CITY COLLEGE

CITY UNIVERSITY OF NEW YORK

Project #1

HONEYCOMB SANDWICH STRUCTURE

ME 548: Aerostructure

Spring 2011

Prof. S.Bayer

Submitted By:

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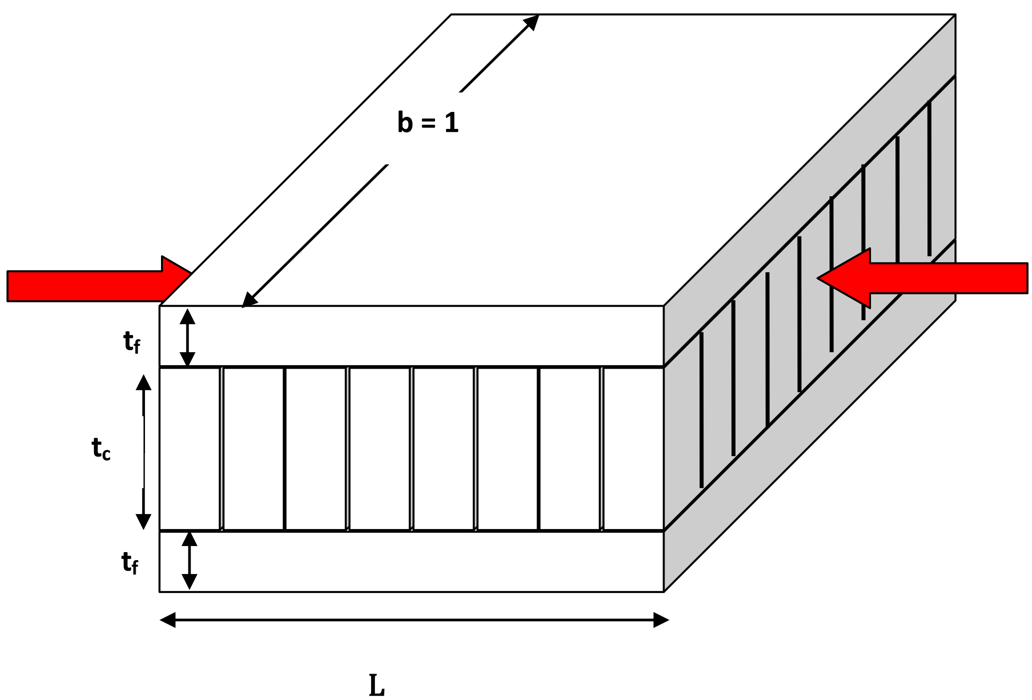
- *Objective of Experiment*

Design a sandwich column hinged at both ends and which can sustain a buckling load P. A choice of three face material is available. Using the honeycomb construction and aluminum alloy 2024 as the core material the most cost effective design is to obtain with respect to strength and cost ratio.

- *Background*

Innovations in aircraft design, motor vehicle technology and light-weight construction have formed the basis for the development of honeycomb structured panels. Their decisive advantage is low weight, combined with great structural strength. Because of their anti-shock properties, honeycomb structures are today used as shock-absorbent layers both in automobile construction and in sports gear and sport shoe production. They are ideally suited for design and architectural applications as a result of their optimal ratio of weight to load-bearing capacity and bending strength. In addition this composite material, which generally consists of a honeycomb core and external facing, can be adapted to individual requirements with regard to strength and choice of materials.



- ## *Procedure*

$$expand\left(2\cdot\left(\frac{b\cdot t_f^3}{12}+b\cdot t_f\cdot\left(\frac{(t_f+t_c)}{2}\right)^2\right)\right)$$

$$\frac{2}{3}\,b\,t_f^3+b\,t_f^2\,t_c+\frac{1}{2}\,b\,t_f t_c^2$$

and ignoring t_f^3 *and* t_f^2 *for* $t_c \gg t_f$

$$IN := \frac{1}{2}\,\beta\cdot t_c\,t_c^2$$

$$\frac{1}{2}\,\beta\,t_c^3$$

Applied Load is P

$$P_{cr} := \frac{\pi^2\cdot E\cdot IN}{L^2}$$

$$\frac{1}{2}\,\frac{\pi^2\,E\,\beta\,t_c^3}{L^2}$$

$$t_{c_{\min}} := \left(\frac{2\cdot\,\mathrm{P}\cdot\mathrm{L}^2}{\pi^2\,E\,\beta}\right)^{\frac{1}{3}}$$

$$2^{1/3}\left(\frac{P\,L^2}{\pi^2\,E\,\beta}\right)^{1/3}$$

for Minimum weight $t_c = t_{c_{min}}$

$$w := \rho_f\cdot\left(B\cdot L\cdot\left(\beta\cdot 2^{1/3}\left(\frac{P\,L^2}{\pi^2\,E\,\beta}\right)^{1/3}+\beta\cdot 2^{1/3}\left(\frac{P\,L^2}{\pi^2\,E\,\beta}\right)^{1/3}\right)\right)$$
$$+\rho_c\cdot B\cdot L\cdot 2^{1/3}\left(\frac{P\,L^2}{\pi^2\,E\,\beta}\right)^{1/3}$$

$$2\,\rho_f B\,L\,\beta\,2^{1/3}\left(\frac{P\,L^2}{\pi^2\,E\,\beta}\right)^{1/3}+\rho_c\,B\,L\,2^{1/3}\left(\frac{P\,L^2}{\pi^2\,E\,\beta}\right)^{1/3}$$

$diff(w, \beta)$

$$2\,\rho_f B\,L\,2^{1/3}\left(\frac{P\,L^2}{\pi^2\,E\,\beta}\right)^{1/3} - \frac{2}{3}\,\frac{\rho_f B\,L^3\,2^{1/3}\,P}{\beta\left(\frac{P\,L^2}{\pi^2\,E\,\beta}\right)^{2/3}\pi^2\,E} - \frac{1}{3}\,\frac{\rho_c\,B\,L^3\,2^{1/3}\,P}{\left(\frac{P\,L^2}{\pi^2\,E\,\beta}\right)^{2/3}\pi^2\,E\,\beta^2}$$

$solve(\%, \beta)$

$$\frac{1}{4}\,\frac{\rho_c}{\rho_f}$$

$$\beta = \frac{\rho_c}{4 * (\rho_f)}$$

For the design we have core material is Aluminum 2024, and $\rho_c = 0.1\frac{lb}{in^3}$

For facing material we have

	Facing Material	Stress, Kips/in^2	Density, lb/in^3	Young's Modulus, Kips/in^2	Relative Price Per Pound, $
1	Aluminum 2024	66	0.1	10.5	10
2	Magnesium Alloy	40	0.065	0.5	15
3	Laminated Composite	30	0.050	2.5	20

L= 48 inch and P=6000 lb

Young's Modulus of Composite is given by:

$$E_{comp} = E_{core} * \vartheta_{film} + E_{film} * \vartheta_{core}$$

where,

$$E_{comp} = Young's Modulus\ of\ Elasticity\ of\ Composite\ \left(\frac{lb}{in^2}\right)$$

$$E_{core} = Young's Modulus\ of\ Elasticity\ of\ Core\ \left(\frac{lb}{in^2}\right)$$

$$E_{film} = Young's Modulus\ of\ Elasticity\ of\ film\ \left(\frac{lb}{in^2}\right)$$

$$\vartheta_{film} = volume\ fraction\ of\ film\ = \frac{V_{film}}{V_{total}}$$

$$\vartheta_{core} = volume\ fraction\ of\ core = \frac{V_{core}}{V_{total}}$$

$$E_{comp} = E_{core} * \frac{V_{film}}{V_{total}} + E_{film} * \frac{V_{film}}{V_{total}}$$

$$E_{comp} = E_{core} * \frac{(2 * t_f * B * L)}{\left(B * L * (2 * t_f + t_c)\right)} + E_{film} * \frac{(t_c * B * L)}{\left(B * L * (2 * t_f + t_c)\right)}$$

$$E_{comp} = E_{core} * \frac{2 * t_f}{(2 * t_f + t_c)} + E_{film} * \frac{t_c}{(2 * t_f + t_c)}$$

Similarly, Ultimate stress, σ $\left(\frac{lb}{in^2}\right)$

$$\rho_{comp} = \rho_{core} * \frac{2 * t_f}{(2 * t_f + t_c)} + \rho_{film} * \frac{t_c}{(2 * t_f + t_c)}$$

Similarly, Ultimate stress, σ $\left(\frac{lb}{in^2}\right)$

$$\sigma_{comp} = \sigma_{core} * \frac{2 * t_f}{(2 * t_f + t_c)} + \sigma_{film} * \frac{t_c}{(2 * t_f + t_c)}$$

For valid design sustainability:

$$For\ a\ long\ section\ of\ member\ of\ length\ L, and\ under\ applied\ load\ P$$

$$P < P_{cr}\ and\ \sigma_{comp} < \sigma_{cr}$$

where

$$P_{cr} = \frac{\pi^2 E_{comp} * I_{comp}}{L_{eff}^2}$$

$$\sigma_{cr} = \frac{P_{cr}}{A} = \frac{\pi^2 E_{comp} * I_{comp}}{L_{eff}^2 * B * \left(2 * t_f + t_c\right)}$$

where

$$L_{eff} = L = length\ of\ the\ member, for\ force\ applied\ from\ two\ end, 48\ inch$$

$$B = width\ of\ of\ the\ member, 1\ inch$$

$$P = Applied\ Load = 6000\ lb$$

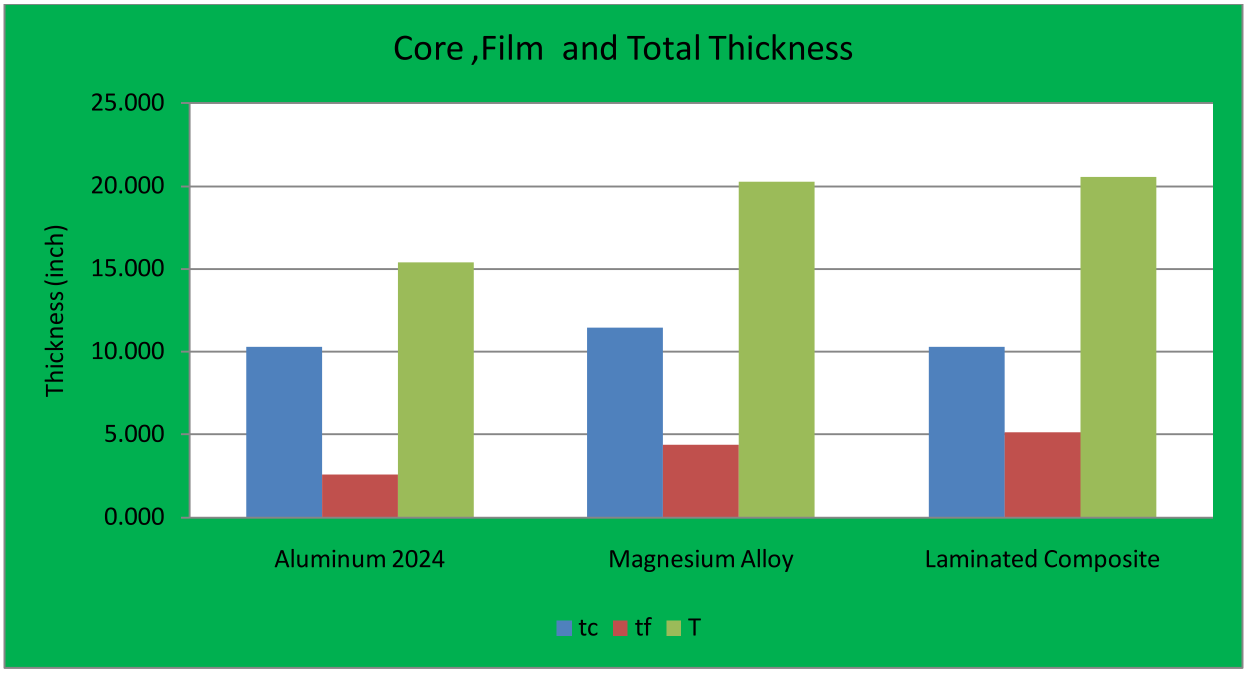
$$I_{comp} = 2 * \left(\frac{B * t_f^3}{12} + B * t_f * \left(\frac{t_f + t_c}{2}\right)^2\right)$$

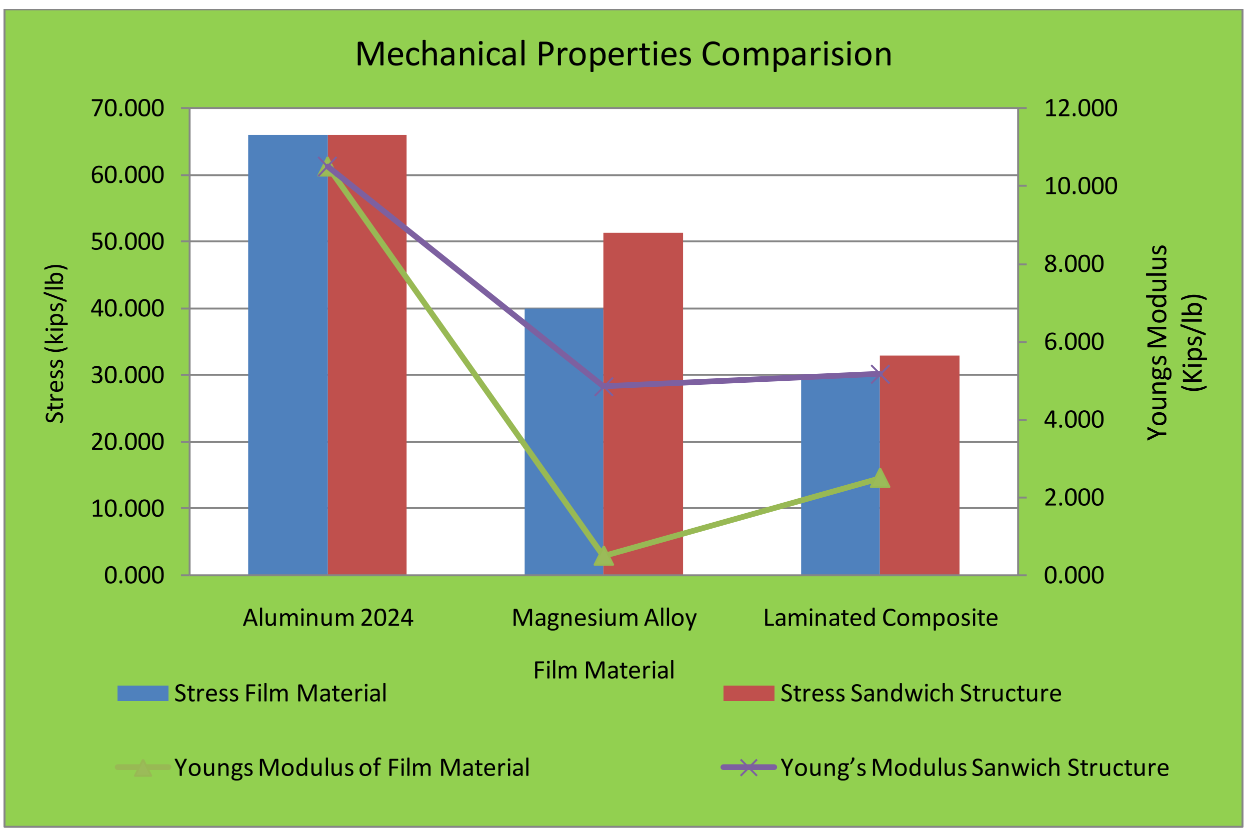
Facing Material	Core: Aluminum Alloy 2024		
	$t_f, inch$	$t_c, inch$	β
Aluminum 2024	2.555	10.219	0.250
Magnesium Alloy	4.405	11.453	0.385
Laminated Composite	5.137	10.274	0.500

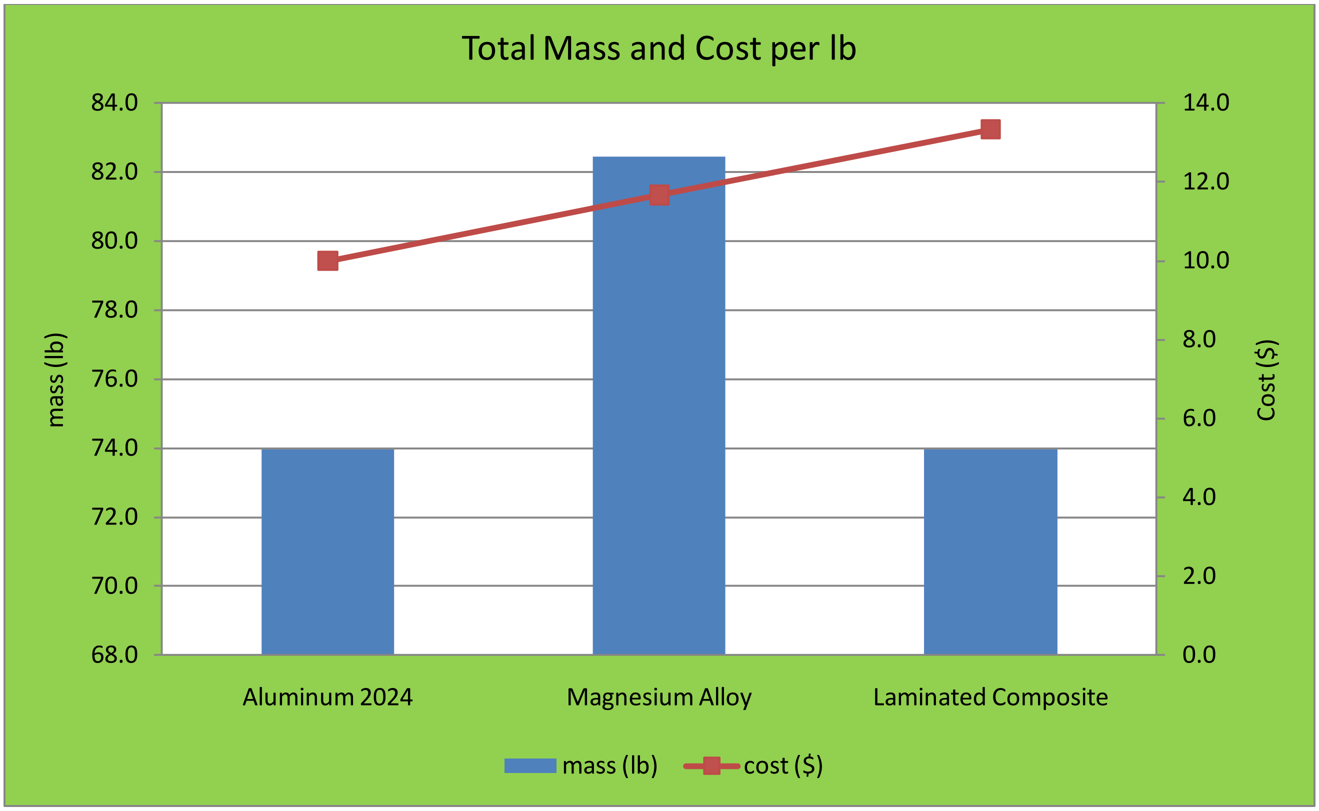
Composite Material Properties						
$Stress, \frac{kips}{in^2}$	$Density, \frac{lb}{in^3}$	$Young's\ Modulus, \frac{kip}{in^2}$	$Mass, lb$	$Relative\ Price\ Per\ Pound,$ $	$Critical\ Load, lb$	$Critical\ Stress, \frac{lb}{in^2}$
66.000	0.100	10.500	73.973	10.000	6000.486	389.364
51.304	0.080	4.848	82.464	11.667	6000.000	296.099
33.000	0.075	5.167	73.971	13.333	6000.000	292.007

- ***Results***

Aluminum 2024 Core







- *Conclusion*

Therefore from the analysis, Aluminum 2024 is the most cost effective with respect to buckling load however, this difference is compromise able with the weight ration which with weight optimization with respect to the same nominal stress Laminated Composite is most effective composite material as respect to mass to cost ratio. Though we assumed that the thickness of the film is very less than thickness of core, however in the graph the ratio of $\frac{t_f}{t_c} = .25$ for laminated composite and $\frac{t_f}{t_c} = 0.5$, therefore validating the design as per the assumption the winner is ***Aluminum 2024 core with Aluminum 2024 as film.***

• *Appendix*

> $A_c := A_J$

A_J

$L := 48$

48

$B := 1$

1

$\rho_{core} := .1$

0.1

$\sigma_{core} := 66 \cdot 10^3$

6600(

$Al\rho_f := .1$

0.1

$Mg\rho_f := .065$

0.065

$La\rho_f := .050$

0.050

$E_c := 10.5 \cdot 10^3$

10500.(

$AlE_f := 10.5 \cdot 10^3$

10500.(

$MgE_f := 0.5 \cdot 10^3$

500.0

$LaE_f := 2.5 \cdot 10^3$

2500.(

$Al\sigma_f := 66 \cdot 10^3$

6600(

$Mg\sigma_f := 40 \cdot 10^3$

4000(

$La\sigma_f := 30 \cdot 10^3$

3000(

$P := 6000$

600(

$cost_{core} := 10$

$$10$$

$$Alcost_{film} := 10$$

$$10$$

$$Mgcost_{film} := 15$$

$$15$$

$$Lacost_{film} := 20$$

$$20$$

$$Al\beta := \frac{1}{4} \frac{\rho_{core}}{Al\rho_f}$$

$$0.250000000($$

$$Mg\beta := \frac{1}{4} \frac{\rho_{core}}{Mg\rho_f}$$

$$0.384615384$$

$$La\beta := \frac{1}{4} \frac{\rho_{core}}{La\rho_f}$$

$$0.500000000($$

$$Alt_f := Al\beta \cdot t_{c_{\min}}$$

$$0.2500000000\, t_{c_{\min}}$$

$$Mgt_f := Mg\beta \cdot t_{c_{\min}}$$

$$0.3846153845\, t_{c_{\min}}$$

$$Lat_f := La\beta \cdot t_{c_{\min}}$$

$$0.5000000000\, t_{c_{\min}}$$

$$AlINERTIA := \frac{1}{2} Alt_f \cdot t_{c_{\min}}^2$$

$$0.1250000000\, t_{c_{\min}}^3$$

$$MgINERTIA := \frac{1}{2} Mgt_f \cdot t_{c_{\min}}^2$$

$$0.1923076922\, t_{c_{\min}}^3$$

$$LaINERTIA := \frac{1}{2} Lat_f \cdot t_{c_{\min}}^2$$

$$0.2500000000\, t_{c_{\min}}^3$$

$$V_{core} := \left(B \cdot L \cdot \left(t_{c_{\min}}\right)\right)$$

$$48\, t_{c_{\min}}$$

$$AlV_{film} := \left(B \cdot L \cdot \left(Alt_f + Alt_f\right)\right)$$

$$24.00000000 t_{c_{\min}}$$

$$AlV_{total} := \left(B \cdot L \cdot \left(Alt_f + Alt_f + t_{c_{\min}}\right)\right)$$

$$72.00000000 t_{c_{\min}}$$

$$MgV_{film} := \left(B \cdot L \cdot \left(Mgt_f + Mgt_f\right)\right)$$

$$36.92307692 t_{c_{\min}}$$

$$MgV_{total} := \left(B \cdot L \cdot \left(Mgt_f + Mgt_f + t_{c_{\min}}\right)\right)$$

$$84.92307691 t_{c_{\min}}$$

$$LaV_{film} := \left(B \cdot L \cdot \left(Lat_f + Lat_f\right)\right)$$

$$48.00000000 t_{c_{\min}}$$

$$LaV_{total} := \left(B \cdot L \cdot \left(Lat_f + Lat_f + t_{c_{\min}}\right)\right)$$

$$96.00000000 t_{c_{\min}}$$

$$Alv_f := \frac{AlV_{film}}{AlV_{total}}$$

$$0.333333333$$

$$Alv_c := \frac{V_{core}}{AlV_{total}}$$

$$0.666666666$$

$$AlE_{comp} := AlE_f \cdot Alv_c + E_c \cdot Alv_f$$

$$10500.0000$$

$$AlP_{cr} := \frac{\pi^2 \cdot AlE_{comp} \cdot AlINERTIA}{L^2}$$

$$0.5696614583 \pi^2 \, t_{c_{\min}}^3$$

$$Mgv_f := \frac{MgV_{film}}{MgV_{total}}$$

$$0.434782608$$

$$Mgv_c := \frac{V_{core}}{MgV_{total}}$$

$$0.565217391$$

$$MgE_{comp} := MgE_f \cdot Mgv_c + E_c \cdot Mgv_f$$

$$4847.82608$$

$$MgP_{cr} := \frac{\pi^2 \cdot MgE_{comp} \cdot MgINERTIA}{L^2}$$

$$0.4046329197 \pi^2 \, t_{c_{\min}}^3$$

$$Lav_f := \frac{LaV_{film}}{LaV_{total}}$$

0.500000000(

$$Lav_c := \frac{V_{core}}{LaV_{total}}$$

0.500000000(

$$LaE_{comp} := LaE_f \cdot Alv_c + E_c \cdot Alv_f$$

5166.66666'

$$LaP_{cr} := \frac{\pi^2 \cdot LaE_{comp} \cdot LaINERTIA}{L^2}$$

$0.5606192131\pi^2 \, t_{c_{\min}}^3$

$$Al\rho_{comp} := Al\rho_f \cdot Alv_c + \rho_{core} \cdot Alv_f$$

0.100000000(

$$Mg\rho_{comp} := Mg\rho_f \cdot Mgv_c + \rho_{core} \cdot Mgv_f$$

0.0802173913

$$La\rho_{comp} := La\rho_f \cdot Lav_c + \rho_{core} \cdot Lav_f$$

0.0750000000(

$$Al\sigma_{comp} := Al\sigma_f \cdot Alv_c + \sigma_{core} \cdot Alv_f$$

66000.0000(

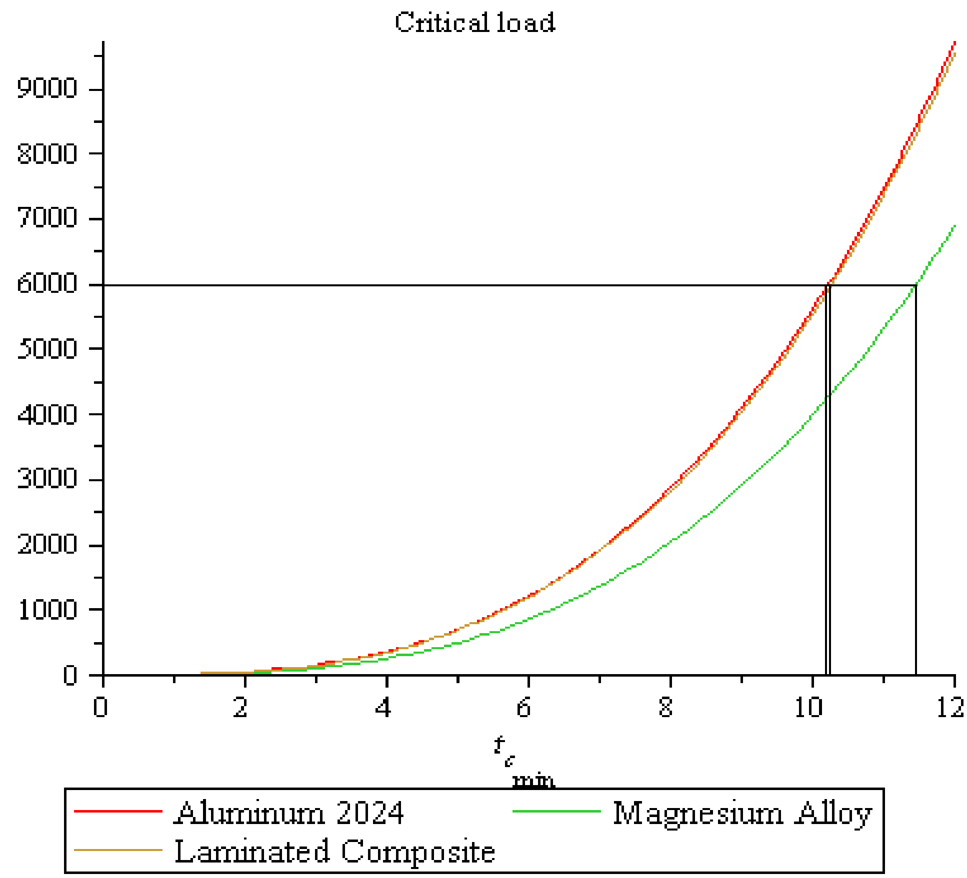
$$Mg\sigma_{comp} := Mg\sigma_f \cdot Mgv_c + \sigma_{core} \cdot Mgv_f$$

51304.3478:

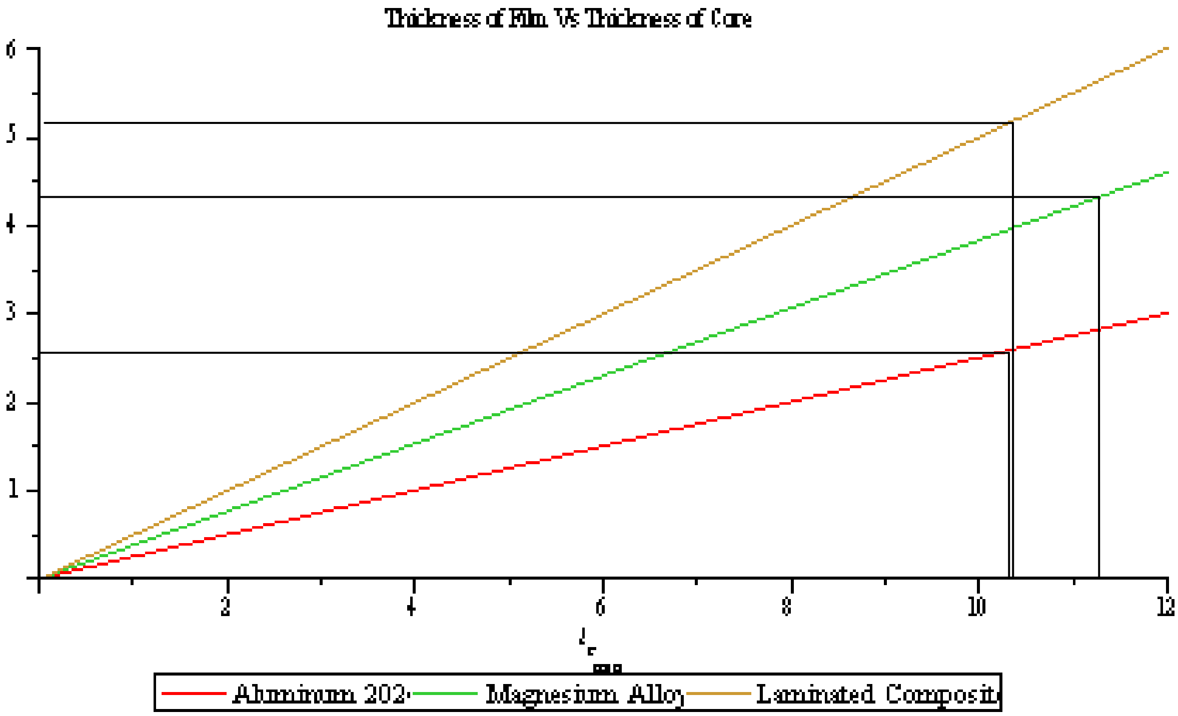
$$La\sigma_{comp} := La\rho_f \cdot Lav_c + \sigma_{core} \cdot Lav_f$$

33000.0250(

$$plot\left(\left[AlP_{cr}, MgP_{cr}, LaP_{cr}\right], t_{c_{\min}} = 0..12, title = \text{"Critical load ,"} legend = [\text{"Aluminum 2024","Magnesium Alloy","Laminated Composite"}]\right)$$



$plot\left(\left[Alt_f, Mgt_f, Lat_f\right], t_{c_{\min}} = 0..12, title\right.$
= "Thickness of Film Vs Thickness of Core", $legend$
= ["Aluminum 2024", "Magnesium Alloy", "Laminated Composite"]$\left.\right)$



$$Alcost := B \cdot L \cdot (2 \cdot Alt_f) \cdot Al\rho_f \cdot Alcost_{film} + B \cdot L \cdot \left(t_{c_{\min}}\right) \cdot \rho_{core} \cdot cost_{core}$$

$$72.00000000 t_{c_{\min}}$$

$$Mgcost := B \cdot L \cdot (2 \cdot Mgt_f) \cdot Mg\rho_f \cdot Mgcost_{film} + B \cdot L \cdot \left(t_{c_{\min}}\right) \cdot \rho_{core} \cdot cost_{core}$$

$$84.00000000 t_{c_{\min}}$$

$$Lacost := B \cdot L \cdot (2 \cdot Lat_f) \cdot La\rho_f \cdot Lacost_{film} + B \cdot L \cdot \left(t_{c_{\min}}\right) \cdot \rho_{core} \cdot cost_{core}$$

$$96.00000000 t_{c_{\min}}$$

$plot\left([Alcost, Mgcost, Lacost], t_{c_{\min}} = 0..12, \text{title} = \text{"Cost Comparision"}, legend = [\text{"Aluminum 2024"}, \text{"Magnesium Alloy"}, \text{"Laminated Composite"}]\right)$