COMETa 2014
2nd INTERNATIONAL SCIENTIFIC CONFERENCE
2nd - 5th December 2014
Jahorina, B&H, Republic of Srpska
University of East Sarajevo
Faculty of Mechanical Engineering
Conference on Mechanical Engineering Technologies and Applications

ROLE AND IMPORTANCE OF LIGHTWEIGHT DESIGN IN THE PRODUCT DEVELOPMENT

Aleksandar Miltenović[1], Milan Banić[2], Vojislav Miltenović[3]

Abstract: Modern society is characterized by a fast rise of world population. This entails excessive consumption of all resources of the country. Land resources are limited and can be reached relatively quickly to their exhaustion. In this sense, the most important resources are related to the materials and energy. The question arises as to slow down the excessive consumption of these resources. One possible approach is to reduce spending of material and energy resources by using lightweight design. This paper provides an overview and presentation strategy lightweight design as well as a systematic approach to lightweight design.

Key words: lightweight design, light materials, development strategy

1. INTRODUCTION

The basic requirement for the successful fulfillment of the function of a structure is that the working stresses in critical sections, do not exceed the allowed limit. The request oflightweight design is to use maximal available material resources in terms of capacity with the minimum weight. We also have to bear in mind the stiffness and allowable strain in the operating conditions. Since there is a great number of variables such material, fabrication, joining, assembly, maintenance and recycling, designers are dealing with different controversies to reach optimum light construction. The most influential parameter was actually costs related to applied materials, manufacturing and testing. In this sense, it is necessary for the entire product life detailed analysis of benefits of application of lightweight materials and cost of producing the construction. The application of lightweight construction is present in spacecraft in wagon construction, shipbuilding, especially in making car body.

One of the turning points of application of lightweight structures is the advantages of joining by welding. High load capacity of welds and the possibilities of their design and performance significantly enhance the concept of constructions structure. As examples may be mentioned laser welded hulls of large aircraft (Airbus A 318, A 380) or the modern way of making body of passenger cars. By usingnumerical

[1]Dr Aleksandar Miltenović, research assistant, Faculty of Mechanical Engineering, Niš, amiltenovic@yahoo.com
[2]Milan Banić, assistant, Faculty of Mechanical Engineering, Niš,milan.banic@outlook.com
[3]Prof. dr Vojislav Miltenović, University of Niš, vojamiltenovic@yahoo.com

methods it is possible today detailed and accurate analysis of stress and strain state of the structure, which enables an optimal lightweight construction.

Key role in developing and implementing lightweight design have new materials. For example, a compound of metal and polymer materials provides a high quality material that integrates extreme rigidity and low weight. Use the "active elements" (transducers) can obtain in future such material systems that can adapt to any kind of external load.

So we can say that the **lightweight design is interdisciplinary engineering approach which aims to develop a system of minimum weight that in the given conditions successfully fulfill the desired function with optimal utilization of available resources.** Requirements for lightweight structures are always extreme, always related to new materials, information and production technologies and solving specific problems.

2. STRATEGIES OF LIGHTWEIGHT DESIGN

The most important factors for lightweight design are methods of design, materials and manufacturing technology. By using strategy of lightweight design is possible to come to optimal solution. In the course of development process of lightweight structures the following strategies play a key role:

- Terms for performing lightweight design.
- The concept of lightweight design.
- Materials for lightweight design.
- Types of lightweight structures.

2.1 Terms for performing lightweight design

Key role for terms for performing lightweight design are:

- Purpose of lightweight design,
- Savings by using lightweight design,
- Influence of lightweight design on environment – eco-lightweight design

The purpose of the lightweight design includes requirements related to the function of the entire system. Reducing weight is only necessary and appropriate if contributes to the fulfillment of prescribed function of the system. In this sense requires a detailed analysis of service conditions, reliability, security and functionality of the entire structure.

Savings using lightweight construction involves reducing production costs, reduce consumption of materials and production processes by integrating these functions.

Eco lightweight design must meet the requirements related to the ecology and economy of the structure of lightweight constructions. These requirements depend on the social, political, legislative and market.

So, in terms of performance lightweight construction highlighted are a number of factors that are related to the structure of lightweight construction in terms of legislation (regulations and standards), operating conditions, customer demands, maintenance, required to fulfill the work function claims related to environmental protection, etc.. These factors are taken as a pre-set size and task developer that has to take them into consideration.

2.2 Concept of lightweight design

The concept of lightweight design is often considered as a system of lightweight construction, and it represent a method for reducing the weight of technical systems or subsystems that take into account all the variable activity in the system as well as general technical and economic constraints. Weight of the entire system can be reduced by the systematic analysis of the applied structure of parts, components and modules and their optimization in a system of lightweight design. On the structure are implanted sensors and control units, by using active materials, composite materials, piezoelements and Carbon-Nano-Tubes.

The weight reduction can also be achieved by developing the structure with an increased integrity and function of the parts. When building lightweight structures in the fabrication and assembly processes should be identify the potential for weight reduction.

2.3 Materials of lightweight design

The number, variety and quantity of materials used today are increasing. It is estimated that today in the application of more than 70,000 types of technical material. As a consequence of the rapid development of military technology in the last 50 years in use is entered more new materials than in all previous centuries. Materials based on iron are stagnating in the production and consumption, while increasing the share of application of aluminum, titanium, magnesium and other alloys, polymer and ceramic composites and special materials. The required characteristics of the material can be obtained by a combination of materials with specific properties, where the dominant role have composite materials.

It is anticipated that in the 21st century will be the intensive production and use of polymeric materials and in a mid-century should be counted with increasing application of composite and ceramic materials

2.3.1 Materials, properties and application

All the materials used in the technique can be classified into four groups: metals, polymers, ceramics and composites. Composite materials consist of the components of the different groups (Figure 1). Semi-and super-conductors, silicone and conductive polymers can be precisely determined which group they belong to.

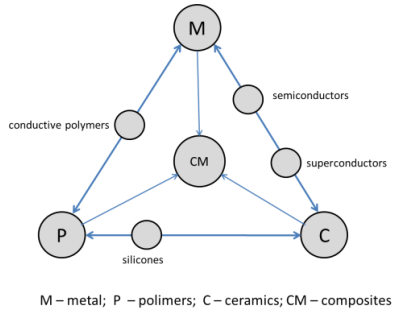

Figure1. *Materials by groups*

Overview of the materials used in the technique is given in Fig.2.

Rating the quality of materials is carried out according to their characteristics. In this sense, the interest are the following material properties:

- Mechanical characteristics (yield strength, strength, durability, hardness...),

- Thermalcharacteristics (thermal conductivity, hardening, …)
- Chemical characteristics,
- Electrical characteristics,
- Price, etc.

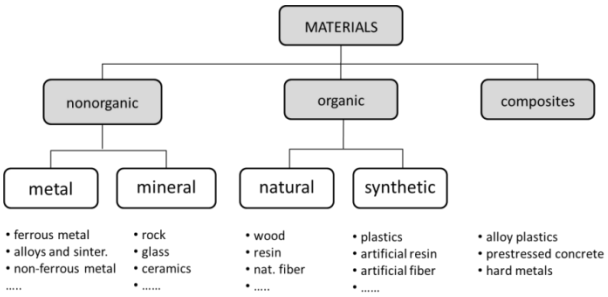

Figure 2. *Overview of the materials used in the technique*

2.3.2 Characteristics of materials used in lightweight design

Lightweight design materials must meet a number of requirements. Requirements related to the structure of lightweight construction should preferably be fulfilled by using lightweight materials of high stiffness and strength. Weight reduction can be achieved by using lower density materials. Table 1 provides an overview of the most commonly used material for lightweight construction.

Table 1. *Overview of materials used for lightweight constructions*

1. Metal materials	2. Non-metal materials
• Aluminum, • Magnesium, • Titan, • Steel (conventional lightweight design)	• Plastics • Ceramics
3. Composite materials	**4. Active materials**
• Composite fiber • Ceramic composite materials • Metal composite materials	• Piezoelectrical materials • Carbon Nano-Tubes (CNT)

When selecting materials should bear in mind the advantages and disadvantages for use in lightweight design (Table 2). One of the most commonly used methods of weight reduction is achieved by a combination of different materials, where the dominant role is played by the application of composite materials. When changing the material it is necessary to test the geometry and technology of manufacture and joining.

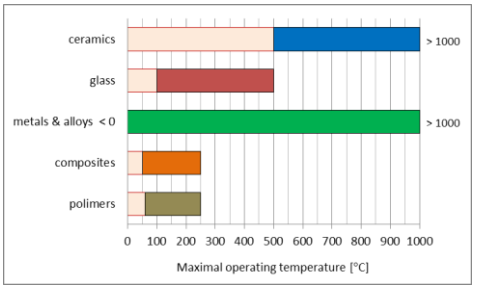

Figure 3. *Operating temperatures of materials*

The material properties largely depend on the operating temperature. Therefore, the area of the operating temperature of the product is a very important factor for the choice of materials. For the above-mentioned materials is given in Figure 3 in the region of maximum operating temperature. At operating temperatures above 1000°C primarily should be used ceramics and fire-resistant alloys. For the area of low operating temperature metal alloys should be used.

Table 2. Advantages and disadvantages of lightweight design materials

METALS	
Advantages	Disadvantages
• high toughness • high elasticity module • high hardness • high wear resistance, • good electrical and thermalconductivity • suitable for casting, plastic deformations and welding • easy for design	• high density • sensitivity on chemicals and some on atmosphere • low damping properties • max operating temperature under 1000°C
POLIMERS	
• low density, • flexibility and deformability • relatively good corrosionresistance • good electrical and thermalinsulator • good damping properties • some polymers are transparent • suitable for getting colors • easy for forming • easy and cheapmanufacturing of complex parts	• low hardness, • no thermalresistance • low stiffness • low wear resistance, • max operating temperature under 200°C, • flammability (ecological problem)
CERAMICS	
• excellent wear resistance • high temperature resistance • corrosion resistance • good electrical insulator • small thermalelongation • high max operating temperature (>1000°C) • good antifriction properties (ceramic bearings) • relatively low density	• low toughness (high fragility) • problems of manufacturing, finishing, testing and thermalresistance • necessary high Know-how for constructive forming
COMPOSITES	
• high hardness, • high stiffness • low weight • good chemical and thermalresistance • good wear resistance • possible optimisation of parts for loads • high flexibility in case of selection of composite components	• relatively low toughness • anisotropic properties • expensive manufacturing • manufacturing and recycling problems • necessary high Know-how for constructive forming

2.4 Forms of lightweight design

Basic objective in determining the form of lightweight construction is to specify requirements for the construction that were set up to obtain an optimal load distribution with maximum weight reduction. In addition to the weight must be met and requirements for compact design and manufacturing technologies. This implies that the

forms of light structures are closely related with the applied concept and choice of materials for lightweight design. Development of lightweight structures requires the implementation of recommendations for the design and construction, as well as numerical methods to optimize the structure. One of the important recommendations for the lightweight design is the application of the principle of integral and differential methods of construction.

Differential method of design involves the separation of a complex part to a greater number of parts of simpler form and is usually applied to individual or small batch production. It is suitable for use in lightweight structures for material selection and process development allows the design of the structural elements of optimal weight. Defining sequence assembly and joining processes are easily obtained complete supporting structure.

Integrated design method involves merging a number of different parts in a single part. Applied in large-series production and in parts where the need to reduce operating stresses. Parts are made of a homogeneous material, but have a complex form. The optimal structure of lightweight construction is obtained by choosing the geometry and shape of surface integral parts and their optimization with respect to the applied materials and process development.

Thus, the forms of lightweight structures are derived by considering the definition of both forms and structure design.

2.5 Prices of lightweight design

The basic question that arises in light structures is their price. The construction cost of lightweight affect a larger number of parameters, one of the most significant is the price of the material. The share prices of materials in the product ranges from 20 to 80% depending on the type of products in which they applied lightweight construction and applied technology in their development, testing and subsequent maintenance. The ratio of price of materials for lightweight design relative to steel is shown in Fig.4. The most expensive is a composite material, but according to Table 2 they have the best properties for use in lightweight design. The structure of composite material (Fig.5) consists of carbon, glass or aramid fibers and a binder matrix that is usually an epoxy or polyester resin. Manufacturing technology used in composite materials are prepreg technology and process injection resin.

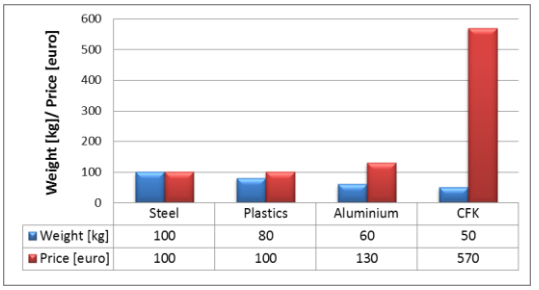

Figure 4. *Comparison of prices of materials used in lightweight design [3]*

The best properties has composite material with carbon fiber (CFK). Choice of fibers and their combination, as well as the matrix, it is possible to adjust the direction of fibers according to stress directions and get the optimal use of materials. As the price of these materials is rather high, their use can be proved by taking the benefits of application for the entire lifetime of the product.

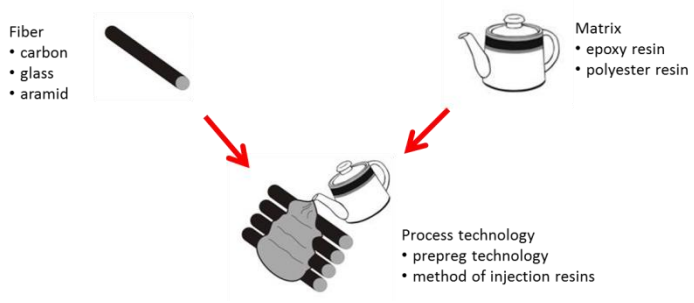

Figure 5. *Structure of composite materials [2]*

Adaptive materials are also very interesting for use in lightweight design. By using piezo ceramics can be greatly damping the unwanted vibrations of the structure, and thus reducing the shock loads.

For evaluating benefits of application of lightweight materials needed is a detailed analysis that includes technology development, installation, testing and resulting savings for the entire lifetime of the product. For vehicles, this analysis is relatively simple. Weight reduction can be achieved by:

- Increased payload or increase the performance of the vehicle;
- Reducing the weight impact on reducing rolling resistance, resistance to acceleration and resistance to movements;
- Finally, it has the effect of reducing fuel consumption and emissions.

In aircraft and spacecraft advantages of lightweight materials are much higher, but it is the economic analysis more complicated.

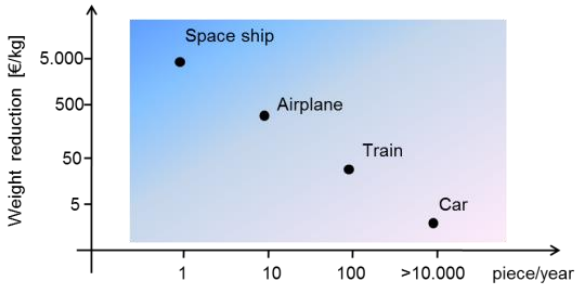

Figure 6. *Prices of lightweight constructions per kg of reduced weight [3]*

When considering the price of lightweight design is more appropriate to ask how much kilograms weight reduction should cost. The answer to this question depends on the area of application of lightweight design and price reduction of weight very much varies (Fig.6).

In any case, seeking the answer to this question is very complex. For example, an automobile effect of weight reduction depends largely on the position where the weight is reduced. Greater effect at reducing the weight of the body on the car roof to the floor. It should also distinguish between the primary and secondary reduction in weight. The reduction of body weight over the material and the concept of a primary reduction in weight. Secondary reduction is related to the further possible changes to the engine, transmission and other aggregates cars.

3. DEVELOPMENT OF LIGHTWEIGHT DESIGN

The development and design of lightweight construction primarily based on a method implemented in accordance with VDI 2222 [5]. So, there is not need for a new methodological procedure, but the procedure VDI 2222 in some degree modified and adapted to the requirements and properties of lightweight structures. The main requirement is the fulfillment of the given function. In addition to this basic requirement, in lightweight structures is important the fulfillment of the following requirements:

- safety / reliability,
- adaptability to manufacture,
- suitability for control,
- suitability for assembility,
- maintainability,
- the impact on the environment,
- recycling etc.

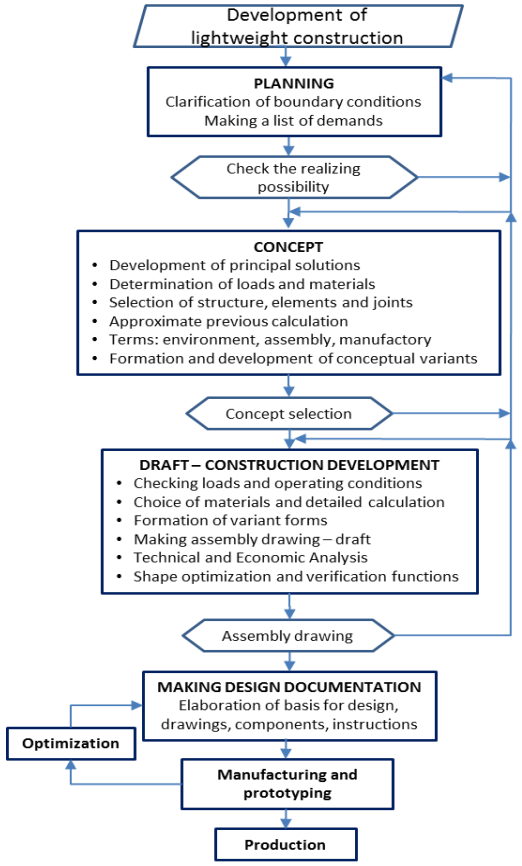

Figure 7. *Systematic approach in development of lightweight constructions*

In Fig.7 is shown the process of development of new constructions, which corresponds to VDI 2222 [5], but has been modified and adapted to the requirements of lightweight design. Development of structures can be divided into four phases: *planning, concept, developing draft design and development of construction documentation.*

Planning

In the planning stage, at the very beginning of the development process and designing structures it is necessary to clarify the precise definition and assignment. The principle here is to collect the necessary data in order to accurately define the requirements to be fulfilled for construction. Requests may be very different, and they should be classified according to the priorities of the requirements that must be met mandatory, minimum requirements that must be met and the desired requirements. Important in lightweightdesign is precisely the definition of boundary conditions and their evaluation in terms of seeking solutions. As a result of this phase gets a list of requirements that construction should meet.

Concept

The second phase is the concepting of the solution idea. By formatting the structure functions, is deniveling the overall (global) functions to partial and elementary functions. These functions are generally reduced to the transformation of energy (force, torque, motion), energy transfer, etc.. Conceived schematic solution is in the form of sketches, analyze and evaluate. A prerequisite for the successful introduction of concept of construction is related to the size of the course and direction of load capabilities of the selected material, the structure of the components and their integration as well as a tentative preliminary calculation. Well chosen concept allows later innovative problem solving. This phase ends with the selection of conceptual variants.

Draft - development of construction

The third phase is the phase of drafting and development of construction which define the perpetrators of principal solutions. It includes the final choice of materials and detailed construction calculation. At this stage, it is necessary in addition to the creativity to make a number of iterative steps, thereby always goes to a higher level with respect to the definition of the structure. This is a very complicated phase because it requires a combination of calculations and defining the form and often several times repeating the same steps with the appropriate changes. As a result of this phase is obtained preliminary conceptual design to scale, which is the third key point of the development and construction of mechanical systems.

Elaboration - development of constuction documentation

The fourth stage is the stage of elaboration and development of construction documentation. This means not only making the assembly of drawings based on the initial draft, but also optimize the shape of parts, components and preparation instructions as well as the elaboration of the basis for the development and assembly of the entire structure. This phase also includes activities related to the prototype (including control of operating functions, assembly, etc..) and testing procedures of the structure (test capacity, reliability and service life). Based on the tests of the prototype performs the appropriate correction or optimization of the structure. The output from this phase is the final constructional documentation according to ISO 9000: 2009 and ISO / TS 16949: 2002.

During the development of lightweight construction in phases given in Fig.7 are necessary expert knowledge of the structure, method of design, materials, processing technology, joining and assembly of lightweight construction. On the other hand it is necessary and appropriate creativity of developers. In this sense, the best results are achieved by a combination of theoretical knowledge and practical experience in the construction of lightweight design.

Prerequisite for successful development of lightweight construction is the use of appropriate calculation methods (mostly using numerical methods), available measuring and test equipment for accurately determinationof structure performance.

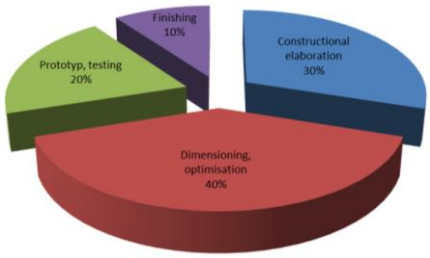

Figure 8*. Distribution of time for projects of lightweight design*

Methods for development and design which can be applied to lightweight structures rely heavily on theoretical engineers discipline. Approximate time appropriation in the execution of these projects is given in Fig.8. Often theoretical considerations amounts to 80% of the time.

3. CONCLUSION

Society of the 21st century is characterized by great challenges to the building of the urban environment and infrastructure. With the rapid growth of the world population and production of consumer goods is growing rapidly. This leads to rapid consumption of resources of the country primarily energy and material resources. There is a need of reducing the use of these resources, and one way is the use of new materials and lightweight design. The paper describes the basic strategies of development and application of lightweight design. The most influential factors related to lightweight design are constructions structures, new materials, technology development, joining and assembly. The best features in the construction of lightweight structures with composite materials primarily composite materials with carbon fiber (CFK). With the optimal structure of the building and the technology of the materials themselves, it is possible with a minimum weight maximum utilization of available resources materials in terms of capacity, so that in spite of their highly appreciated economical price possible application in a large number of modern products. The present method of development of lightweight construction offers the possibility of obtaining an optimum lightweight structure for use in modern high-quality and market competitive products.

REFERENCES

[1] Albers, A., & Burkardt, N (2011). :Systemleichtbau – ganzheitliche Gewichtsreduzierung.In *Henning, F., Moeller, E.:* Handbuch Leichtbau - Hanser Verlag, pp. 115–132.
[2] Burkardt, N. (2013). *Konstruktiver Leichtbau. Vorlesung*, IPEK, Karlsruhe.
[3] Klein, B. (2011). Leichtbau-Konstruktion Berechnungsgrundlagen und Gestaltung Vieweg & Sohn Verlag
[4] Wiedemann, J. (2006). Leichtbau: Springer Verlag, 2006.
[5] VDI-Richtlinie (2002). VDI 2222 Blatt 1 Konstruktionsmethodik - Methodisches Entwickeln von Lösungsprinzipien.2002.