Lecture Notes in Mechanical Engineering

Francisco Cavas-Martínez ·
Félix Sanz-Adan · Paz Morer Camo ·
Ruben Lostado Lorza ·
Jacinto Santamaría Peña *Editors*

Advances in Design Engineering

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Preface and Acknowledgements

The INGEGRAF 2019 Conference originates as the 29th International Conference on GRAPHICS ENGINEERING "The Digital Transformation in the Graphic Engineering".

INGEGRAF 2019 has been organized by the area of graphical expression of the University of La Rioja. Cutting-edge topics in product design and manufacturing, innovative design and computer-aided design were especially encouraged.

The list of topics (and subtopics) covered in the present edition is the following:

- Product design and development: Green engineering and eco-design; User-centred design; Product lifecycle-based design; Robust design, reliability and maintenance; Modelling and simulation-based design; Ergonomics and human factors; Global product development.
- Computer-aided design and interactive design: Virtual approaches for interactive design; Virtual prototyping-based design; CAD, CAE, IFC and BIM; Image processing and analysis; Geometric modelling and analysis; Reverse engineering; Virtual and augmented reality.
- Manufacturing and industrial process design: Integrated/advanced manufacturing; Manufacturing process and production management; Rapid prototyping; Additive manufacturing; Flexible assemblies; Remanufacturing; Industry 4.0.
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- Innovation in design: Creativity and innovation methods; Collaborative engineering; Intellectual and industrial property management; Design and research methods.
- Teaching/learning in graphic engineering: Teaching on graphic expression; Theoretical and applied geometry; Graphic design; New approaches in teaching/learning process; Project-based learning; Interactive 3D modelling.

- Engineering and construction: Sustainable building. Sustainable construction; Building information modelling; Photogrammetry and remote sensing; Geo-information. Data capture; Virtual environments. Augmented reality in AEC; Urban regeneration; Heritage and territory. Industrial heritage conservation.

We would like to thank our main organizers/institutions, High Technical School of Industrial Engineering from the University of La Rioja, and the rest of the sponsoring/collaborating companies and institutions for their support and grants.

We would also like to express our gratitude to the members of the different committees for their support, collaboration and good work. Thanks to all reviewers for their selfless effort reviewing contributions, which positively influenced the quality of the final papers presented at the conference.

Last, but not least, thanks to all the participants of INGEGRAF 2019.

November 2019

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Contents

Product Design and Development

Use of Composite Materials in the Design of a Ventilation Grille Attending to Eco-Sustainability Factors

F. Xavier Espinach Orús[1], Fernando Julián Pérez[1](✉), Manel Alcalà Vilavella[1], Marc Delgado Aguilar[2], and Quim Tarrés Farrés[2]

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Abstract. This work deals with the design, the engineering of products and the selection of materials destined to the manufacture of a ventilation grille. Additionally, simulates a process of identification and use of agricultural waste for the formulation of composite materials. These materials, once characterized, can be used for the manufacture of new products.

The final product is expected to combine design attributes, technical and legal feasibility, along with the implementation of new biologically based materials that ensure a reduction in the environmental impact.

Taking into account the industrial design, a final concept is proposed and modeled. The product geometry, production technology and legal specifications will be the input data for the product engineering.

The selection of material will be based on the technical and environmental impact requirements. Thermo-mechanical fibers from corn stalks reinforced high-density polyethylene composite was prepared and characterized. These properties are used, together with the boundary conditions, to model and test a virtual model. The final product will be obtained by injection. The new product must be able to deploy under the expected use conditions. The new materials present an economically attractive opportunity to replace other materials, metallic, composite or virgin.

Keywords: Product design · Sustainability eco-design · Composite materials · Use of waste

1 Introduction

Both in the process of designing or redesigning a new product intervene a large number of experts in different fields. The experience of the different actors is devoted to industrial design, product engineering and materials science, among others [1].

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The redesign process includes all the necessary activities and knowledge of the actors previously indicated to adapt an existing design to other requirements, which may be legal, technical or economic. In the case of the study, a ventilation grille is redesigned for its manufacture using another material and another technology. The redesign implies that the resulting product must retain the technical and use [2, 3].

The process of redesigning a ventilation grille is presented taking into account a factor that we consider important, such as sustainability. The original appearance and size have been maintained. The innovation that allows generating value is mainly the change of material.

In order to obtain the reinforcements, an agroforestry waste was used. The fibers were obtained by steam treatment of corn stems. Subsequently, a defibration was carried out and then the fibers were mixed with a high density polyethylene (HDPE). Such composite materials, based on thermo-mechanical fibers of corn and HDPE are recyclable and can save up to 50% or more of the volume of the polymeric matrix, in this case HDPE. At the end of their life cycle, the products manufactured with these materials can be incinerated without the generation of waste. In the construction sector, in the case of the grid, the useful life of the materials is especially long, and it is for this reason that the recycling of its components must be promoted.

In terms of materials selection, the current tendency is to look after natural-based composites in order to take into account the sustainability of the final product [4, 5]. Natural fibers or cellulosic fillers/fibers can be classified under four categories depending on their performance when incorporated in a plastic matrix: (i) wood flour or agroforestry waste flour in general, (ii) wood fibers (iii) natural strands or bundles of strands and (iv) fibers from agroforestry residues [6, 7]. The agricultural residues can be considered as particle fillings that improve the tensile and flexural modulus of the compounds with little effect on the composite resistances [8, 9].

Agroforestry residues, made up of stalks and leaves, use to be chipped and buried, or incinerated in land. The overall exploitation of corn stalks and leaves results in different products suitable for their use as filler or reinforcement of composite materials. Hence, the milling process brings to a corn flour with small aspect ratio (L/d), able for the production of wood plastic composites. However, if corn residues are submitted to a defibering process under aqueous conditions, a fibrous material with higher aspect ratio is obtained, suitable for somewhat better product requirements [10]. Both types of processes show almost 100% of yield, with respect to the initial corn residue. Furthermore, the use of thermo-mechanical processes (vaporization followed to defibering) results in a fibrous matter with intrinsic properties, at a very competitive yield [11]. Finally, the utilization of more aggressive treatments such as organosolv processes or sosa-antraquinone treatments (semi-chemical processes) bring to fibers with better mechanical properties [12, 13].

This work focus on then use of agroforestry reinforced polyolefin. Product design and innovation researchers have worked together with experts in materials science in the development of an ecological ventilation grid. The development of the new product presents innovative objectives in the application of new materials to meet the final requirements of the market sub-sector.

2 Methodology

In order to create value, a process divided by knowledge areas is proposed, converting agricultural waste into product proposals. To get from the starting point to the goal, follow the steps proposed in Fig. 1.

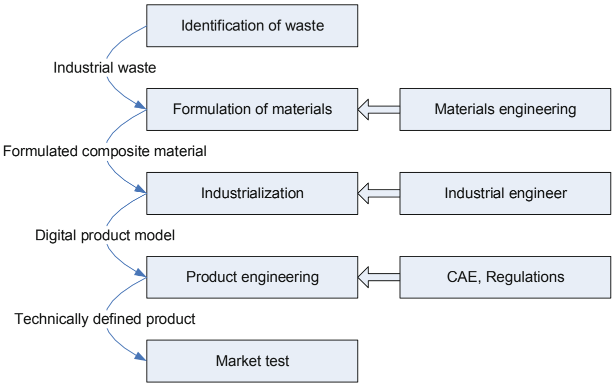


Fig. 1. Research framework for product development.

In the first stage, those materials capable of being recovered are identified. This stage can be the result of an investigation or the proposal of a company that wants to value its waste. It is important the participation of experts in materials science to establish the suitability of the proposed materials.

The second stage comprises the formulation of the composite materials. It is a typically experimental stage. Material science experts have to establish the matrices upon which the composite material will be based. In this way, the uses of the elements to be inertized as loads or reinforcements will be established. All laboratory tests are carried out to establish the physical and chemical characteristics of the formulated materials. At the end of the stage all the graphs and tables characteristic of the composite materials and their variations will be provided to the engineers and designers responsible for the industrialization stage.

The third stage of industrialization combines knowledge in engineering with those of industrial design. Throughout the stage, the product to be designed or industrialized is established, taking into account the production processes. You can start from an existing product or redesign one again. This stage is applied research. At the end of the stage, a digital model of the product is obtained. This model includes all the geometric specifications that must allow adaptation to the use and manufacturability of the product.

The fourth stage has to establish if the design is able to respond positively to the boundary conditions to which it will be subjected. In this way, the loads, pressures, limitations of the degrees of freedom that are either defined in homologation norms or deduced from their use will be applied to the digital model. The stage is typically applied. Computer-aided engineering (CAE) programs are used to reach the results.

During this stage, optimization loops are established with the previous ones since it is typically necessary to make modifications in the geometry or in the specifications of the materials to ensure a correct result. At the end of the stage, a feasible product is obtained from a technical point of view [1].

The next stage includes all market studies and economic analyzes that must ensure economic and market feasibility. This stage is beyond the scope of this investigation.

3 Formulation of the Material

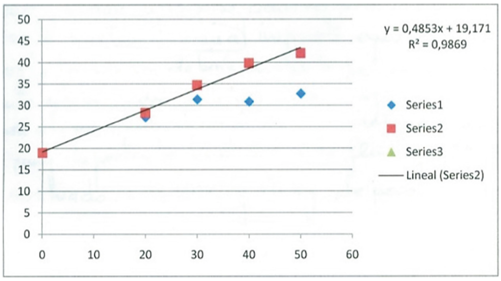
Fibers from corn are identified as the result of agricultural activity. The stems of corn are subjected to a treatment with steam to extract the fibers. For the matrix of the composite material, the use of HDPE is proposed.

Table 1 shows the flexural properties of the materials with the coupling agent (2% de Maleated Polyetylene - MAPE) for formulations at 20, 30, 40 and 50% (w/w).

Table 1. Flexural properties with and without coupling agents for % w/w formulations.

%w/w	Flexural modulus: E_f^c		Flexural strength: σ_f^c	
	2% MAPE	0% MAPE	2% MAPE	0% MAPE
0	0.520 (0.03)	0.52 (0.03)	18.92 (0.35)	18.92 (0.35)
20	1.55 (0.12)	0.51 (0.06)	27.24 (0.56)	28.24 (0.34)
30	1.98 (0.07)	1.92 (0.17)	31.36 (0.4)	34.7 (0.81)
40	2.53 (0.06)	2.61 (0.04)	30.85 (0.34)	39.81 (0.43)
50	2.86 (0.13)	2.78 (0.1)	32.69 (0.66)	42.13 (0.24)

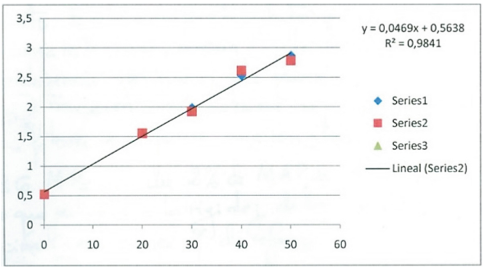
Regarding the σ_f^c, two situations can be verified that refer to its evolution with the reinforcement percentage (Fig. 2). In the case of the formulation without coupling agent, the resistance to bending (σ_f^c) increases linearly up to 30% (w/w) to then inflect. Probably in the first part the increase in σ_f^c is due to the mechanical anchoring of the HDPE on the surface of the fibers. This capacity of diffusion and anchoring of the HDPE on the fibers stabilizes when increasing the percentage of reinforcement, because of the absence of chemical interactions between the fibers and the matrix. On the other hand, it is verified that using only 2% of MAPE the σ_f^c increases linearly with the reinforcement percentage. This is a consequence of the creation of hydrogen bonds between the hydroxyl groups of the surface of the fibers and the maleic anhydride phase of the MAPE. Thus, the interphase of the coupled composites is stronger that uncoupled ones. The highest tensile strength was obtained for the composite with 50% w/w reinforcement content. This composite showed a strength 133% higher than the matrix.



% w/w	0% MAPE	2% MAPE
0	18.92 (0.35)	18.92 (0.35)
20	27.24 (0.56)	28.24 (0.34)
30	31.36 (0.4)	34.7 (0.81)
40	30.85 (0.34)	39.81 (0.43)
50	32.69 (0.66)	42.13 (0.24)

Fig. 2. Flexural strength: σ_f^c.

On the other hand, it was observed that the flexural modulus evolves linearly with the reinforcement percentage and that this evolution is independent of the coupling agent (Fig. 3). Therefore, for this type of application the composite material without coupling agent could be used.



% w/w	2% MAPE	0% MAPE
0	0.520 (0.03)	0.52 (0.03)
20	1.55 (0.12)	0.51 (0.06)
30	1.98 (0.07)	1.92 (0.17)
40	2.53 (0.06)	2.61 (0.04)
50	2.86 (0.13)	2.78 (0.1)

Fig. 3. Module strength: E_f^c.

Figure 4 shows the holes generated by the fibers during the tensile test and can be compared to the interface of a fiber that generates a tensile strength of 20.36 MPa with 2% MAPE (40% w/w)).

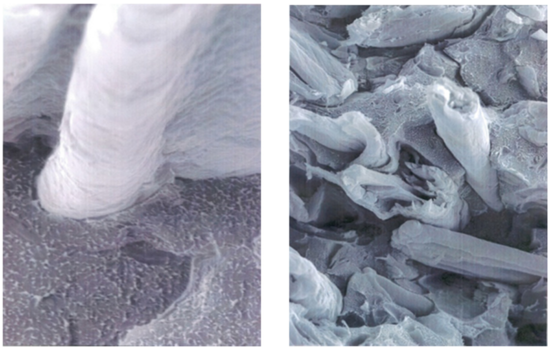
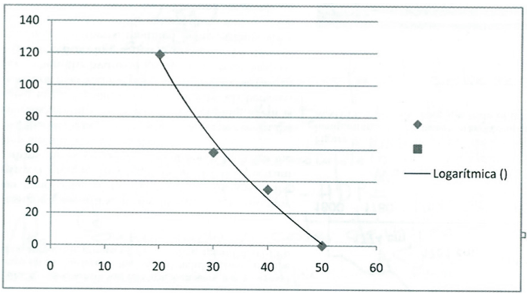


Fig. 4. Gaps that generate fibers, without MAPE and with MAPE.

Regarding the rigidity of the materials, a linear evolution is observed with the reinforcement percentage, typical of this type of materials.

Facing the industrialization of these composites, a very important parameter is the flow index (Melt Flow Index - MFI). In this case, it was evaluated at 210º and 10 kg of weight (Fig. 5). In the case of materials at 50% (w/w) it is observed that at 210 ºC and 10 kg. The pellets do not flow. This would indicate that between 2 and 3% of lubricating agent should be used in this case to drive the MFS to values to 8 ÷ 10 g 10 min.



% (w/w)	MFS
20	118.9
30	58.1
40	34.82
50	0

Fig. 5. MFS fluency index.

From the results analyzed and according to economic and sustainability technical criteria, it can be inferred that a good option would be the use of the 40% (w/w) formulation that allows compliance with the required requirements, saving on the consumption of a product like HDPE and inert a significant amount of agricultural waste. From an economic point of view, although the manufacture of the composite material involves an additional transformation operation, the balance is positive.

4 Results and Discussion

The starting points for the choice of the product to be industrialized are, on the one hand, the formulation of the investigated material, the market to which it is addressed, elements and materials for the construction and on the other the manufacturing technology chosen, in this case the injection. These conditions establish that the product to be designed must be of small or medium dimensions, high production, and not subject to great stress or strain. The number of construction elements that respond to these requirements is very high; boxes for meters or electrical connections, mailboxes, answering machines, IP switches, luminaires, cladding…

The choice of the product responds to a search for references and a creativity session with the entire research team. The techniques used were the Synectics and Metaplan to obtain a list of ideas and then an evaluation of them [14–16]. The criteria of choice have been; technical feasibility, market possibilities, and potential improvements in the aspects of industrial design. Under these conditions, the chosen product has been a ventilation grid (Fig. 6).

Fig. 6. Ventilation grid 400 × 400. Reference element and aluminum grid.

The starting product is an aeration grid of 400 × 400 mm. This element is built in concrete. The current product has a mass of 4.5 kg. In the market there are similar products made of aluminum, plastic, steel … but we have not identified any manufacturer that uses composite materials with characteristics similar to the one formulated in this article.

The boundary conditions are established in the Technical Building Code (CTE). The main loads to which it will be subjected are those of the wind. The calculation hypothesis will be an installation in a type building of 25 m in height, located in a C zone and with a degree of roughness V (CTE, Formula 1). For these requirements, the final request is approximately 1000 N/m^2.

$$q_e = q_b \cdot c_e \cdot c_p \tag{1}$$

For the calculations and the redesign we add a coefficient of maximization of loads of 1.5, with which the design solicitation becomes 1500 N/m^2.

Following the steps proposed in the methodology, we modeled the current product, obtaining a 3D model and subjected it to the boundary conditions. The characteristics of the test material are those corresponding to a standard concrete, E: 2.1 GPa. The model is subjected to a load of 1500 N/m^2 perpendicular to the outer face and all its embedded sides are considered (restriction of all degrees of freedom). The most interesting results are an equivalent safety coefficient of 317 and a maximum deformation in the 0.02 mm model (Fig. 7a). The oversized is due to the sections of material used, due to the parameters of manufacturing parts molded with concrete. This type of manufacturing requires large sections to ensure the filling of the molds. The design is acceptable due to the low cost of the material.

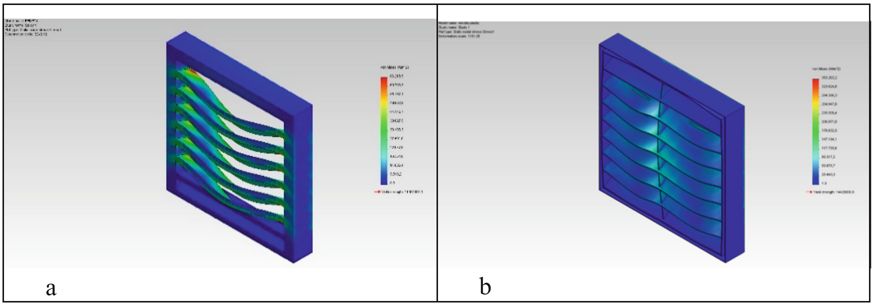


Fig. 7. A: Resulting stresses in the grid subjected to the boundary conditions (def. scale x2242). B: Resulting stresses in the grid subjected to the boundary conditions (def. scale x1151).

To ensure that the product can be manufactured by injection it is important that the thickness of the piece is constant and that there are no barriers to unmold. For the piece to be economical, the mold must be of two pieces, without sliders or inserts. The redesigned product shares the appearance with the starting one, with the inclusion of a central rib that acts as a reinforcement and as a filling channel. The thickness of the wall is 2.5 mm and the final mass of the piece is 1.2 kg. For the realization of the calculations, the small rounding in the edges or the angles of demolding of the piece are not contemplated.

The model is subjected to the same boundary conditions as the original part and the most outstanding results are an equivalent safety coefficient of 41 and a maximum deformation of 0.04 mm (Fig. 7b).

The cost attributable to the material would be, for HDPE virgin 2.04 €, and for HDPE + 40% w/w 1.32 €. In this way, a saving of 35% is established. The final cost of the product would be € 1.62.

With the economic data and the geometric proposal (Fig. 8) it is possible to start the market study stage to verify if the product is totally feasible and can go into production.

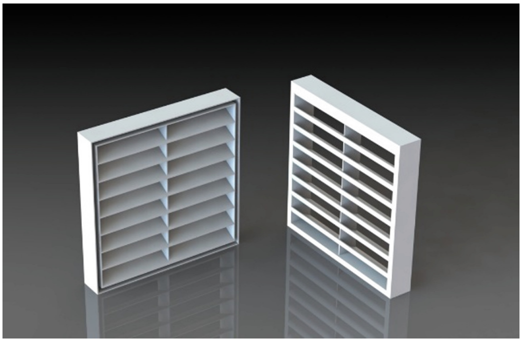


Fig. 8. Final proposal

5 Conclusions

A methodology for the design and development of products based on the reuse of waste materials is proposed, which is able to establish a new composite material and a new technically viable product. The application to building materials, regardless of the final product (ventilation grille) opens a wide range of possibilities. The creation of opportunities establishes the need for collaboration between different areas of knowledge. In this case the collaboration between materials science, design and engineering is able to develop a new material and turn it into a product proposal.

The agricultural residues of corn stem are susceptible to be used as reinforcement load of composite materials with an HDPE matrix. With the same and depending on the percentage of reinforcement with and without coupling agent, products capable of satisfying the requirements of a certain gamma of market products can be obtained. This constitutes a clear contribution to sustainability, reducing the consumption of a petroleum product and inerting an agricultural waste that is usually incinerated.

Nonetheless, to stablish clearly the environmental advantages of the proposed composite materials, a life cycle analysis is needed. The use of natural fibers hinders recycling the materials.

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Improvement in the Design of a Front Hub for the BMX Bicycle

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Abstract. Bicycle wheels for BMX (Bicycle Moto Cross) are subjected to considerable stresses during the practice of this sport, particularly in the Freestyle mode where the execution of stunts and large jumps often causes the breakage of certain components.

This study describes the improved design of a front hub for this type of bicycle, which presents two essential advantages in comparison with the existing hubs according to a market survey. Its shell has been optimized to reduce the risk of broken spokes by redesigning the flanges to avoid stress concentration points while increasing their support surface. Moreover, the protection of the spokes is also improved by a new hub cover and the creation of a subdivision of the cone whose assembly provides greater fixation, which allows for maintaining the assembly of all the hub components either with or without the hub cover.

Other aspects of the design have been considered based on several investigations and surveys regarding both aesthetic concepts and other demands of this extreme sport.

Keywords: Bicycle Moto Cross · BMX · Hub · Spokes

1 Introduction

The BMX (Bicycle Moto Cross) emerged in California (USA) in the 60's as teenagers imitated motorcycle racing with their bicycles, which, little by little, increased in popularity until it became a cycling discipline that was recognized by the International Cycling Union in 1993 [1], although there are video references that date back to 1955 in the Netherlands [2, 3].

The "Racing" modality consists of racing at the highest possible speed through bumpy or obstacle-laden courses while the "Freestyle" mode entails the difficulty of performing jumps and acrobatic sequences in the different environments that define its various modes ("park", "Street", "flat", "vertical" and "dirt"), and on different structural elements (benches, stairs, railings, and vertical walls) [1]. Bicycles of a relatively smaller size (frames between 950 and 1025 mm with 20-in. wheels) are used, and these

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