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# STRUCTURAL OPTIMIZATION FOR COST

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***Abstract:*** *The paper deals with the cost of composite materials. It shows, that there are several benefits using composite materials, but to select the proper composite one should know its properties better. The factors governing fibre selection include; density, cost, strength and modulus. An example shows the cost calculation of a composite beam with prepreg.*
***Keywords:*** *composite materials, cost calculation, fibre selection*

## 1. INTRODUCTION

Composites offer engineers a new freedom to optimize structural design and performance. Composites have several advantages over conventional metallic structures. The most significant of these are:

- Low density leads to high specific strength and modulus. Very strong and stiff structures can be designed, with substantial weight savings.
- Fibre can be orientated with the direction of principle stresses, increasing structural efficiency.
- Exceptional environmental and corrosion resistance.
- Improved vibration and damping properties.
- The ability to manufacture complex shapes and one offs from low cost tooling.
- Very low and controllable thermal expansion.
- Excellent fatigue resistance, carbon fibre composites can be designed to be essentially fatigue free.
- Potential for energy absorbing safety structures.
- Damaged structures can be easily repaired.

The costs of the composites are very different. Some of them are relatively cheap, some are expensive. The aim of this study is to show some information about cost calculation, to help designers to choose the proper material. For comparison the main metals, the wood and the concrete is compared to composites through density, tensile modulus and tensile strength [1]. Figure 1-3 show these comparisons.

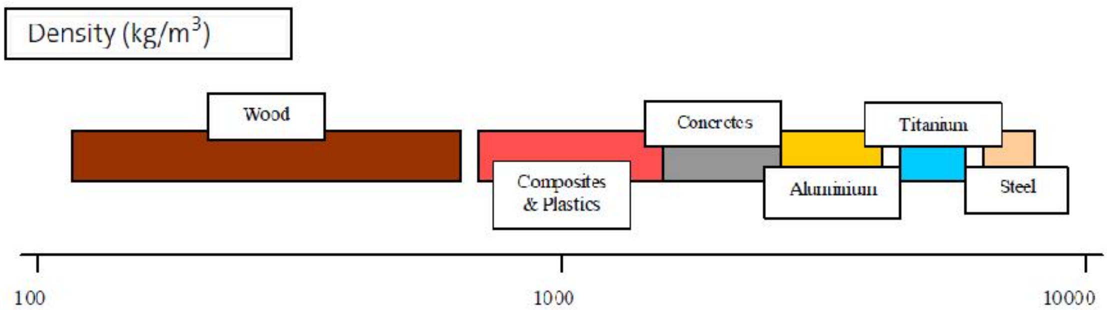


**Figure 1**. Comparison of the density of different materials

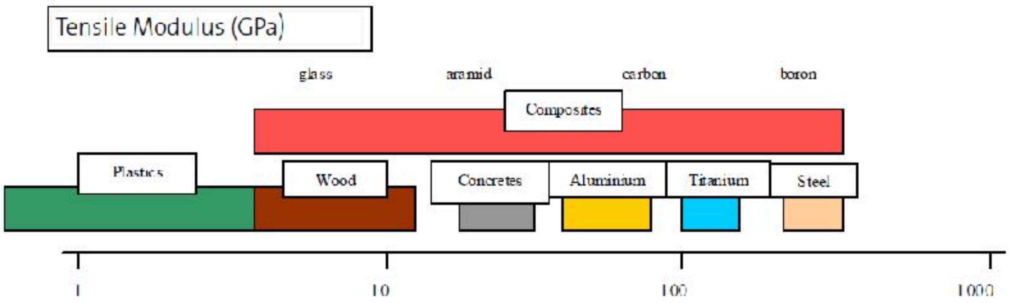


**Figure 2**. Comparison of the tensile modulus of different materials

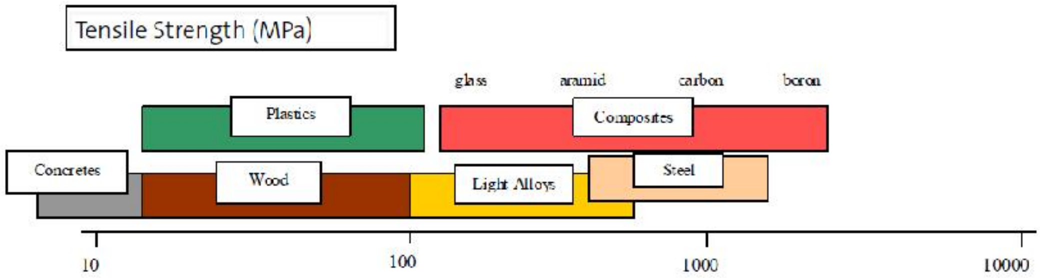


**Figure 3**. Comparison of the tensile strength of different materials

## 2. KEY FIBRE SELECTION CRITERIA

Within the composite materials there is still a great difference between the properties. Factors governing fibre selection include; density, cost, strength and modulus. Figures 4 to 7 give comparisons of these factors for a range of fibre types.

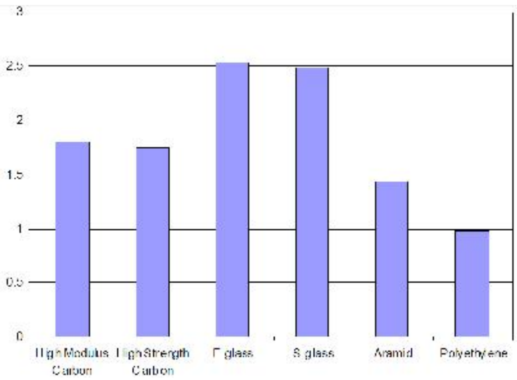


**Figure 4**. Relative Properties – Density

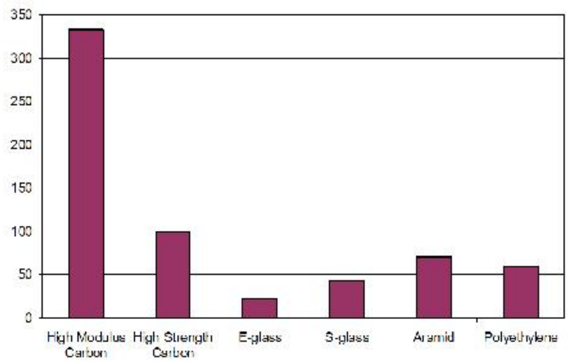


**Figure 5**. Relative Properties – Cost Ratio

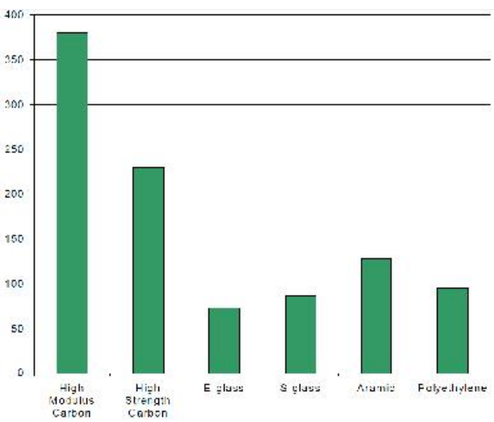


**Figure 6**. Relative Properties – Modulus GPa

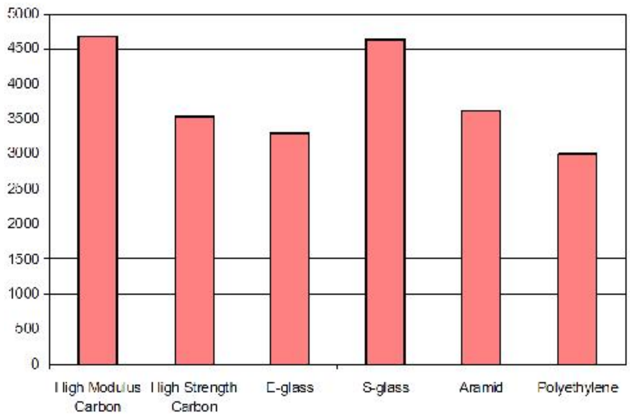


**Figure 7**. Relative Properties - Tensile Strength MPa

## 3. THE COST FUNCTION

Calculate different structures the cost function may include the cost of material, assembly, the different fabrication costs such as welding, surface preparation, painting and cutting, edge grinding, forming the geometry and are formulated according to the fabrication sequence. Not too much research has been done in this field, but we have to refer to the work of Klansek & Kravanja [3,4], Jalkanen [5], Tímár et al. [6], Farkas & Jármai [7,8,9]. For composites the calculation is very different and there are some good information available on the internet [10, 11].

### 3.1. The cost of material

$$K_M = k_M \rho V, \tag{1}$$

for steel the specific material cost can be $k_M = 1.0$ \$/kg, for glass fibre 20-30 \$/m$^2$ depending on the thickness. where $K_M$ [kg] is the fabrication cost, $k_M$ [\$/kg] is the corresponding material cost factor, $V$ [mm$^3$] is the volume of the structure, $\rho$ is the density of the material. For steel it is 7.85x10$^{-6}$ kg/mm$^3$. If several different materials are used, then it is possible to use different material cost factors simultaneously in Eq. (1).

### 3.2. The fabrication cost in general

$$K_f = k_f \sum_i T_i, \tag{2}$$

where $K_f$ [\$] is the fabrication cost, $k_f$ [\$/min] is the corresponding fabrication cost factor, $T_i$ [min] are production times. It is assumed that the value of $k_f$ is constant for a given manufacturer. If not, it is possible to apply different fabrication cost factors simultaneously in Eq. (2).

## 4. GENERIC ATL PROCESS LOOKS AS FOLLOWS

Tooling Manufacture
Clean Mould
1 Tooling Preparation
Pre-preg
2 ATL pre-preg tape n layers
Consumables
3 Thermo form
4 Curing
5 Remove part & debag
6 Part Finishing
7 Non Destructive Testing
8 Part Transfer

**Table 3** Mechanical properties and feedstock cost for typical prepreg laminates (fibre fraction-0.6, QI lay-up) [2]

| Fibre | Resin | Young's modulus (GPa) | Shear modulus (GPa) | Design tensile strength (MPa) | Laminate density (kg/m$^3$) | Feed-stock costb (€/kg) |
|---|---|---|---|---|---|---|
| E-glass | Epoxy | 22 | 8.7 | 110 | 1980 | 65 |
| Aramid | Epoxy | 30 | 11 | 112 | 1382 | 95 |
| HS carbon | Epoxy | 55 | 22 | 220 | 1560 | 100 |
| IM carbon | Epoxy | 68 | 27 | 280 | 1560 | 220 |

### 4.1. Fixed capital investments and manufacturing cost estimation for higher capacities of carbon fibre plant

Fixed capital investment estimation for similar kind of plant:

$$C_{FC,b} = C_{FC,a} (r_{mb}/r_{ma})^{0.7} \quad (3)$$

where,

$r_{ma}$ = monthly production rate of plant a

$r_{mb}$ = monthly production rate of plant b

$C_{FC,a}$= Fixed capital investment of plant a

$C_{FC,b}$ = Fixed capital investment of plant b

This method is an adaptation of the six-tenth-factor rule, which applies for use in estimation of equipment cost A similar rule is applied to fixed capital investment except that the absolute value of the power term is governed by following conditions:

- For the average chemical process, the power term will be 0.7 as shown in equation
- For very small installation or for processes employing extreme conditions of temperature or pressure, the value of power term will be from 0 3 to 0 5
- For plant achieving higher capacities through the employment of a high proportion of multiple units rather than large-sized equipment, the term will be 0 8

**4.2. Manufacturing cost estimation for carbon fiber plant:**

$$A_p = 0.09*C_{FC} + 16200*C_L*N + A_U \quad (4)$$

where

$A_p$ = Annual processing cost

$C_{FC}$ = Fixed capital investment

$C_L$= Labour charges (€/hr)

$N$ = Number of persons working per shift

$A_U$ = Annual utility and raw material cost

$A_p$ = 0 09*125000000 + 16200* (300/24)*25 + 150000*300

= 3100 / year for 20000 kg of carbon fibres

= 3100 €/kg of carbon fibre

The annual processing cost for $A_{p2}$ for a similar plant of a different size designed for annual production rate $R_2$ can be approximately calculated by

$$A_{p2} = 0.09*C_{FC1} (R_2/R_1)^{0.7}+ 16200*C_L *N_1 (R_2/R_1)^{0.25} + A_{u1} (R_2/R_1) \quad (5)$$

A similar approach for estimating manufacturing cost with a power factor of 0.8 for utilities is as

$$A_{p2} = 0.09*C_{FC1} (R_2/R_1)^{0.7}+ 16200*C_L *N_1 (R_2/R_1)^{0.25} + A_{u1} (R_2/R_1)^{0.8} \quad (6)$$

**Table 2.** Estimated fixed capital investment (excluding land, building and fire hydrant system)

| Plant capacity of carbon fibres tons/ year | Estimated fixed capital investment (Crores) | Estimated manufacturing cost of carbon fibres €/kg Eq.5 | Estimated manufacturing cost of carbon fibres €/kg Eq.6 |
|---|---|---|---|
| 20 | 12.5 | 45.8 | 45.8 |
| 100 | 35 | 39.1 | 30.3 |
| 300 | 65 | 37.4 | 23.6 |
| 600 | 100 | 36.5 | 20.4 |
| 1000 | 150 | 35.9 | 18.5 |

## 5. SIMPLE EXAMPLE FOR COST CALCULATION AT FRP

We have made a calculation of the composite beam cost considering the recurring and non-recurring cost system.

Part Dimensions and Features (Figure 8)

| | | | |
|---|---|---|---|
| Part Length | 10 m | Flange Width | 0.13 m |
| Web Height | 0.9 m | Flange Thickness | 0.02 m |

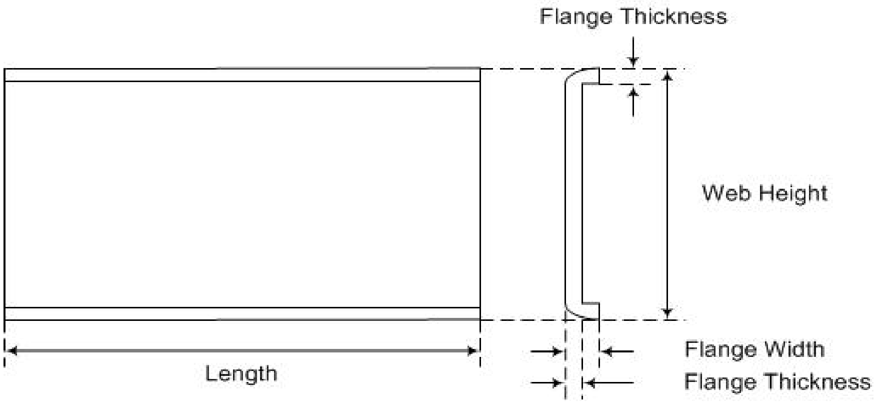

**Figure 8**. The composite beam cross section

### 5.1. Recurring Cost Summary Sheet

Labour Recurring Costs [2]

| Labour | Manufacturing Hours | Charge Rate €/hour | Cost € |
|---|---|---|---|
| Clean Mould Tooling | 1.99 | 64.3 | 127.9 |
| ATL Part | 5.26 | 138.5 | 728.5 |
| Forming | 5.68 | 80.4 | 456.7 |
| Autoclave Cure Part | 0.50 | 80.4 | 40.2 |
| Debag Part | 2.71 | 80.4 | 217.9 |
| "finishing" (machining) | 3.72 | 138.5 | 515.2 |
| Non Destructive Inspection | 5.30 | 80.4 | 426.1 |
| Part Transfer | n/a | n/a | 0.00 |
| | | Sub total | 2512.5 |
| Machine Rib Posts and de-burr on bench | 3.00 | 86.6 | 259.9 |
| Assembly metal Rib Posts to Part | 4.00 | 77.9 | 311.7 |
| Total Labour Recurring Costs | 32.16 | | 3084.0 |
| Total Material Recurring Costs | | | 9490.3 |
| Total Recurring Costs | | | 12574.3 per Part |

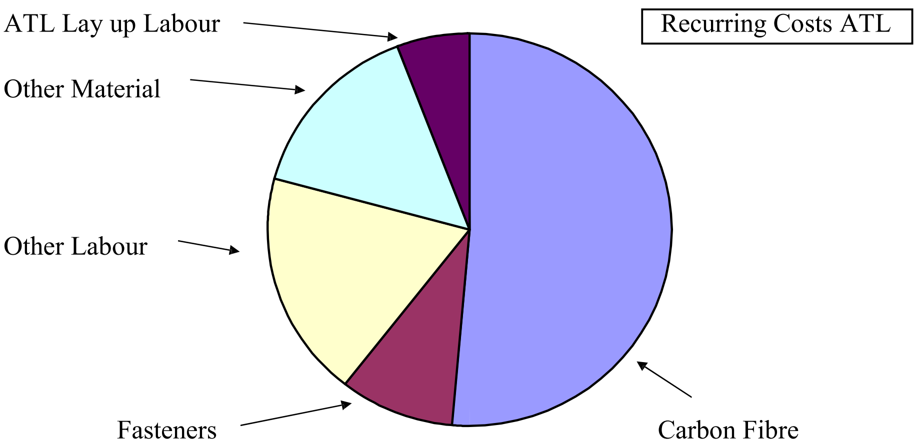

**Figure 9.** Distribution of the recurring costs at CFRP beam

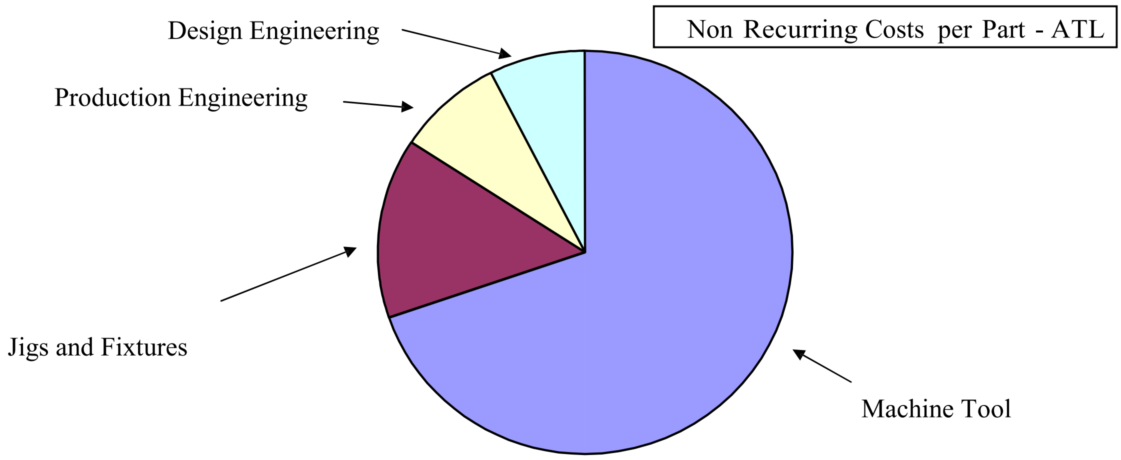


**Figure 10.** Distribution of the non-recurring costs at CFRP beam

## 6. CONCLUSION

The composites offer engineers new opportunities to optimize structural design and performance. Composites have several advantages over conventional metallic structures. The paper deals with the cost of composite materials. It shows, that to select the proper composite one should know its properties better. The factors governing fibre selection like density, cost, strength and modulus have an important role. An example shows the cost calculation of a composite beam.

## ACKNOWLEDGEMENTS

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## REFERENCES

[1] http://www.advanced-composites.co.uk/data_catalogue/catalogue%20files/sm/SM1010-INTRO%20TO%20 ADV%20COMPS-Rev06.pdf
[2] http://www.acoste.org.uk/uploads/EMC_seminars/COST-STUDIO-example.pdf
[3] Klansek,U. & Kravanja,S. (2006a) Cost estimation, optimization and competitiveness of different composite floor systems – Part 1. Self manufacturing cost estimation of composite and steel structures, *Journal of Constructional Steel Research*, **62** No. 5, pp. 434-448.
[4] Klansek,U. & Kravanja,S. (2006b) Cost estimation, optimization and competitiveness of different composite floor systems – Part 2. Optimization based competitiveness between the composite I beams, channel-section and hollow-secsion, *Journal of Constructional Steel Research*, **62** No. 5, pp. 449-462.
[5] Jalkanen,J. (2007) *Tubular truss optimization using heuristic algorithms*, PhD. Thesis, Tampere University of Technology, Finland. 104 p.
[6] Tímár,I., Horváth,P. & Borbély,T. (2003) Optimierung von profilierten Sandwichbalken, *Stahlbau*, **72** No. 2. 109-113.
[7] Farkas,J. & Jármai,K. (1997) *Analysis and Optimum Design of Metal Structures*. Balkema Publishers, Rotterdam, Brookfield,
[8] Farkas J. & Jármai K. (2003) *Economic design of metal structures*, Millpress Science Publisher, Rotterdam, 340 p. ISBN 90 77017 99 2
[9] Farkas,J.,Jármai,K.: Design and optimization of metal structures, Horwood Publishers, Chichester, UK, 2008. 328 p. ISBN: 978-1-904275-29-9
[10] R. G. Boeman, N. L. Johnson, "Development of a Cost Competitive, Composite Intensive, Body-in-White," Proceedings of 2002 Future Car Congress, Arlington, Virginia, June 3-5, 2002
[11] Michael G. Bader, Selection of composite materials and manufacturing routes for costeffective performance, Composites: Part A 33 (2002) 913–934.