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Design optimization based on eco-design and mechanical analysis

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1. Article Information

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2. Abstract

The work presented here attempts to show the advantages of relating design tools and methods that impact on improvement methodology and outcome of product design, in this case eco-design and the mechanical analysis are related in order to optimize the design to generate a lower environmental impact without loss of functional performance. The methodology proposes a market survey to select the objects to analyze, in which observe the environmental impact analysis with a specific tool so the ranges of optimal values in production, use and disposal of values and objectives and as the use of eco-design strategies are set. At the same time, a mechanical study using reverse engineering, loads and stress analysis, by means of finite elements that just results in a number of conditions and values to be taken into account in future design.
Once the research and analysis raises the design stage in which proposals are made, those are analyzed using the same tools, in terms of environmental impact and structural strength, to establish more robust design from a series of alternative proposals according to predetermined design criteria.
This work aims to link the findings of both analysis so as to enable optimum results and compatible design specifications and thus show the current need to develop hybrid methods that relate to the different techniques and tools.

1. Introduction

The design of any type of product has a high complexity, because, to obtain a competitive and attractivedesign for the market, it must fulfill some and diverse design specifications: mechanical, environmental, manufacturing, material, economical, packaging, logistical, appearance, etc.
So, in the design phase, diverse knowledge areas must be involved; this means an increase of the complexity of final design process and in the development timing.
This paper is centered mainly in two design criterions: environmental and mechanical ones, but some other design aspect are take in care.
To illustrate this design process, it is going to be applied to an existing and commonproduct: a clothes peg. In the process it is going to carry out a market analysis to know the existing designs with the aim to obtain some design criterions using inverse engineering tools.
The ending objective is anenvironmentally more efficient clothes peg design with similar functional characteristic than the existing pegs in the market.

2. Design process, stages and methodology

The design process developed in this paper, pursues to prove the utility of the interrelation between some design criterions, like the mechanical and the environmental ones, so this process needs a specify design phase for each one to determine the specific requirements that will establish the guidelines of the project (see table 1).

The phase's structure is common to other design methodologies, although there are some differences in some phases; in the table 1 it can be observed the differences, actions and specific works developed in each phase, as well as the obtained results.
The market study and the existing products research allows to have a clear idea of the state of the art and the technical research to evaluate the best existing designs; it has made too aninternational patents research[2, 3 y 4].
With some previously selected commercial pegs, it can be made an environmental study to determine the design criterions that makes possible an environmental impact analysis and reduction, both in the manufacturing, use and removing.
As well it is going to be determined the materials and the manufacturing process with less environmental impact, that will turn into one of the design specifications. However it will be made a mechanical analysis with allows obtaining the criterions and specifications for the mechanical design. Furthermore some other analysis will be made: structural, economical, ergonomically, functionally, shape, etc. that define all the design requirements and specifications for the product.

Phase	Actions	Results
Bibliographical research and market analysis	Information and documentation research	Existing products knowledge.
	Market analysis	Establish the state of the art and the technical
	Environmental analysis	Environmental design requirements and conclusions.
	Mechanical analysis	Mechanical design requirements and conclusions.

	Other design analysis	Other requirements and design conclusions.
Conceptual design	Design proposals	Evaluable concepts
	Environmental evaluation	Selection and acceptation
	Mechanical evaluation	Selection and acceptation
	Other criterions evaluation	Selection and acceptation
	Design revisions	Selection of the best design
Detail design	Mechanical optimization	Results validation
	Environmental optimization	Results validation
Acceptation	Aims to compare	Final design acceptation

Table 1: specify requirements to develop the project

In the conceptual design phase, there will be generated some design proposals that, after the evaluation using the established design criterions, allows to make a review and to select the best proposal.
In the detail design phase it will be made an optimization of the selected concept, using mechanical and environmental tools to evaluate and develop the design. After the obtained results validation, the next phase is an acceptation one, in which it is compared with the design objectives. After that the design is accepted or refused once and for all.

3. Design Criterions

The design methodology of this article is based on the application of some eco-design and mechanical design criterions; to illustrate the use of both design criterions, it has been used a practical case, that consist on a clothes peg design; this element has a low complexity, so it is easy to establish improvement criterions that allows to obtain easily conclusions; besides it is an useful and high intake element, so it is susceptible to be re-designed
To do the redesign, some considerations and eco-design and mechanical criterions must be taken in care, so it is going to be submitted separately and it is going to show their interrelationship and their common effect in the final design. It is necessary to take in care some other design criterions like packaging, mechanical, environmental, manufacturing, material, economical, logistical, appearance, etc., but then the present article will exceed the initial aims that were to link two design methods, oriented to the product optimization and redesign;although there were analyzed in the first stage, the research and documentation one[1].
Initially, it has been made the most representative product analysis that exists in the market; the aim of this analysis is to obtain some environmental and mechanical design criterions using inverse engineering tools. To do this task thirteen clothes peg designs were analyzed (seefig 1 table 2).

Fig.1: analyzed clothes pegs (left to right and up to down: pegs 1 to 13)

Element	Quan	Weight (g)	Material	Opening force (N)	Closing force (N)
Peg 1	1	9,4		15	4,5
Base	2	4,3	PP		
Spring	1	0,7	Steel		
Peg 2	1	3,7	PP	8	5
Peg 3	1	6		7	6
Base	2	2,2	Madera		
Spring	1	1,6	Steel		
Peg 4	1	9,1		6	42
Base	2	4,3	PVC		
Rubber	1	0,6	Silicone		
Peg 5	1	5		18	6
Base	2	1,8	PP		
Spring	1	1,3	Steel		
Peg 6	1	9,4		15	7
Hand rubber	2	0,8	Silicone		
Clothes rubber	2	0,8	Silicone		
Base	2	2,5	PP		
Spring	1	2	Steel		
Peg 7	1	10,8		18	8,5
Hand rubber	2	0,8	Silicone		
Clothes rubber	2	0,8	Silicone		
Base	2	2,8	PP		
Spring	1	2,3	Steel		
Peg 8	1	5,2		16	6
Base	2	1,4	PVC		
Spring	1	2,2	Steel		
Peg 9	1	14,5		14,5	4
Base	2	6	PP		
Spring	1	2,4	Steel		
Peg 10	1	4,5		12	6
Base	1	3,9	PP		
Spring	1	0,6	Steel		
Peg 11	1	11,7		13	6
Base	2	4,2	PP		
Spring	1	3,2	Steel		
Peg 12	1	7,2		14	3,5
Base 1	1	3	PP		
Base 2	1	3,1	PP		
Spring	1	1,3	Steel		
Peg 13	1	16,8		23	3
Rubber	2	2,3	Silicone		
Plate	1	2,2	PP		
Base	2	5	PE		

Table 2: main characteristics of the analyzed clothes pegs.

3.1. Eco – design criterions

Initially it has been made an environmental impact analysis of thirteen clothes pegs using the easily software called ECO-it[5], version 1.4.This software allows to compare the different impact, and the results are expressed in CO_2 g. emitted (carbon footprint) or in a unit called milipoint (mPt), that has a relationship with an environmental index know as eco-index 99[6]. This index allows to compare some material, productive process, energetic consumes, transport requirements and wasting aspects.

Initially it has been made an evaluation taking in care two different wasting processes, with the same production process. The first one with a controlled wasting, in which the users of the pegs, after the useful life of the pegs, take in care to drop each component of the peg in an adequate green point to optimize their waste. In the second case, the peg will be waste using the local rubbish wasting system

After seeing the results, it will be determined the most unfavorable but usual method is the local rubbish wasting system and will be used as a criterion for all calculus and evaluations.

With the obtained results, the established objective is to design a product with the same functional requirements of a clothes peg, but with minimizes the environmental impact more than a 10%

Figures 2 and 3 shows the environmental impact for the evaluated pegs in their manufacturing and erasing.

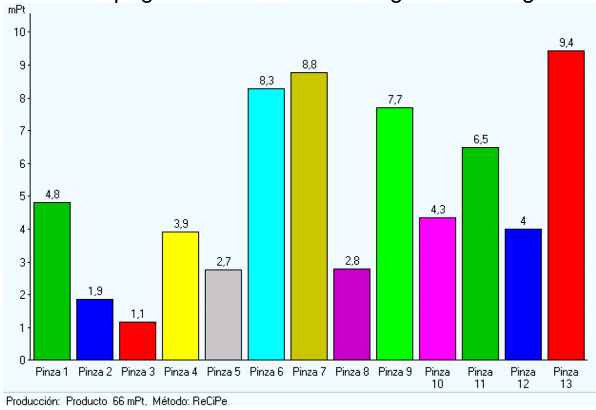


Fig. 2: Manufacturing environmental impact analysis (in mPt)

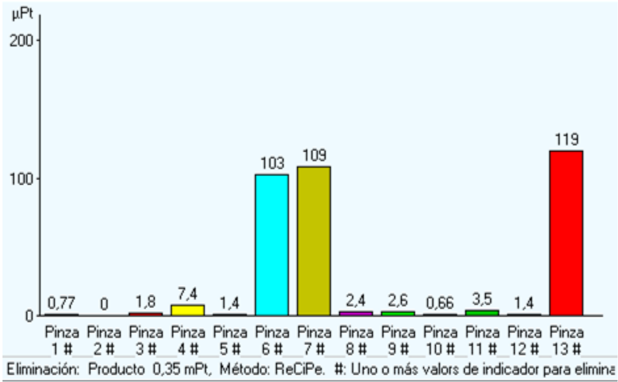


Fig. 3: Erasing environmental impact analysis (in mPt)

It is observed that the number tree peg has the lower impact, but it is going to use as a reference the number two peg because it is the plastic one with lower impact, and the number tree is a wood peg and her carbon footprint is not real; this is because the program considers that the material is obtained with a replacement program and new trees are planted

It can be taken into account that there is only environmental impact in the production because, observing figures 2 and 3, the erasing process carbon footprint is insignificant compared to the production one.

Wirth this results it can be stated that the environmental impact depends mainly on the weight of the design, the material selection and the manufacturing process.

There are some other criterions and design specifications established using the DfE (design for environment)[7] tool. It incorporate some environmental considerations into the design process and into the product development stage, and offers new prospects and approaches to the product, providing a systematic framework use and to analyze the life cycle of the product.

To innovate in the clothes peg that has the lowest environmental impact, it will be used some optimization and material reduction strategies. A design criterion will be to design using the material elasticity to supply the function of the spring.
Some other strategies that must be used are: the use of the shape and the structure to reduce the material quantity and a mono part and mono material design. These strategies allow avoiding an assembly and un assembly process and a different material process at the end of the useful life of product, so the peg can be recycled easily.

3.2. Mechanical criterions

The main mechanical criterions used in any estructural element are the stiffness and the strength. Initially, there are not any mechanical criterions defined in any regulation so it must be made an inverse engineering process to determine the mechanical criterions; the first step is the determination of the opening and closing forces using a dynamometer and some experimental test. These forces allow making a finite element analysis for the diverse type of pegs with the aim to obtain the Von Misses Stress and the security coefficient. The clothes pegs are simulated using the CAD program Solid Works 2010 with the geometry and specifications of the real ones, and the FEM tool Solid Works Simulations.
In table 3 it can be observed the obtained results in terms of stress and security coefficient.

Clothes Peg model	Material	Opening force (N)	Von Mises Stress (MPa)	Segurity coeffiecient	Closing force (N)	Von Mises Stress (MPa)	Segurity coeffiecient
1	PP+steel	15,00	8,40	3,90	4,50	1,80	18,22
2	PP	8,00	9,40	3,49	5,00	1,40	23,43
3	Wood+steel	7,00	5,60	3,55	6,00	0,52	38,27
4	PVC	42,00	2,40	15,67	6,00	21,30	1,77
5	PP+steel	18,00	5,60	5,86	6,00	15,40	2,13
6	Silicone+PP+steel	15,00	16,00	2,46	7,00	14,80	2,66
7	Silicone+PP+steel	19,00	12,30	3,20	8,50	16,30	2,41
8	PVC+steel	16,00	2,90	12,97	6,00	20,20	1,86
9	PP+steel	14,50	3,40	9,65	4,00	16,40	2,00
10	PP+steel	12,00	17,00	1,93	6,00	18,40	1,78
11	PP+steel	13,00	18,00	2,18	6,00	13,90	2,83
12	PP+steel	14,00	14,80	2,66	3,50	11,00	3,57
13	Silicone+PP	2,30	13,30	2,95	3,00	14,80	13,30
Average value:		15,06	9,93	5,42	5,50	12,79	8,79

Table.3: Results of the mechanical analysis of some commercial clothes pegs.

The main result obtained from this analysis is that, for a new clothes peg design, the mechanical criterions to fulfill are:

- Maximum opening force: 15 N (average force)
- Minimum closing force: 6 N (average force)
- Minimum security coefficient: 3 (30th percentile)
- For non-articulated pegs: maximum displacement at the end: 10 mm (wire: 7 mm and blanket: 3 mm)

2.3. Other design criterionsand specifications

It is necessary to establish other design criterions and specifications; the ergonomic criterions are defined in the peg analysis stage, and can improve the uses aspects. A design with the non-sliding grabbing zones and with a well-defined fixing points and adapted allows that the peg needs less use efforts; this is an interesting aspect for users with joining problems or with efforts deficiencies. Moreover, it must adapt to any finger size, so the anthropometry measures and the users profiles must be taken into account;then the 50th percentile tables have been used.
About the use and environment aspects, the peg can be used in clothes lines and bar with a 3 to 7 mm diameter and with a 3 mm maximum clothes thickness. Functionally it must be guarantee that the clothes are firmly hold in the clothes lines or in clothes horse and that the insertion and the exit must be easy and intuitive.
About the materials selection, it must be made with materials that can support the sun and the open air effectswithout degrading (PP, PE, PVC, wood, steel, etc.) [8 y 9] and with adequate mechanical properties.
The best manufacturing process for the plastics will be an injection or extrusion process, with a final design composed of only one mono material part. These aspects allow the recycling process and an assembly and manufacturing cost reduction; these aspects are fundamentals to obtain an environmental and economic viable design.

4. Design Methodoly Used

For both design methodologies it has been used the CAD program Solid Work 2010. This program allows simulating elements and assemblies. In this article, it is presented an interactive and joint working form where the mechanical requirements are defined and after that the environmental impact is evaluated (using the Solid Works sustainability tool); this tool allows comparing materials with similar characteristics, and so, the optimal one is determined, because the program supply the impact and the mechanical results and allows to make design modifications and material selection changes to satisfy the initial established objectives.

4.1. Eco – Design Methodology

With the Solid Woks Sustainability tool help, it has been analyzed the environmental impact of each design during all their life cycle and with the Solid Works Simulations the mechanical behavior. With the previous obtained environmental and mechanical results, the selected materialis the polypropylene (PP), because, althought the polyethylene (PE) is more adequate for our mechanical necessities, the PP has an environmental impact lower and the mechanical properties are not much worse. There are two alternatives for the PP, a copolymer or a homopolymer, and both have similar mechanical characteristics; the homopolymer has a lower melting point so the energy needed during the injection process is lower and so it is the selected material.

The values to take into account for the study are in the one hand, the carbon footprint that is the most famous environmental impact indicator. And, in the other hand the energy consumed during all the life cycle of the product in mega-Julius (MJ). In this case it must take only into account during the manufacturing process. There are some other aspects like the air acidification and the water eutrophication. After the analysis, the Eco-it obtained results are used to compare the new designs with the commercial design and with then self.

The calculus is made depending on the piece design, the material characteristics, the manufacturing location, the transport and the use energy. Basically the steps are defined in the LCA system (life cycle assessment) and in the MET matrix (Material / energy / toxic), used traditionally in the eco-design and environmental design..

4.2. Mechanical Design Methodology

The mechanical design has been made using the finite elements methodology (FEM), using the Solid Works Simulation tool. This tool allows obtaining easily and quickly the mechanical results for the peg designs.

Structurally, there are some factors and aspect that must take in case to obtain a good mechanical design[10]:

- To round and to avoid open edges.
- Reduce the thickness in lower loaded zones
- Increase the thickness in higher loaded zones
- Modify the peg resentence section depending on the main efforts en each zone

Moreover, it must take into account the manufacturing process that, usually is a plastic injection process, so some facts must be included like the cast angles, minimum mold numbers, injection points, etc.[11].

To make the numerical simulation, after obtaining the peg CAD model, it must establish the material for each part of the assembly, the boundaries, the loads and the load cases.

In the particular case of a clothes peg there are two load cases to analyze: the opening and the closing load case; in figures 4 and 5 appear the loads and the boundaries for each case.

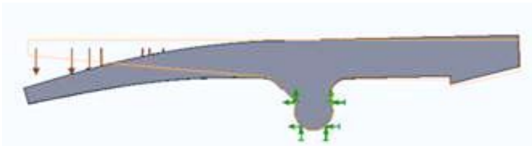


Fig. 4: Boundaries and loads for the opening load case

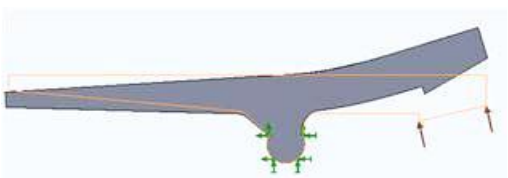


Fig. 5: Boundaries and loads for the closure load case

After this stage, the software makes an automatic finite element mesh usingtetrahedral volumetric element (the FEM code used internally is "COSMOS"). Solid Works makes too the numerical simulation and shows the results in terms of strength and stiffness.

Solid Works has another function that allows making a parametric redesign of any type of structure, but it is not adequate for this model because it works well with simple geometries with not too many parameters. So in our redesign it will be used a "try and trial" methodology.

Figure 6 shows the stress results for analyzed peg, and in table 3 appear the results for each commercial peg.

The results have been obtainer after the CAD simulating all the pegs with Solid Works and analyzing with the Simulation tool both lad cases: opening and closing. With this results and using inverse engineering tool they have been obtained the stress and stiffness criterions.

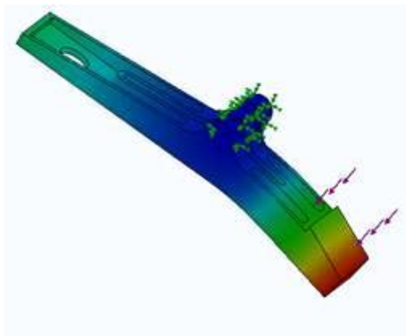


Fig. 6: Stress map for a peg during the opening load case

5. Cases to study

To show the article results, they have been applied to a simple peg; there it can be observed some stages of the project: design process, material selection, optimization (environmental and mechanical) and evaluation to acceptation.

5.1 Conceptual design

Some concepts have been generates using the DfE strategies Wheel; some of them have been selected and it has been made too a morphological table in which they are established as design features the environment and user adaptation, comfort, minimum effort and stress in the hand and maximum grab force. In figure 7 it can be observed the first conceptual design of one the alternatives, where it enhance the arc that allows the deformation and allows the opening of the peg, and the two grab zones to insert the peg up to down, in a higher than the clothes line position.

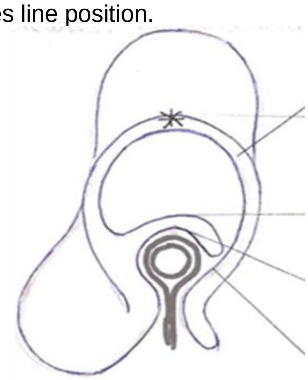


Fig. 7: First sketch under the defined requirements for the design specifications

Before making the environmental and mechanical analysis of the concepts using Solid Works, it has made an initial selection using prototypes. These prototypes are made with a 4 mm thickness PVC plate. In figure 8 two of the selected concepts are compared. This experimental test allows, in a user level, to determine the force to make in the insertion and in the extraction process, the comfort and the grab in the specific zones. The test is made with a 10 mm steel wire that simulates a wire and a blanket.

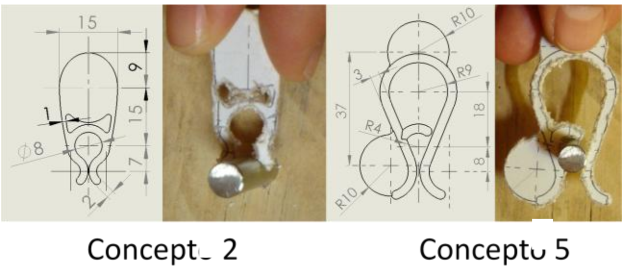


Fig. 8: User test for the first sketch upon the design specifications

With the experimental test and a first dimensional approach, one of the conceptual alternatives is chosen, that is simulated with Solid Works and analyzed mechanical and environmentally to make the optimization. Figure 9 shows the one of the first CAD model concepts.

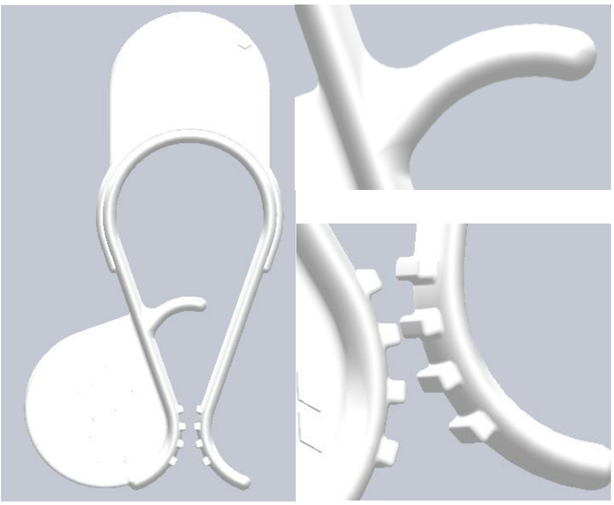


Fig. 9: CAD model for the concept 5

5.2 Mechanical Analysis

With the mechanical analysis it can be evaluated the stress level and the security coefficient for the developed model; the acceptation of refusal criterion are the established in the 4.2 section.

Figure 10 and table 4 shows the obtained results. Before analyzing these results for the concept 5, the main mechanical conclusions obtained are that the peg must be re-designedbecause is not enough stiff and it can not support the efforts so it will break in the future.

To increase the stiffness and the strength, it has been modified the cross section in the most solicited zones and the design has been modified to obtain the design that appear in the figure 11. This last design passes the mechanical criterions and the maximum security coefficient is quite similar to the minimum security coefficient allowed (3), so the peg is not over dimensioning.

In figure 12 it can be observed the Von Misses stress map for this last concept.

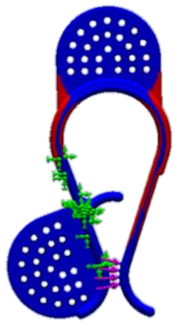


Fig 10: Opening load Case for the concept 4. Red zones: security coefficient under 3.

Opening load case				
	Force (N)	Maximun Von Mises Stress (Mpa	Segurity Coef.	Displacement (mm)
Allowed limits	<15		>3	10
Concept 5	12	131	0,31	88,6
Concept 6	12,3	13	3,08	11,4
Closure Load Case				
	Force (N)	Maximun Von Mises Stress (Mpa	Segurity Coef.	Displacement (mm)
Allowed limits	>7		>3	
Concept 5	8,3	205	0,20	46,2
Concept 6	7,4	11,5	3,48	2,4

Table. 4: mechanical results for the concepts 5 and 6

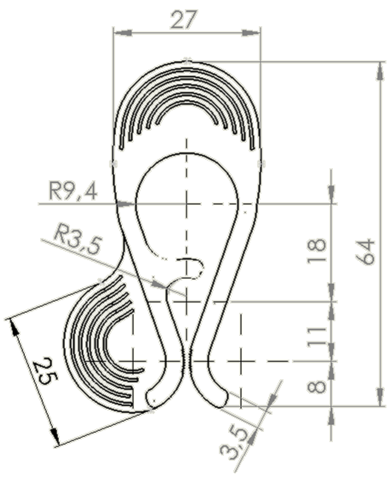


Fig. 11: Concept 6. Ultimate peg design

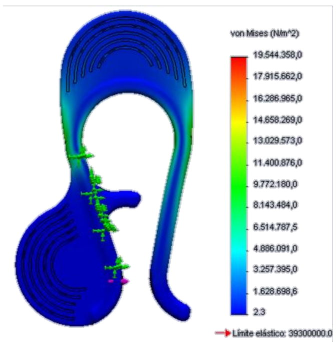


Fig. 12: Von Misses Stress (MPa) for the concept 5 in the opening load case

5.3 Environmental analysis

The materials to analyze the environmental impact have been chosen depending on their density and their specify strength (Young stress/density). These materials are: PP copolymer, PP homopolymer, high density PE, PVD and Polyester resin (only to compare). This materials have a good environment resistance and to the sun degradationso they are suitable for this particular case. Although, they have a suitable and similar mechanical properties.
Finally it has been the PP homopolymer (see point 4.2); this material has the lowest environmental footprint, and it has been made a comparative analysis between the developed design and best environmental the commercial peg (the peg number 2)
The main objective was a new design with anenvironmental footprint reduction higher than a 10 %. Both pegs are made with PP homopolymer and with the same manufacturing process, so the environmental footprint will be directly proportional to the weight, and then it is necessary to reduce the weight more than a 10%.
In this analysis it is not take into account the packing, but this aspect is not dependent on the element design.
Table 5 shows the results obtained with the Solid Works Sustainability tool.

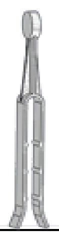
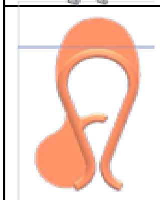
	Material	PP homopolimer
	Volume (mm^3)	3722
	Weight (g)	3,7
	CO2 emissions (g)	14,94
	SO2 emissions (g)	3,25E-02
	PO4 emissions (g)	5,17E-03
	Used Energy (kJ)	369
	Material	PP homopolimer
	Volume (mm^3)	1730
	Weight (g)	1,72
	CO2 emissions (g)	6,95
	SO2 emissions (g)	1,50E-02
	PO4 emissions (g)	2,40E-03

Table.5: environmental comparative analysis

It can be observed a 53% environmental footprint reduction, quite higher than the environmental design criterion, so the results are quite satisfactory. This is because the high improvement potential that some of the commercial elements have, that usually are designs without taking into account eco-design aspects.
It must be stand out that it has been made a comparative analysis with a peg that has a very good environmental design compared with the normal commercial pegs, so the results are better. If it is compared the ECO-it results of this peg with the average results of the 13 commercial pegs, the average result is 30.55 mPt and the result for this peg is 1.53 mPt, and 2,9 mPt for the number 2 peg, so we can see a high environmental footprint reduction.

6. Conclusions

The main conclusion that can be obtained in this article is that, using a methodology based on the joint application of environmental and mechanical design tools, new more environmental improved design can be generated, and this aspect do not have bad effects in some aspects like the functionality, ergonomic, cost, durability, etc.
The relationship between two different design specifications and criterions allows establishing some interdependent objectives to fulfill, so there are some variables that affect to other criterions and are dependent of both criterions. With this methodology it can be establish the limits, objectives and design requirements, but in other separately design process they are not enough in deep detailed
A good example is the analyzed case for the clothes peg. In this case it has been obtained a new design of a functional piece that can resist the efforts, is cheaper and has a 53% of environmental improvement in term of CO_2 emissed than the best commercial peg.
It must be enhance that, the fact to include environmental aspect in any design process suppose an additional cost in economic and time terms, but it compensate in environmental, marketing and final cost terms. Moreover, usually the environmental design improvements have associated weight reductions in the final weight, so the individual cost and the transports decrease and the additional effort is highly compensated.
The initial design specification can define conceptually a product, the calculus and evaluation tools are useful to make the optimization and the consecutions of the previously established objectives are necessary. It is necessary to comment that there are some cases where it is impossible to plenty fulfill the previously established objectives because there are some difficulties to define then, so with a higher detailed initial analysis with more concrete specifications, more real are the objectives, fruit of this initial effort.

7. Acknowledges

Acknowledge specially their contribution for this paper, within it can not be made, to the design engineers Laura Tomas and Leticia Marrades

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