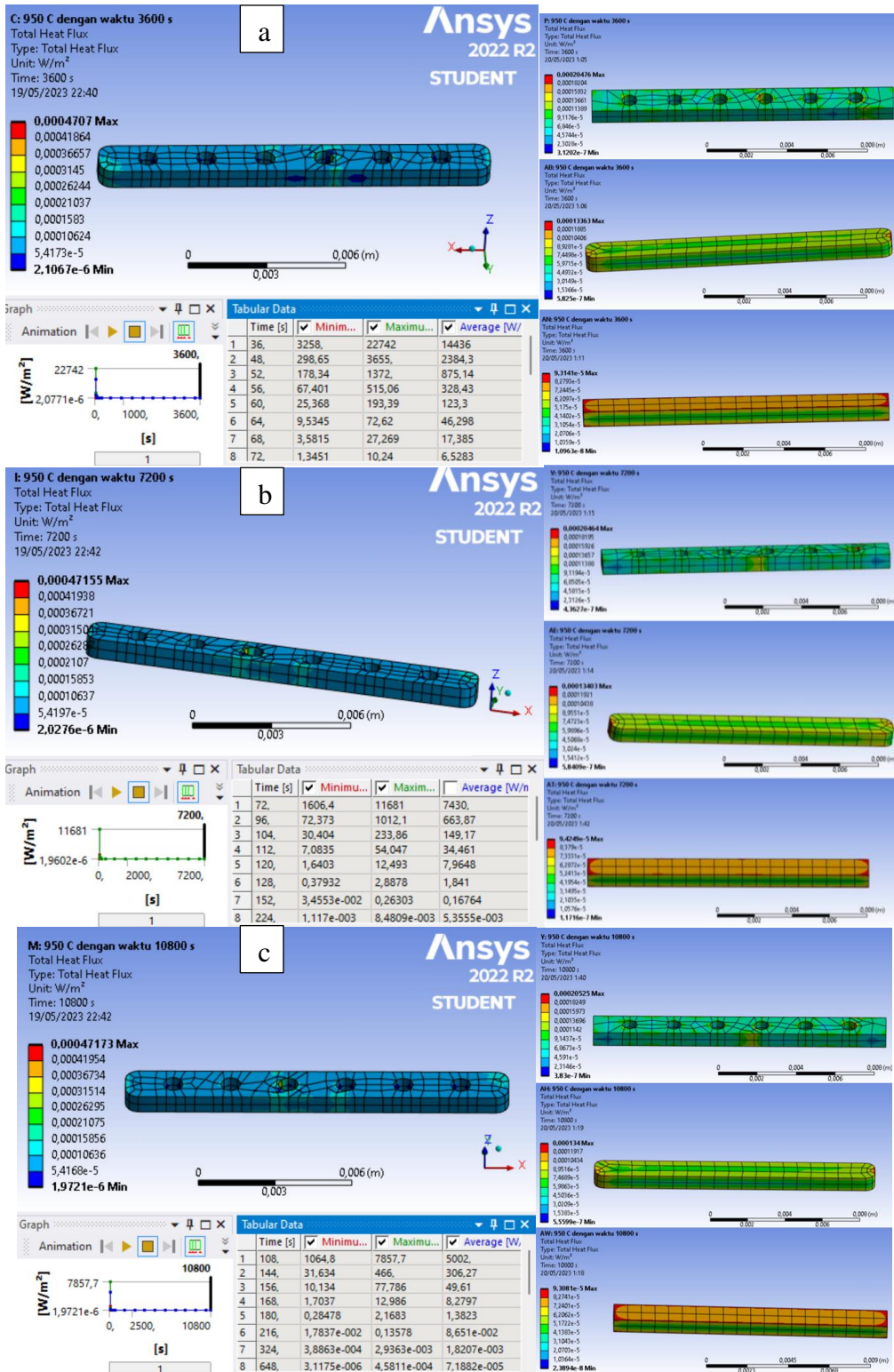


**Gambar B.4** Distribusi *Heat Flux* dengan Pemanasan 750°C pada Waktu  
 a)3600 detik, b)7200 detik, dan c)10800 detik

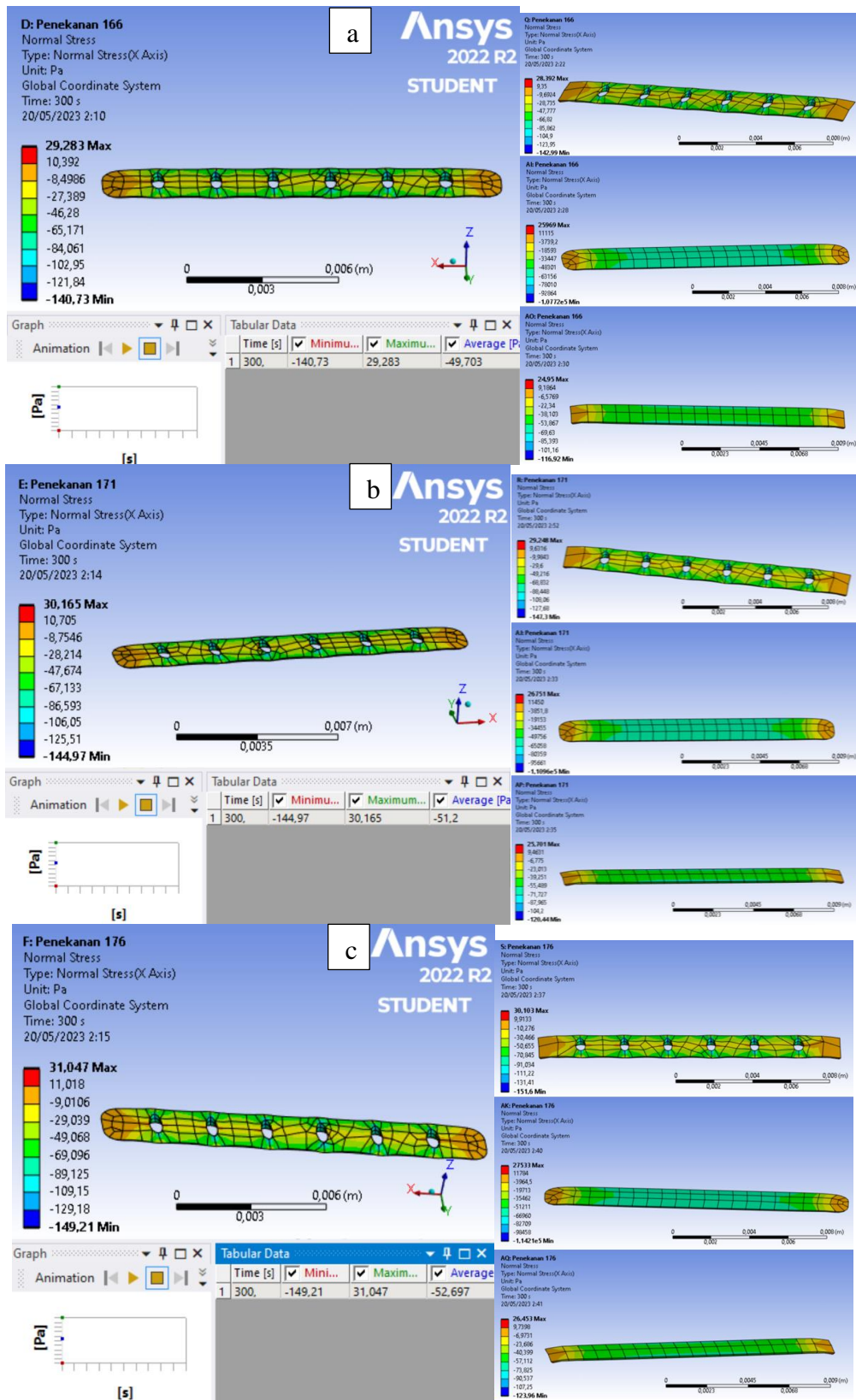




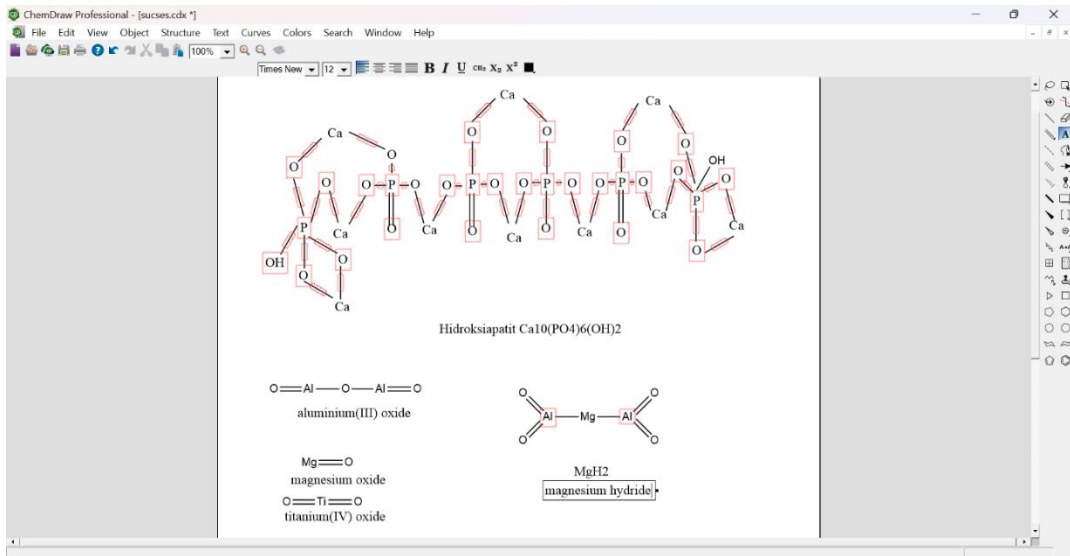
**Gambar B.5** Distribusi *Heat Flux* dengan Pemanasan 850°C pada Waktu  
a)3600 detik, b)7200 detik, dan c)10800 detik



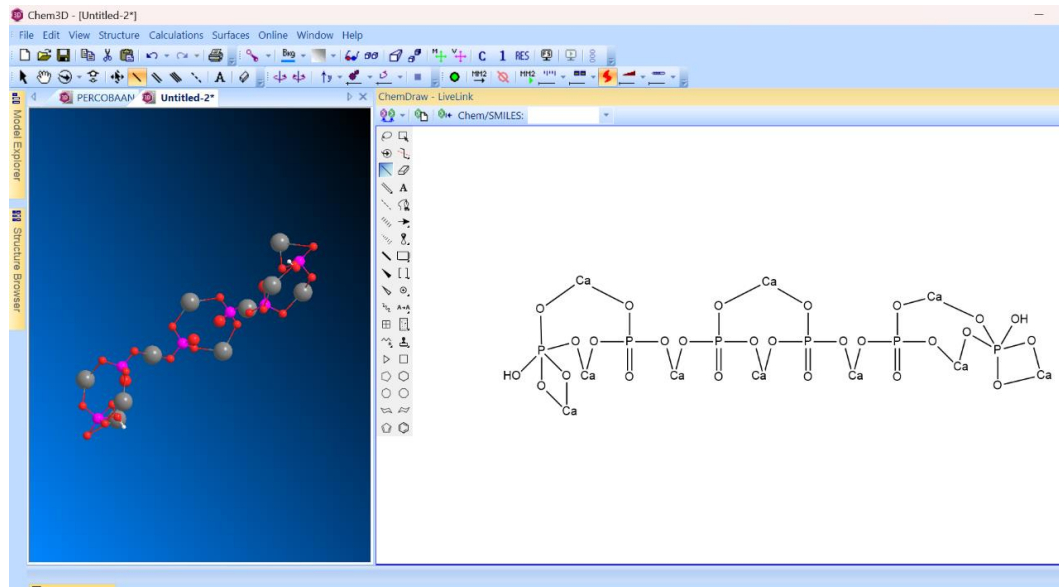
Gambar B.6 Distribusi Heat Flux dengan Pemanasan 950°C pada Waktu  
d) 3600 detik, b) 7200 detik, dan c) 10800 detik



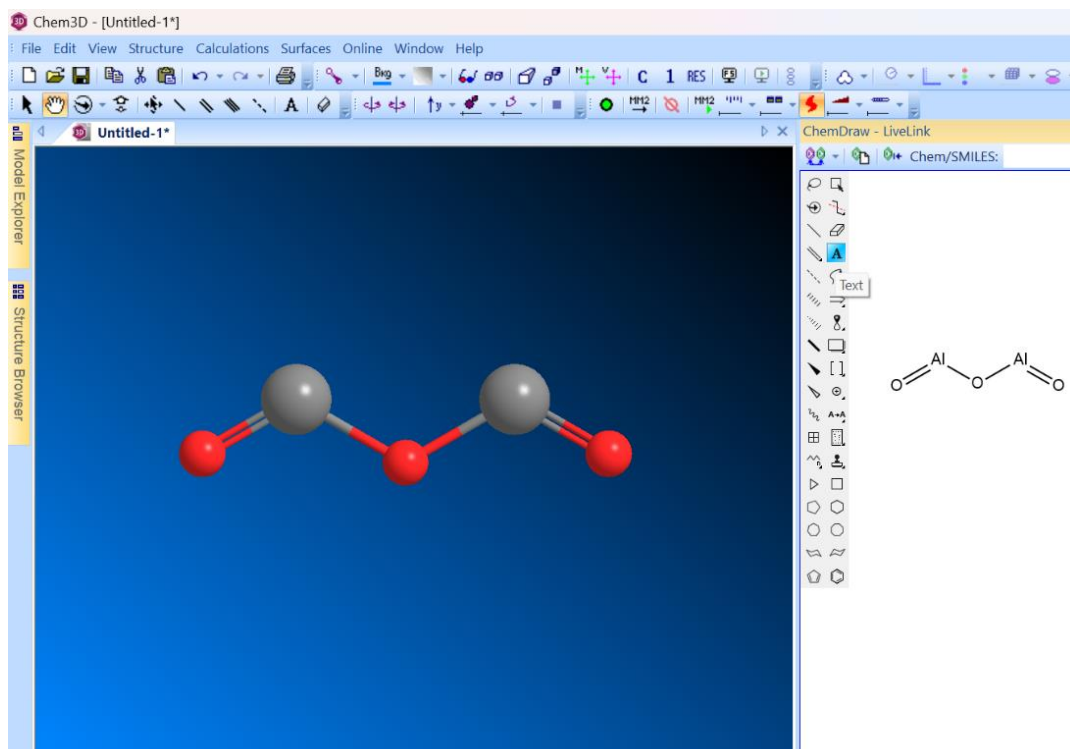
Gambar B.7 Normal Stress pada Tekanan a) 166 MPa; b) 171 MPa; c) 176 MPa



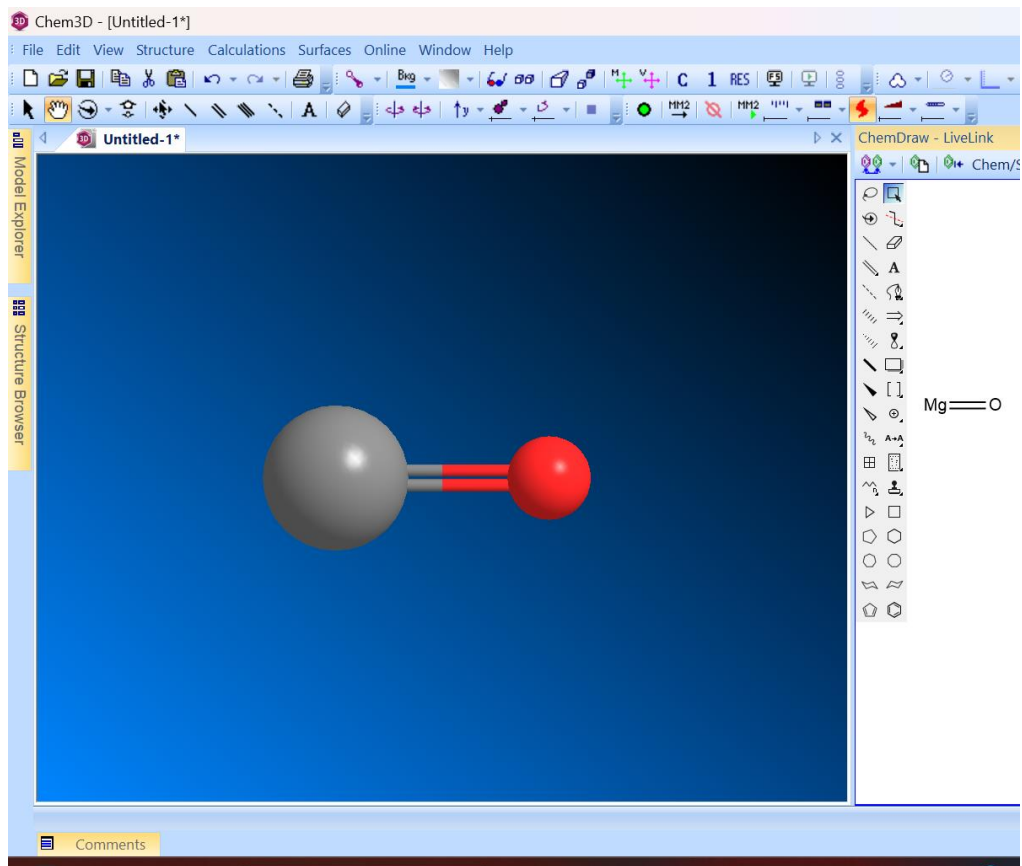
**Gambar B.8** Hasil Struktur Kimia dari Chem Draw



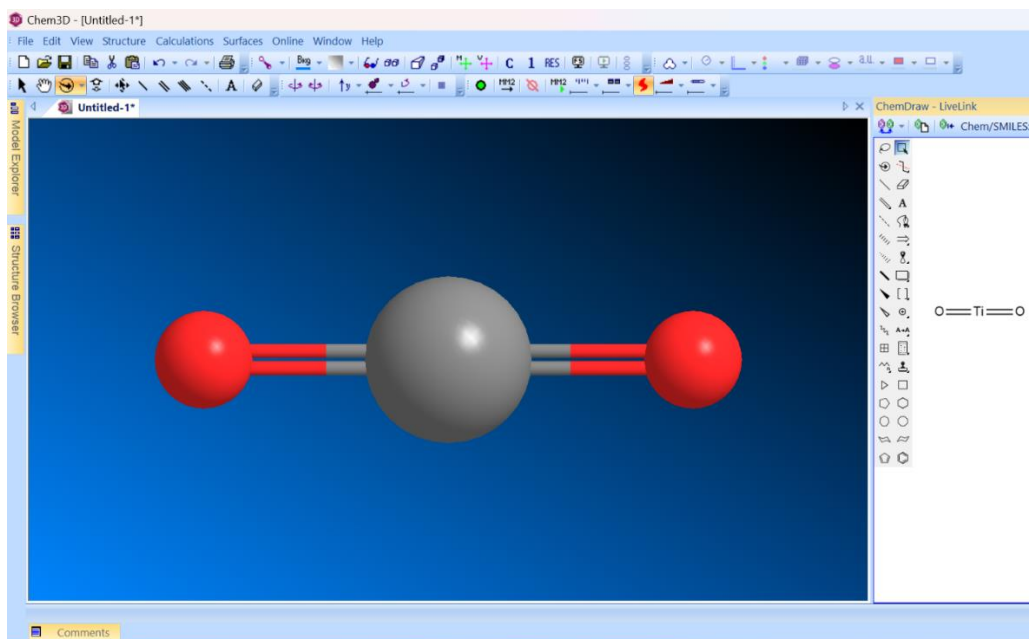
**Gambar B.9** Ikatan Atom Hidroksiapatit



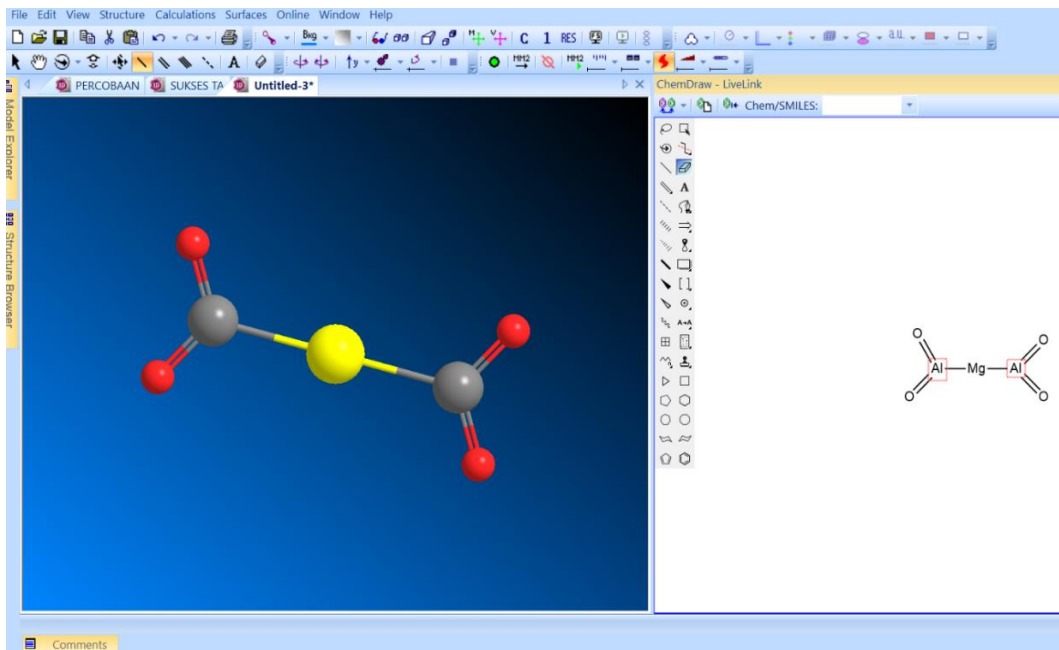
**Gambar B.10** Ikatan Atom Aluminium (III) Oxide



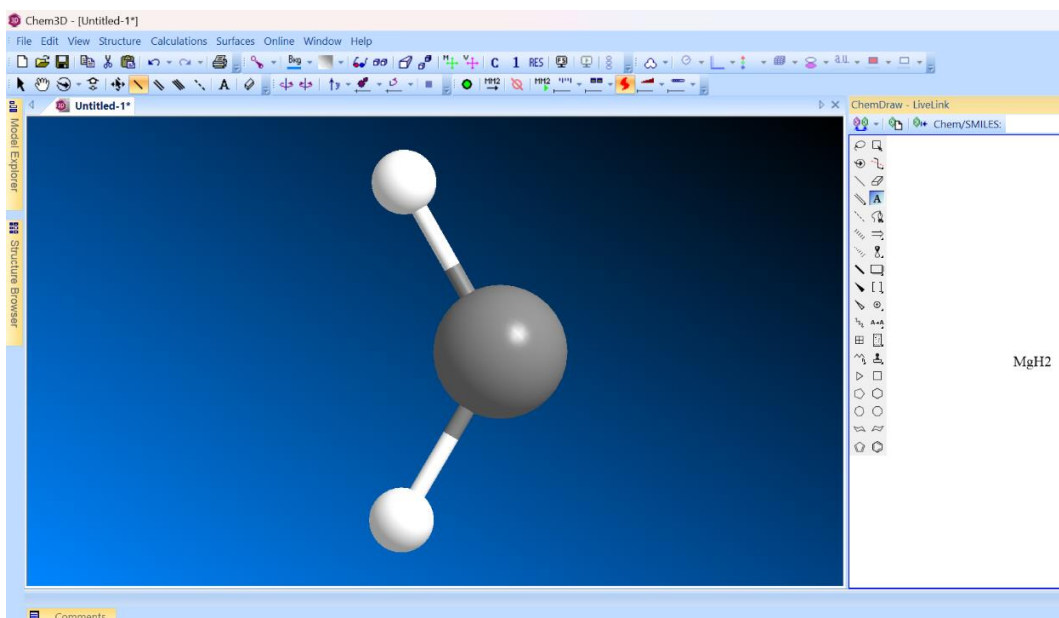
**Gambar B.11** Ikatan Atom Magnesium Oxide



**Gambar B.12** Ikatan Atom Titanium Oxide



**Gambar B.13** Ikatan Atom Magnesium Aluminate (Spinel)



**Gambar B.14** Ikatan Atom Magnesium Hydride