A Brief Review on Determinant Aspects in Energy Efficient Solar Car Design and Manufacturing

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Abstract. In the past decades, sustainable means of transportation have become an important issue once they are potentially able to supply modern transport needs whilst not harming the environment. Accordingly to this general interest, solar vehicles have been developed by several institutions worldwide to participate in international class races, promoting this research field. As the competitiveness increased, solar technologies evolved toward noteworthy solutions for a modern and sustainable mobility. Hence, this work intends to provide a general overview on solar vehicles, particularly regarding the main design and manufacturing features that allowed to increase energy efficiency, considering the relevance of this factor for solar cars. Due to the huge amount of information available, a limited number of aspects was selected for further analysis, mainly related to design and engineering, such as: weight reduction, aerodynamics and kinematics, mechanics and advanced materials.

Keywords: Solar cars · State-of-the-art · Energy efficiency · Sustainable design

1 Introduction

The demand for more efficient means of transportation arose as an important segment, once fossil fuel powered vehicles are dependent on a progressively scarce energy source while being responsible for producing massive toxic pollutant substances, aggravating the green-house effect [1]. Addressing to supply the need for environmentally harmless means of transportation, solar cars emerged as a remarkable option, receiving a crescent interest from renowned research centers worldwide [2–5].

Although powered by a renewable energy source, a solar vehicle is only viable if embedded with the highest level of energy efficiency, which depends on various design and manufacturing facets. Aiming to provide a broad review on those factors showing their characteristics and evolutions, this work provides a state-of-the-art background on the variables related to mechanical aspects, e.g. design, materials and aerodynamics. Most of the researches are performed on racing solar cars, the most propitious area for innovations, considering the attention given by universities and research centers in developing novel technologies, focused on competitive race events realized throughout the globe.

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2 Energy Optimization

The main performance difference that apart conventional motor sport races and solar racing, is the limitation on the total power available for generating movement: the power output of the solar panels is limited [6]. Then, it is fundamental to include solutions for the optimal use of energy. Several design factors influence the performance of the vehicle in terms of energy, and weight is a major concern [7]: the lower the weight, the higher the energy efficiency.

Physically, the power needed to provide movement to a body is dependent on its weight. Not differently for solar cars, their design should be focused on a lightweight goal approach. However, there is a limit even for decreasing the weight of the car if one desires to keep the stability of the vehicle at a safe level: the center of gravity should be kept close to the road, and the weight should be high enough for the car to remain stable when subjected to side wind gusts, which is a potentially threatening influence [5], especially on solar races held in desert regions [3].

The energy efficiency improved by weight optimization can be noticed on electric vehicles, once a 10% reduction results in a 13.7% electric range increase [8]; or specifically in the case of a solar car where a reduction as small as 452 g is responsible for an energy saving of 18.6 Wh [4]. In another solar racing vehicle, classified as 2nd in the Cruiser class of the most competitive solar race, the World Solar Challenge (WSC), the innovation of manufacturing a carbon fiber monocoque chassis provided a weight reduction as high as 55 kg [3]; which leads to the importance of the materials for performance.

Significant improvements that relate the impact on energy efficiency by design, aerodynamics and materials have been thus realized in solar vehicles.

3 Design

3.1 Number of Wheels

The decision on the number of wheels for solar races might either be indicated on the competition categories regulations, or depend on the designer decision. Up to now, the basic parameters to decide which layout to adopt can be defined by the advantages and disadvantages of each one [6]:

- Three wheels: The major concern of this layout is related to instability. After all, if the center of gravity moves towards the axle with two wheels, the rolling tendency is decreased. But, if it moves towards the single wheel, the vehicle will tend to tip over. On the other hand, the less number of parts infers in decreased weight and cost, while the single wheel, most likely configured with a steering arm suspension [2], brings with it an ideal steering and conserves energy on bumpy roads once it allows only vertical movements [9].
- Four wheels: Despite provided of more movable parts, hence with more weight, this system grants a higher stability and improved aerodynamics, once the frontal area is considerably smaller.

At first sight, aiming at achieving the most energy efficient design, the three wheels layout seems adequate for offering a weight reduction on this aspect. However, it is important to highlight that the aerodynamics improve caused by the reduction of frontal area in the case of a four-wheeled-vehicle is important on its performance. The drag caused by the air resistance can be optimized at a higher level, and it might not be a coincidence that solar vehicles provided with such design had achieved outstanding results, even though in different categories, at the most recent edition of the World Solar Challenge 2015 [2, 3].

3.2 In-Wheel Motors

Electric propulsion has been used for many years in vehicles [10], and it is a crucial topic of study if an efficient design is required, especially in solar vehicles where driving force is fundamental to acceleration and power performance [10]. Therefore, in-wheel motors emerged as an efficient solution for solar cars, with early applications in solar competitions dated of 1990 [11].

What makes this alternative so attractive to designers respects to the facts that a direct drive eliminate drivetrain power losses [12], generally excluding the need for a gearbox and its associated power dissipation [2]; backed up by a simple in-wheel packaging where the individual wheel control improves handling and safety [13]. Also, an important consideration for the design of a car is the unsprung weight reduction, which is covered by a motor entirely housed by the wheel (as an integral part of it) [13].

Further studies [14] on how to enhance its efficiency have been performed, comparing Axial Flux Permanent Magnet (AFPM) to Radial Flux Permanent Magnet (RFPM) motors. It was realized that even though AFPM motors are a bit more expensive, they are essential in improving the performance of solar vehicles at the WSC; being a good alternative at low torque and low-to-medium speed applications. The explanation is based on the fact that ironless AFPM motors have a high torque-to-mass ratio compared with RFPM, and lack of iron eddy currents.

Some in-wheel motor application examples for the WSC show that the brushless DC motors are more efficient (converting approximately 97% of their electric energy) and lighter (about 8 kg) than other alternatives (with efficiency ranging between 92–95% and weight 12–16 kg) [12]. To exemplify their power, the 2nd placed competitor in Cruiser category at the WSC 2015 has a maximum power of 42 kW, i.e. 57 BHP [2].

3.3 Suspension

Responsible for absorbing external and internal vibrations of a car, the suspension is certainly one of the most vital systems in any terrestrial vehicle, softening shocks, preserving all mechanical components, and granting comfort to the passengers. In solar cars, the suspensions are designed to be as stiff as possible without abandoning the aforementioned characteristics, in order to decrease energy loss in driving.

An energy efficient-focused optimization of a suspension can either involve diverse factors due to its kinematic complexity, or be as simple as in a weight reduction process [15]. For example [4], the shape of a wheel knuckle being redesigned in order to save

452 g of overall mass in the vehicle can generate an energy saving of approximately 18.6 Wh; which is especially important once this change was done in a solar vehicle competing in the competitive Challenger category at the WSC.

Basically, the suspension systems can be subdivided into two main groups [16]: dependents and independents. The first ones have an axle connecting both right and left wheels in front and in the rear, in a way that every vertical displacement on one side, affects the performance of the opposite. When used in solar vehicles, are generally in form of a transversal leaf spring; aiming at reducing the total weight of the structure [17]. The independent systems, as the name states, are free to realize vertically autonomous movements, without affecting other wheels. Nowadays, the vast majority of solar cars adopt independent systems. The principal types of independent suspensions, and their contributions to improve energy efficiency are:

- MacPherson: consists of an A-arm or a compression link stabilized by a second link that offers a bottom mounting point for the axle (or hub) of the wheel; carrying a coil spring and a shock absorber. It is low cost, lightweight and compact [18].
- Wishbone (Fig. 1b): generally in double wishbone configuration, it is the most spread configuration [19, 20], composed by two A-arms that provide great steering precision and an adequate camber angle. Allows the vehicle height to be set lower, hence lowering the center of gravity and increasing stability. As for energy efficiency, this system allows the suspension to be set stiffer (decreasing energy loss) and keep the wheels always in contact with the road (even in hard cornering), providing good propulsion.
- Trailing arm (Fig. 1a): It is generally used in three-wheeled solar cars in alliance with two wishbones in the other wheels. Its contribution to energy efficiency is given by the fact that it is a lightweight alternative that does not perform sideways movements, hence saving energy on bumpy roads [9].

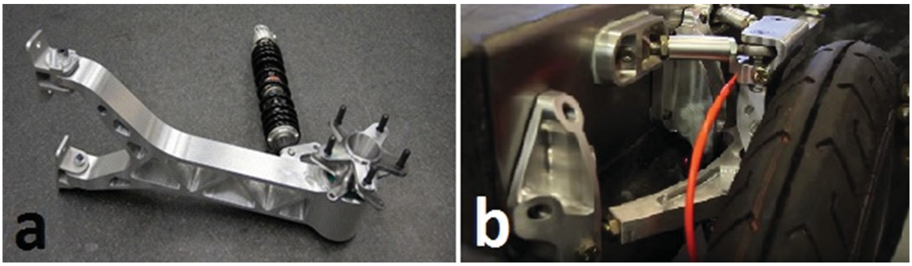

Fig. 1. (a) Trailing arm [2] and (b) double wishbone suspensions applied to solar cars

4 Aerodynamics

Every body that moves in space has to overcome the resistance imposed by the environment around it. In solar cars, this challenge is particularly crucial because, given the limited source of energy available and the dependency on the area of the solar arrays, the more efficient the design of the vehicle, the less energy it will spend to move (i.e. more efficient it will be). To define the ideal shape of a car in these terms, simulations are required using Finite Element Analysis (FEA) techniques performed through the use of computational software.

In this context, the two parameters to be defined to make a design feasible are the coefficient of drag (C_D) and lift coefficient (C_L), determined with the use of FEA considering a certain speed. In short, C_D is a positive value that quantifies how much the vehicle is being held by the resistance of the air to move. The closer to zero the C_D value, the more aerodynamic the body. For example, a reduction of 31% in C_D can provide an energy saving as high as 442.6 W considering a 100 km/h speed [21].

As for C_L, it defines the following behavior of the vehicle in motion: if the value is negative, it means that the car continues with a vertical downwards force resultant; if the value is positive, the car suffers the possibility of lifting from the ground. Therefore, this value must always be kept negative for maneuverability and safety of the driver [5].

For optimizing the shape of the vehicle and achieving a good efficiency, numerous factors must be taken in account [21], such as the fairing position, body-and-fairing fillet blend, fairing leading edge curvature, driver position and canopy design. It is possible to notice a few aspects in common from the first three classified cars in the Challenger category of the WSC 2015, in other words, the fastest cars of the most competitive category and event: for example, the drivers were placed sideways in all cases, between one front and one rear wheel. One can infer that the reason to justify this pattern in the fact that the frontal area of the vehicle is reduced, increasing the efficiency. This case is illustrated on Fig. 2.

Fig. 2. Solar vehicles designed by the universities of (a) Delft, (b) Twente and (c) Tokai [3]

The teardrop shape is known to provide, ideally, a perfect shape design in order to maximize the aerodynamic efficiency [22], which is actually a trend that can be noted in all competitive solar cars (Fig. 2). Nevertheless, there was a case regarding an attempt to realize a new design [23] inspired on a boxfish; but this attempt showed to be inefficient producing a car with drag and lift coefficient respectively equal to 0.35 and −0.19; while a common teardrop design given as good [5] grants more efficiency, backed up by drag and lift coefficients of approximately 0.11 and −0.11, respectively.

The shape of the car, however, is not exclusively focused to decrease the drag influence, but also to enhance the heat removal from the solar array, thus increasing the power generated by photovoltaic modules [24]. The heat removal is an important issue on solar car design, and as having an active cooling system is unfeasible due to the weight it would bring to the car composition, convection is the only source of cooling [24].

5 Materials, Manufacturing and Safety

According to the 21st century demand for innovative products and technologies [25], the selection of materials for building efficient solar cars have become an important task due to the alliance of the importance of having a safe and efficient design, while novel materials have been gradually developed. After all, the solar races realized nowadays present such high technological standards and extensive courses, that if one might build a car with off-the-shelf parts regardless of the material properties, the competitor probably won't even be able cross the finish line [26].

Essentially, mechanical systems are designed to maintain both weight and friction to a low level, and at the same time keeping strength and stiffness. In most vehicle architectures, the preferred materials to attain this goal are aluminum, titanium and composites [27]. Even though all of them might be strong and stiff while being fairly light; the application of metals in solar cars, such as aluminum chassis [26], present a massive weight share to the detriment of energy efficiency. Thus, composites are the most indicated solution as structural material in this case.

Therefore, although polymeric materials present particular deterioration characteristics highly dependent on environmental conditions [28–30], this is not relevant to motorsport parameters once each vehicle is basically built for a reduced number of races, as the regulations suffer constant changes and new improved technologies arise, not exposing the vehicles to noxious environments for long periods.

The application of composite materials in structural parts is a reality in modern mobility industry aiming at providing more energy efficiency, ranging from aviation [31] to high tech Formula 1 competition cars; which nowadays are composed of over 75% of various forms of composites [32]. Particularly in solar cars, these materials are applied in mechanical components such as suspension springs [33], or even linked to aluminum suspension parts by adhesive bonding, not only decreasing the overall weight, as well as increasing their safety factors [19].

The evolution of chassis in solar cars has also shown to be a determinant factor to a good performance, relying on its material to maintain a strong and safe chassis and decreasing its weight. While past designs used to involve aluminum assemblies [26], the latest trend recognized as the most advantageous is to build a carbon fiber monocoque chassis; proved to grant a competitive design [2, 3]. It's preferred manufacturing technique, vacuum infusion, consists of assembling the composite layers on a solid mold, cover the material with plastic, and make a vacuum bagging (Fig. 3) which is succeeded by an autoclave curing process at controlled temperature and pressure.

Fig. 3. Vacuum bagging (a) and post cured (b) monocoque chassis for a solar car [3].

Safety is a mandatory characteristic in all means of transportation, and should be emphasized as priority in all projects and classes of vehicles, even though it might be neglected in some occasions despite its utmost importance [34]. Thus, the materials selected for the arrangement of the vehicle must present great resistance, which, in the case of solar cars, should be necessarily allied to low weight to provide an energy efficient design.

Fulfilling this premise, the application of carbon fiber as reinforcement for composite materials is a concern of study for energy-efficient and safe vehicles (EESVs) [35], presenting interesting properties in terms of elastic modulus, tensile strength, thermal and electrical conductivity, thermal stability, gas barrier and flame retardant [35]; although the last characteristic can also be noticed in basalt composites [36].

6 Sustainability

As aforementioned, regarding the application of composites in solar cars, carbon fiber reinforced composites are undoubtedly the most widely used material due to its advantageous properties. However, the intensification of usage of such material is noticeable in the last years, with an expected global demand of 208 000 tons per year in 2020 [37]. This results in an increase of waste, inferred by both end of life products and production processes [38]. Therefore, accordingly to the sustainable products premise of being easy recycling, easy reuse and easy degradation [39]; studies involving recycling methods for this material have been developed, boosted by pyrolysis/oxidative recovering processes [38].

Besides recycling, another sustainable solution in composites is the use of biodegradable fibers, if possible allied with eco-friendly resins, such as vinylester [40]. Basalt, even though not biodegradable, is a natural and relatively new alternative in reinforcing polymers and structural composites [40], not only being made with by a toxic-free process (unlike glass fiber), as well as featuring enhanced mechanical properties, which have been studied and quantified [41]. In comparison with carbon fiber and aramid, for instance, it presents a wider temperature resistance [36, 42], higher oxidation and radiation resistance, and higher compressive and shear strengths [40]. Also, comparing to glass fiber, the mechanical properties of basalt are either similar or better [43–45].

7 Conclusions

This work provided a brief review of some important topics on design of solar cars crucial to provide an energy efficient design. The topics analyzed were weight optimization; materials; design; aerodynamics and sustainability.

Attaining an optimal overall vehicle weight is proved to be determinant to its performance. Also, in-wheel motors have shown to be a common trend among all solar car teams for decades, once eliminating the energy losses caused by extensive power transmission chains is a necessity for solar vehicles considering their high efficiency demand.

The materials used in solar cars vary from metals to composites in diverse systems among the solar cars nowadays, mainly restricted to budget. After all, the crescent usage of carbon fiber is a noticeable tendency, powered by its lightweight, safety and sustainability with recent studies regarding recyclability techniques for its composite. Yet speaking of sustainability, basalt is a material with various advantageous structural properties, having also a low toxicity production process. Its usage is encouraged, even if in non-structural parts, once it would be a great eco-friendly accomplishment to design a solar car in the less environmentally harmful way possible.

Suspension, as well as some aerodynamic factors and the decision on adopting either a three or a four-wheeled design, are subjective settlements particular to each design team. However, some characteristics commonly found on the current world top solar cars include a four-wheeled design, with sideways driver position and wishbone suspension; so it is advisable to take these in account as well.

The study on improving solar cars energy efficiency is an ongoing research topic, presenting significant evolutions in the most diversified aspects lately. Therefore, it is advised to constantly seek for updating the state-of-the-art on this topic, keeping up with all recent developments.

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References

1. Rizzo, G.: Automotive applications of solar energy. In: 6th IFAC Symposium Advances in Automotive Control, Munich, pp. 174–185 (2010)
2. Mathijsen, D.: Redefining the motor car. Reinf. Plast. **60**, 154–159 (2016)
3. Tamura, S.: Teijin advanced carbon fiber technology used to build solar car for world solar challenge. Reinf. Plast. **60**, 160–163 (2016)
4. Betancur, E., Mejia-Gutierrez, R., Osorio-Gomez, G., Arbelaez, A.: Design of Structural Parts for a Racing Solar Car. In: Eynard, B., Nigrelli, V., Oliveri, S.M., Peris-Fajarnes, G., Rizzuti, S. (eds.). LNME, pp. 25–32. Springer, Catania (2016)

5. Kin, W.D., Kruger, S., van Rensburg, N.J., Pretorius, L.: Numerical assessment of aerodynamic properties of a solar vehicle. In: ASME International Mechanical Engineering Congress and Exposition, San Diego (2013)
6. Ersoz, E.: Development of a racing strategy for a solar car. MSc thesis, Ancara, Turkey (2006)
7. Taha, Z., Md. Dawal, S.Z., Passarella, R., Kassim, Z., Md. Sah, J.: Study of lightweight vehicle vibration characteristics and its effects on whole body vibration. In: 9th Asia Pacific Industrial Engineering and Management System Conference, Bali, pp. 629–633 (2008)
8. Joost, W.: Reducing vehicle weight and improving U.S. energy efficiency using integrated computational materials engineering. JOM **64**, 1032–1038 (2012)
9. Thosar, A.: Design, analysis and fabrication of rear suspension system for an all terrain vehicle. Int. J. Sci. Eng. Res. **5**, 258–263 (2014)
10. Taha, Z., Passarella, R., Rahim, N.A., Sah, J.M.: Driving force characteristic and power consumption of a 4.7 kW motor. ARPN J. Eng. Appl. Sci. **5**, 26–31 (2010)
11. Cambier, C.S.: Brushless motors and controllers designed for GM Sunrayce. IEEE AES Mag. **5**(8), 13–15 (1990)
12. Lovatt, H.C., Ramsden, V.S., Mecrow, B.C.: Design of an in-wheel motor for a solar-powered electric vehicle. IEEE Proc. Online Power Appl. **145**, 402–408 (1998)
13. Lovatt, H.C., et al.: Design procedure for low cost, low mass, direct drive. In: Wheel Motor Drivetrains for Electric Vehicles, pp. 4558–4562. IEEE (2011)
14. Al Zaher, R., de Groot, S., Polinder, H., Wieringa, P.: Comparison of an axial flux and a radial flux permanent magnet motor for solar race cars. In: XIX International Conference on Electrical Machines, Rome (2010)
15. Camargo, F.V., Fragassa, C., Pavlovic, A., Martignani, M.: Analysis of the suspension design evolution in solar cars. FME Trans. **45**, 394–404 (2017)
16. Gadade, B., Todkar, R.G.: Design, analysis of A-type front lower suspension arm in commercial vehicle. Int. Res. J. Eng. Technol. **2**, 759–766 (2015)
17. Vivekanandan, N., Gunaki, A., Acharya, C., Gilbert, S., Bodake, R.: Design, analysis and simulation of double wishbone suspension system. Int. J. Mech. Eng. **2**, 1–7 (2014)
18. Purushotham, A.: Comparative simulation studies on MacPherson suspension system. Int. J. Mod. Eng. Res. **3**, 1377–1381 (2013)
19. Hurter, W.S., van Rensburg, N.J., Madyira, D.M., Oosthuizen, G.A.: Static analysis of advanced composites for the optimal design of an experimental lightweight solar vehicle suspension system. In: ASME International Mechanical Engineering Congress and Exposition, Montreal (2014)
20. Paterson, G., Vijayaratnam, P., Perera, C., Doig, G.: Design and development of the Sunswift eVe solar vehicle: a record-breaking electric car. J. Automobile Eng. **230**, 1972–1986 (2016)
21. de Kock, J.P., van Rensburg, N.J., Kruger, S., Laubscher, R.F.: Aerodynamic optimization in a lightweight solar vehicle design. In: ASME International Mechanical Engineering Congress and Exposition, Montreal, pp. 1–8 (2014)
22. Beres, J.: Sunrunner: the engineering report. Solar Cells **31**, 425–442 (1991)
23. Passarella, R., Rahim, N.A., Sah, J.M., Ahmad-Yazid, A.: CFD for a solar vehicle. J. Comput. Theoret. Nanosci. **4**, 2807–2811 (2011)
24. Vinnichenko, N.A., Uvarov, A.V., Znamenskaya, I.A., Ay, H., Wang, T.H.: Solar car aerodynamic design for optimal cooling and high efficiency. Sol. Energy **103**, 183–190 (2014)
25. Fragassa, C., Pavlovic, A., Massimo, S.: Using a total quality strategy in a new practical approach for improving the product reliability in automotive industry. Int. J. Qual. Res. **8**, 297–310 (2014)
26. Sah, J.M., Passarella, R., Ghazilla, R., Ahmad, N.: A solar vehicle based on sustainable design concept. In: IASTED International Conference on Solar Energy, Phuket (2009)

27. Mohsan, M.D.B.M.: Front and rear suspension for a solar car. Bachelor thesis, Pahang, Malaysia (2010)
28. Camargo, F.V., Guilherme, C.E.M., Fragassa, C., Pavlovic, A.: Cyclic stress analysis of polyester, aramid, polyethylene and liquid crystal polymer yarns. Acta Polytech. **56**, 402–408 (2016)
29. Fragassa, C.: Investigations into the degradation of PTFE surface properties by accelerated aging tests. Tribol. Indus. **38**, 241–248 (2016)
30. Giorgini, L., Fragassa, C., Zattini, G., Pavlovic, A.: Acid aging effects on surfaces of PTFE gaskets investigated by Fourier transform infrared spectroscopy. Tribol. Ind. **38**, 286–296 (2016)
31. Katsiropoulos, C., Chamos, A., Tserpes, K., Pantelakis, S.: Fracture toughness and shear behavior of composite bonded joints based on a novel aerospace adhesive. Compos. B Eng. **43**, 240–248 (2012)
32. Tremayne, D.: The Science of Formula 1 Design: Expert Analysis of the Anatomy of the Modern Grand Prix Car. Haynes Publishing, California (2011)
33. Sancraktar, E., Gratton, M.: Design, analysis, and optimization of composite leaf springs for light vehicle applications. Compos. Struct. **44**, 195–204 (1999)
34. Pavlovic, A., Fragassa, C.: General considerations on regulations and safety requirements for quadricycles. Int. J. Qual. Res. **9**, 657–674 (2015)
35. Elmarakbi, A., Azoti, W.L.: Novel composite materials for automotive applications. In: 10th International Conference on Composite Science and Technology, Lisbon (2015)
36. Wittek, T., Tanimoto, T.: Mechanical properties and fire retardancy of bidirectional reinforced composite based on biodegradable startch resin and basalt fibres. Express Polym. Lett. **2**, 810–822 (2008)
37. Jahn, B., Witten, E.: Composites Market Report. AVK – Industrievereinigung Verstarkte Kunststoffe e.V. (Federation of Reinforced Plastics) (2013)
38. Giorgini, L., Benelli, T., Mazzocchetti, et al.: Recovery of carbon fibers from cured and uncured carbon fiber reinforced composites wastes and their use as feedstock for a new composite production. Polym. Compos. **36**, 1084–1095 (2015)
39. Zhou, C.C., Yin, G.F., Hu, X.B.: Multi-objective optimization of material selection for sustainable products: artificial neural networks and genetic algorithm approach. Mater. Design. **30**, 1209–1215 (2009)
40. Fragassa, C.: Effect of natural fibers and bio-resins on mechanical properties in hybrid and non-hybrid composites. In: VIII AIP International Conference on "Times of Polymers and Composites", Ischia, vol. 1736 (2016). Article No. 4949693. doi:10.1063/1.4949693
41. Lapena, M.H., Marinucci, G., Carvalho, O.: Mechanical characterization of unidirectional basalt fiber epoxy composite. In: 16th European Conference on Composite Materials, Seville (2014)
42. Brandt, A.M., Olek, J., Glinicki, M.A., Leung, C.K.Y.: Brittle Matrix Composites. Woodhead Publishing Limited, Warsaw (2012)
43. Valentino, P., et al.: Mechanical characterization of basalt fiber reinforced plastic with different fabric reinforcements – Tensile tests and FE-calculations with representative volume elements (RVEs). In: XXII Convegno Nazionale IGF, pp. 231–244, Rome (2013)
44. Zivkovic, I., Pavlovic, A. et al.: Influence of moisture absorption onthe impact properties of flax, basalt and hybrid flax/ basalt fiberreinforced green composites. Compos. Part B **111**, 148–164 (2017)
45. Boria, S., Pavlovic, A., et al.: Modeling of Falling Weight ImpactBehavior of Hybrid Basalt/ Flax Vinylester Composites. ProcediaEng. **167**, 223–230 (2016)