ANALYSIS OF THE IMPACT OF MATERIAL SELECTION ON THE WEIGHT AND COST OF CANTILEVERS AND GIRDERS OF CRANES

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Abstract:

Crane load-bearing structures are traditionally made of structural steel. Aluminium alloys are used for low load capacity and reach, and composites have recently been proposed for specific crane models, but without a systematic application study. This paper analyses how material choice affects the mass and material cost of the main structural elements under a simple loading case. Materials include S275 steel, 6061 T6 aluminium, and carbon- and glass-fibre composites. Rectangular cross-section carrier elements per EN 10210-2 were considered. The analysis calculates maximum load, stress, and deflection for various beam lengths, materials, and cross-sections. Results show the benefits of each material application.

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1 Introduction

Structural steels are common materials for constructing cranes and related equipment because of their affordability, advanced welding capabilities, and high modulus of elasticity. The steel's high density increases weight, which places greater demands on drive systems, transportation, and assembly processes, leading to higher overall costs. One method to reduce weight is by using a sandwich structure made of steel. Proper forming techniques can achieve weight savings of 19-40% compared to standard steel structures [1].

The second approach involves researching alternative materials, considering their stiffness, density, and cost, to help reduce overall costs and weight. The first alternative material is aluminium, used in certain cranes and related structures, where its lower density decreases weight. Examples include applications for auxiliary construction on marine platforms, assembled and disassembled by hand and used occasionally [2]. The comparative analysis shows that aluminium achieves a 50% weight reduction compared to steel for a bridge crane with a 30 m span and a maximum load of 10 t [3].

Another alternative material includes carbon fibre-based composites. For example, in constructing a crane with a 29 m tower height and a 46.5 m reach [4], using composites results in a 75% weight reduction compared to steel but also with four times the initial cost of the load-bearing structure. When propulsion system costs are included, the composite-based design, which requires less power, ends up being twice as expensive as steel-based construction [4]. Overall, considering energy consumption costs, the composite solution has slightly lower total costs over the crane's lifetime. Another example of applying carbon fibre for long reach and light load is presented in [5], where the carbon-fibre design weighs 20% of the steel-based design for the same load and reach. Additionally, in [8], a comparison of a large mobile crane indicates that composite materials offer 34% weight savings over steel.

A comparison of the application of different materials for advanced bridge crane construction with a pre-load [7] still shows that aluminium and carbon-fibre composites provide solutions weighing 40% and 16%, respectively, of the equivalent steel structure for the same small span and load weight. However, only a single design is analysed. For the cantilever crane with a short reach and load, weights equal to 21% and 29% of the

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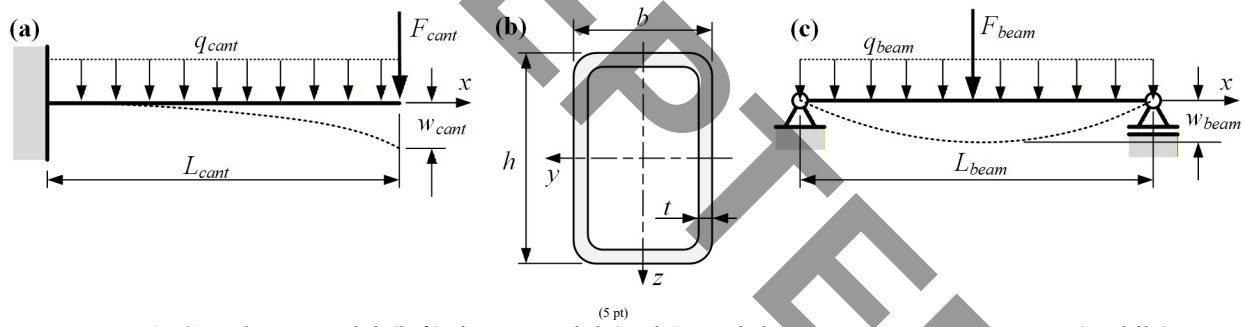
steel version's weight were obtained for 6061 T6 aluminium and a carbon fibre-based composite, respectively [8].

The third alternative material, glass fibre composite, was presented in a slightly broader analysis conducted in [9], which compared the use of different materials for a crane with a low weight and load capacity (500 kg) where S275, 6061 T6, fiberglass composite, and carbon composite were used. Weight savings of 36%, 44%, and 82% are achieved compared to steel. Carbon fibre is the most expensive, while steel, aluminium, and glass fibre are cheaper, at 66%, 56%, and 69% of carbon fibre's cost, respectively.

This article aims to systematically analyse the application of four materials (S275 steel, 6061 T6 aluminium alloy, carbon fibre composite, and glass fibre composite) for cantilever spans up to 7 meters with rectangular cross-sections, in accordance with EN 10210-2-2019. It seeks to determine the maximum load within feasible limits based on acceptable stress and deflection, which in turn influences the structure's mass and cost, depending on the span and load weight. Beyond establishing results for a specific geometry, the goal is to develop a foundation for a systematic analysis method applicable to other geometries and materials. The remaining sections are organized as follows: Section 2 describes the design and calculation process, including cost estimation; Section 3 presents the results obtained; and Section 4 provides the conclusions.

2 Design Principle

Steel and aluminum structures are typically designed in accordance with Eurocode 3 and 9. Recently, Eurocode has been evolving more rapidly with the introduction of the EN 13001 standard, which will also be applied here. The process of calculating load-bearing structures generally involves the following steps: (i) selecting a static model, (ii) calculating design loads by applying partial safety and dynamic factors to the static loads, and (iii) computing design stresses and deflections and comparing them with the allowable limits values.



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Figure 1. Cantilever model (left), beam model (right), and the cross-section geometry (middle)

Figure 1a shows a static model of a cantilever with a load as a concentrated force at the end of the cantilever and its own mass as a continuous load, which presents the mass of the hoist load and the mass of the crane itself from Load combination A (i.e. regular load) as defined by EN 13001-2. The calculation continuous (q_{calc}), and concentrated (F_{calc}) loads are thus calculated in accordance with EN 13001-2 by multiplying the static continuous load q (which represents the weight of the structure) and the concentrated load F (from the load mass) with the related partial dynamic factor (ϕ) and the partial safety factor (γ) so that:

$$q_{calc} = f_1 g_1 q = f_1 g_1 A r \tag{1}$$

$$F_{calc} = f_2 g_2 F \tag{2}$$

where the continuous load is determined from the cross-section area (A) and the density of the material (ρ).

Deflection (w_{cant}) and stress (σ_{cant}) are determined from analytical equations for a cantilever [10], and compared against permissible values. Permissible deflection is calculated from length of the cantilever/beam and stiffness index (I_S) while permissible stress is calculated from the yield strength of a given material (σ_{yield}) and general resistance factor (γ_m):

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$$w_{cant} = \frac{F_{calc} L_{cant}^3}{3EI} + \frac{q_{calc} L_{cant}^4}{8EI} \leq \frac{L_{cant}}{I_S} \tag{3}$$

$$s_{cant} = \frac{F_{calc} L_{cant}}{W} + \frac{q_{calc} L_{cant}^2}{2W} \leq \frac{s_{yield}}{g_m} \tag{4}$$

Equivalently, for the beam, deflection (w_{beam}) and stress (σ_{beam}) are equal to:

$$w_{beam} = \frac{F_{calc} L_{cant}^3}{48EI} + \frac{5}{384} \frac{q_{calc} L_{beam}^4}{EI} \leq \frac{L_{beam}}{I_S} \tag{5}$$

$$s_{beam} = \frac{F_{calc} L_{beam}}{4W} + \frac{q_{calc} L_{cant}^2}{8W} \leq \frac{s_{yield}}{g_m} \tag{6}$$

The next step is to determine the length of cantilevers and beams, and concentrated loads. Three cantilever and beam lengths were selected as $L_{cant} = \{1, 4, 7\}$ m and $L_{beam} = \{1, 7, 14\}$ m. Loads were chosen as the maximum loads for each combination of cross-section area and cantilever length that satisfy both deflection and stress limits. Therefore, for each cross-section and cantilever length combination, the maximum feasible load is determined as the smaller of the loads calculated from Eq. (3) and (4):

$$F_{cant} = \min\left\{ \frac{3EI}{750L^2} - \frac{3q_{calc} L}{8}, \frac{s_{yield} W - q_{cant}/2}{L} \right\} \Big/ (f_2 g_2) \tag{7}$$

Equivalently, the maximum feasible load for each beam is calculated from Eqs. (5) and (6) as:

$$F_{beam} = \min\left\{ \frac{48EI}{750L^2} - \frac{240q_{calc} L}{384}, \frac{4s_{yield} W}{L_{beam}} - \frac{q_{calc} L_{beam}}{2} \right\} \Big/ (f_2 g_2) \tag{8}$$

Maximum feasible loads are then used to calculate deflection and stress for each case (Eqs. (3) and (4) for cantilever, and (5) and (6) for beam case), which are compared against permissible values, thus confirming that the chosen maximum load is correct. For each correct solution, the weight of the console is calculated as

$$m = r\, AL \tag{9}$$

While the cost is calculated as (material cost per mass c are listed in Table 1):

$$C = mc \tag{10}$$

Numerical values for (i) cross-sectional areas, (ii) material properties, (iii) safety factors, and (iv) permissible deflection values are obtained as follows. Cross-sectional area values comply with EN 10210-2-2019 for all four materials (Figure 1b). Profiles from various steel grades are readily available worldwide in accordance with said standard, and some manufacturers also offer the same dimensions in aluminum. By contrast, composite materials are not readily available on the market; they must be manufactured to order. To facilitate meaningful comparisons across the four investigated materials, it was assumed that the same geometry applied to all four.

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Material properties of each material are provided in Table 1, obtained from [4].

Table 1. Properties of materials [4].

	S275	6061 T6	Carbon fiber composite
σ_{yield} [MPa]	275	275	2200
E [MPA]	210 000	69 000	180 000
ρ (kg/m3)	7800	2700	1600
c [EUR/kg]	5	10	80

Safety factors include partial safety factors (ϕ_1 = 1.1, γ_1 = 1.22, ϕ_2 = 1.1, γ_2 = 1.34) and a general resistance factor (γ_m), all obtained EN 13001-2. Stiffness index was determined as for normal workshop cranes with medium positional accuracies which can use simple control systems (I_S = 750) as defined by ISO 22986 standard.

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3 Experimental investigation

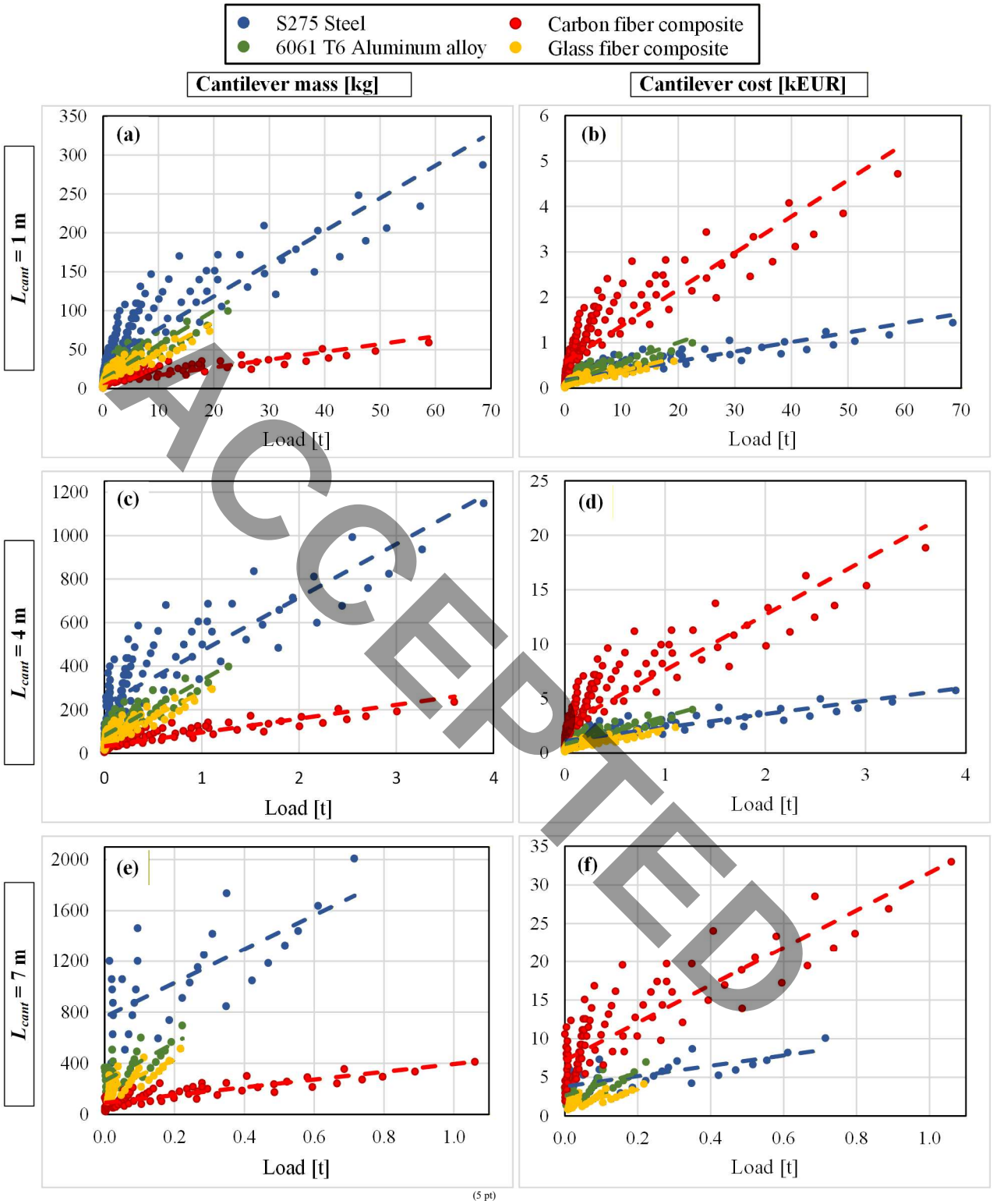
The results for all three cantilevers and beam lengths are shown in Figures 2 and 3, respectively. For the cantilever case, the maximum load is always limited by the deflection limit. For the steel beam, at the shortest span and for medium-to-maximum cross-section areas, the maximum load is limited by the maximum stress, whereas the maximum deflection is the limiting requirement in all other cases. Since cases where stress is the limiting requirement involve somewhat unrealistic combinations of high load and small span, it may be concluded that deflection is the principal limiting parameter. Hence, higher-strength steel will not change the results, since material choice influences deflection through the modulus of elasticity, which has the same value for all types of steel. Some combinations of cross-section and cantilever/beam length, especially those with low cross-sectional height and maximum cantilever length, resulted in negative load values, indicating that the cantilever/beam weight will cause excessive deflection. Such combinations were not taken into further consideration.

From the results for the cantilever case, it is possible to observe the following:

1) Steel always gives the highest structural mass for the same load and reach
2) Carbon fiber provides the highest material cost for the same load and reach
3) Aluminum and glass fibers exhibit structural masses that fall roughly midway between steel and carbon fiber solutions at a cost comparable to steel.
4) Steel supports the heaviest loads at short to medium reach, while carbon offers the highest payload at long reach due to its lower dead weight compared to high rigidity.

From the results for the beam case, it is possible to conclude the following:

1) Steel always gives the highest mass for the same load and reach
2) Carbon fiber provides the highest material cost for the same load and reach
3) Carbon always gives the highest load capacity, although not necessarily much higher than steel.
4) Aluminum and glass can have a small to medium load capacity with about half the weight of steel at a similar, relatively low cost.



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Figure 2. Results for cantilever case

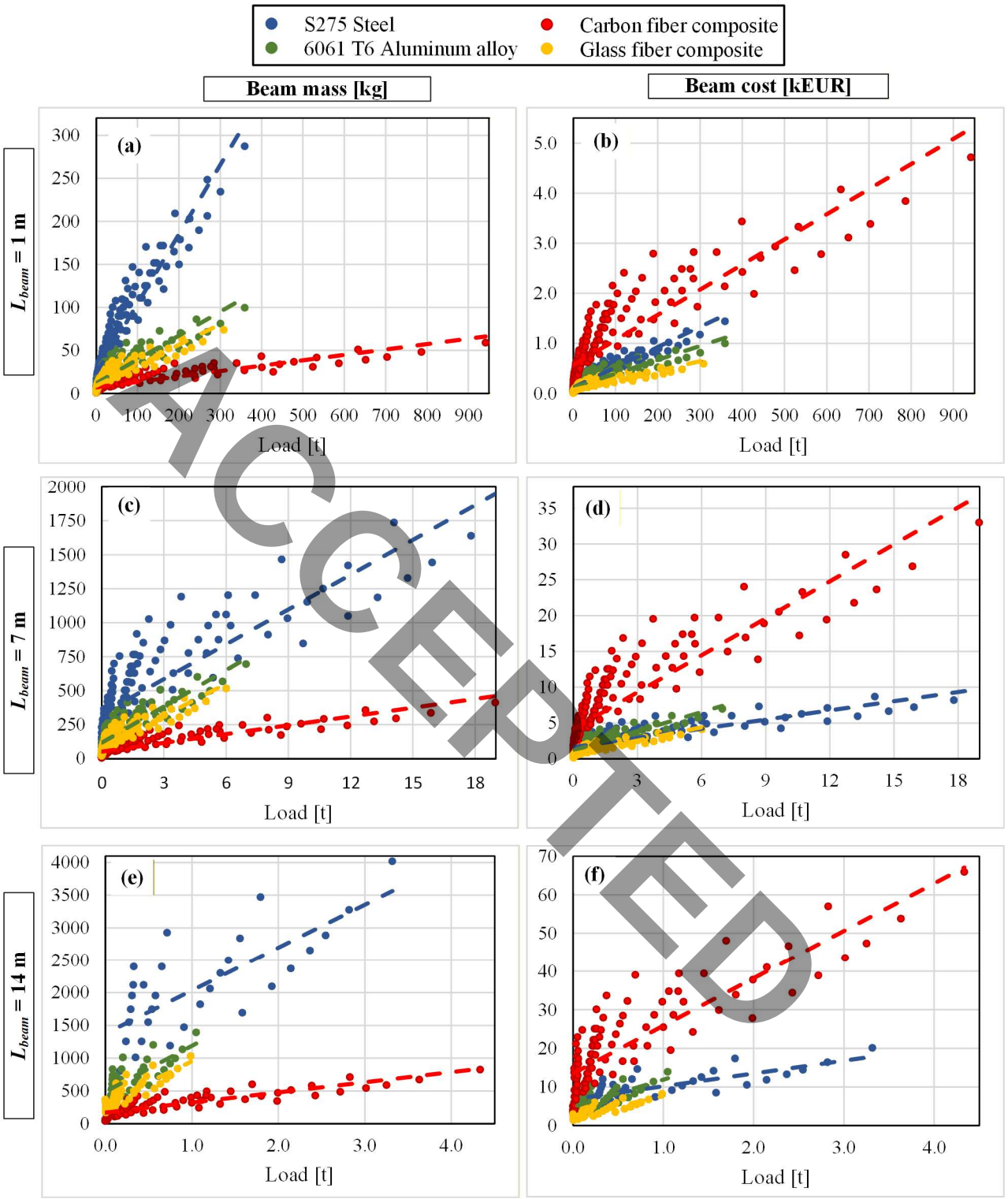


Figure 3. Results for cantilever case.

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4 Experimental investigation

The article provides a detailed analysis of four materials—steel, aluminum, carbon fiber composites, and glass fiber composites—for the design of two basic load-bearing elements: brackets and beams. The results indicate that steel consistently offers the heaviest and most cost-effective solutions, while carbon fiber composite

solutions are at the opposite end. Options using aluminum and glass-fiber composites offer a better balance of weight and cost than steel and carbon-fiber composites and are feasible for small- to medium-sized loads.

Steel is recommended when the lowest material price is the top priority. Carbon is suggested when minimizing weight is most critical. Aluminum and glass suit small to medium load capacities, offering significant weight savings over steel at a slightly higher material cost. It can be noted that comparing these four significantly different materials can also help determine the relationships among similar materials within the same group. For example, the relationships obtained here will be approximately valid if S235 or S355 is used instead of S275 steel. Additionally, it should be emphasized that the analysis includes only the cost of the material itself, excluding manufacturing and operational costs, which, if taken into account, may show carbon fiber as the overall most cost-effective solution [4].

The proposed method provides the foundation for a more comprehensive, systematic analytical approach that incorporates more detailed calculations, optimized cross-sections, and guidance on selecting materials and dimensions to meet the required operating parameters.

References

[1] P. K. Gangurde, N. P. Salunke, "Design analysis and optimization of crane platform base on composite structural sandwich plate", *International Journal of Mechanical Engineering and Technology (IJMET)*, vol. 9, no. 4, p. 878–885, 2018. *(Journal article)*

[2] V. Ntaskagianni, "Aluminium in Modular Structures for Offshore Lifts", *Key Engineering Materials*, vol. 710, p. 402-405, 2016. *(Journal article)*

[3] L. Solazzi, N. Zrnić, "Modal Analysis of Gantry Crane and Superstrucutre Made by Steel and Alluminium Alloy", *FME Transactions* vol. 53, p. 225-232, 2025. *(Conference paper)*

[4] L. Solazzi, "Feasibility of the tower crane jib made of composite material", 52nd Conference on Engineering Mechanical Design and Stress Analysis (AIAS 2023), *IOP Conf. Series: Materials Science and Engineering* vol. 1306, 012010, 2024. *(Conference paper)*

[5] A. Tulekov, B. Togizbayeva, A. Kenesbek, and A. Zabiyeva, "The Use of Composite Materials in the Production of Tower Cranes", *Acta Polytechnica Hungarica* Vol. 20, No. 9, 2023. *(Journal article)*

[6] L. Solazzi, "Feasibility study of a very big crawler crane using composite materials", *Composites Part C: Open Access* 13, 100430, 2024 . *(Journal article)*

[7] L. Solazzi, Tomasi, I. "Design of an Overhead Crane in Steel, Aluminium and Composite Material Using the Prestress Method", *J. Compos. Sci.* 8, 380, 2024. *(Journal article)*

[8] L. Solazzi, N. Danzi, "Jib crane lightweighting through composite material and prestressing technique", *Composite Structures* 343, 118283, 2024. *(Journal article)*

[9] L. Solazzi, M. Vaccari, "Feasibility study of a jib crane made of composite materials considering deterministic and probabilistic approach", *Composites Part C: Open Access* 9, 100323, 2022. *(Journal article)*

[10] H.A. Rothbart, T.B. Brown, "Mechanical Design Handbook", Mcraw-Hill, New York, 2006. *(Book)*

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