NEW METHODOLOGY FOR LIGHTENING PARTS MADE FROM ADDITIVE MANUFACTURING TECHNOLOGIES

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INTRODUCTION

Nowadays, new technologies such as additive manufacturing enable complex geometries unsuitable to be fabricated by other procedures. Additive Manufacturing (AM) technology involves the manufacture of prototypes and end-use products using layer by layer fabrication. AM enables fabricating hollow parts with internal light structures, formed by hollow cells. This option allows to manufacture parts achieving not only minimum requirements of stiffness but also lower weight, thus more efficient such as those needed in some applications where the weight is primordial factor (automotive, aeronautic, etc). On this context, there is a need of developing a practical and simple method for designing lightened parts, starting from a solid CAD model, using commercial CAD software (in this work SolidWorks) and other tools, available in the market , for reducing the time of design and enabling fabrication by additive manufacturing technologies.
FDM is presented in this paper as suitable option for making lightening parts. In the Fused Deposition Modeling (FDM) process, parts are fabricated, layer by layer, by extruding a plastic filament onto a platform. Commercial FDM equipments provide two different plastic materials: base material (usually ABS) and support material, being the support necessary for overhanged or cantilever features. However if some rules of maximum length of cantilever are followed, on the context of this research, the support material is not needed because the internal surface of the part could be quite stable during the cooling process of the material.. Therefore, in order to avoid problems with the internal deformation of the plastic, meanwhile is solidifying, the maximum length of each internal hollow cell has to be limited. SolidWorks is very well known as 3D CAD software and it was used as base of the design process.

DEVELOPED METHODOLOGY

Although there are different alternatives for lightening parts, in this work is approached to use simple geometric patterns which are going to be repeated inside the part. In general, to a great extend the application of cellular structures makes easier the generation of the geometry in CAD environments.
In order to see the best geometry for cells different basic geometries were analised (Figure 1), calculating the relative stiffness (stiffness/mass) of the solid model (Rs) divided per the relative stiffness of the hollow model (Rl). One example of this comparison is seen in figure 2, where several scenarios were compared modifying the dimensions of cells for each weight reduction. 25% represents the targeted decreasing of weight and tensile is the hypothesis of loading in such samples (plastic ABS 20x20x80 mm).The conclusion of this study was that squares prisms achieve always the best results, independently on the loading hypothesis and lightening percentage.

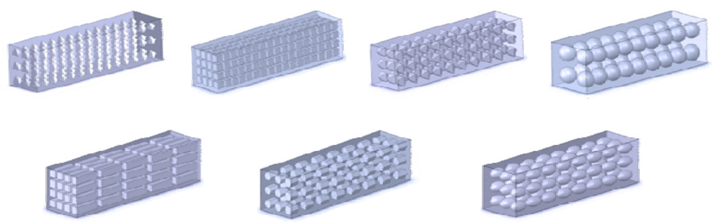

Figure 1. Different geometries of basic cells

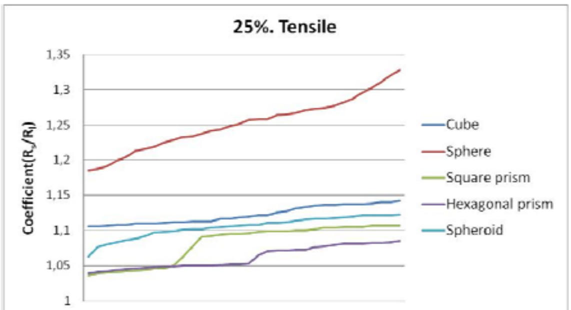

Figure 2. Comparison among different basic geometries

The approach is as follows:

1) The 3D solid is designed as well as automatic parametric model with internal hollow cells, repeated by a matrix according with a pattern.

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2) A mechanical analysis is defined including the loads, boundary conditions, mesh dimensioning, material, etc. In order to automatically control the results of simulations, several target variables (sensors) will be implemented: stress, deformation, mass, etc.
3) A study is defined for optimal design. This study needs “factors of design” with upper and lower limits, restrictions and targets. The factors of design are corresponding to geometric dimensions of the internal cells and the targets would be associated to “sensors” for evaluating the suitability of the optimal design.
   At this point is important to clarify that SolidWorks enables studying optimal design by design of experiments (based on Box-Behnken) . Despite this tool can be very useful, its practical application, in the context of this research, has some limitations mainly when the geometry of the 3D part is complex. For instance if any experiment is not calculated, because of problems with the meshing or geometry regeneration, the other experiments would not be finished. Otherwise, in case of no problem with automatic process, SolidWorks provides the best solution according to restrictions, but it is just a prediction. If this estimated solution does not achieve the restrictions when is simulated, the optimization process would be wrong and would not show, in the computer display, the design factors for such scenario. In the context of this research and taking into account the limitations of SolidWorks on this purpose, the approach is to complement SolidWorks with other software such as Statgraphics and Matlab with the aim of considerably reducing the processing time and obtaining an optimal and reliable solution. In fact the proposed methodology initiates the process working with similar design study to optimization in SolidWorks but choosing as type of variable “range with step” in such a way that is necessary not only to define upper and lower limit for each variable but also the “step”. Once the design study is executed for n scenarios the designer must decide whether or not the best solution should be improved (going to next phase).
4) In this phase statistical software is used, such as Statgraphics, where the n scenarios are introduced and the response surface is determined (equations corresponding to an adjusted regression model).The response surface should achieve an acceptable adjustment with the original n scenarios. Response surface allows knowing whatever results of any scenario without making more simulations in SolidWorks, saving processing time. The next step is to know the optimal scenarios.
5) Applying a program developed in Matlab for this purpose and introducing the equation of response surface, from the step before, every possible cases are so optimal R scenarios are calculated under a processing time lower than 1 second.
6) Finally the best R scenarios are introduced in SolidWork for checking the viability of them and for calculating the real value, beyond the estimated value in Matlab. The advantage of this method is that only the best n scenarios are finally simulated in SolidWork, guaranteeing the optimal solution.

The developed methodology was applied to a case study consisting of the blade of a micro-wind turbine. This blade cannot be deformed more than 15 mm when a distributed force (total force 50 N) is loading the bottom face in vertical direction. The conclusion of this case study is that the initial solid blade had a weight of 3046.10 g; the preliminary study in SolidWork decreased this weight to 2042.92 g (32.93 % lower than the solid model) and the application of the following steps achieved to reduce the weight to 1845.64 g (39.41%). Since the number of scenarios simulated in SolidWork was 37, being 27 in the first stage and 10 in the last, the time for processing was about 400 minutes because the processing time of Matlab is negligible, less than 1 second. Note that Matlab estimates the optimal solution under 2000 scenarios (if the step is 0.5 mm); if all these scenarios were evaluated by SolidWork the total computational time would be around 20000 minutes (5000% bigger than applying the proposed methodology). Figure 3 shows a section of the optimal solution.

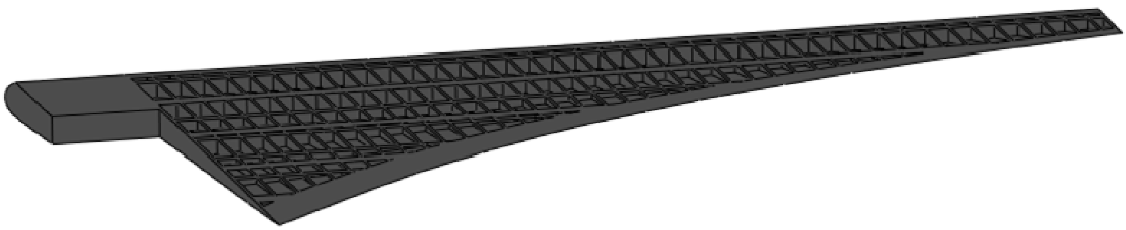

Figure 3. Section of lightened blade of micro-turbine wind power

CONCLUSIONS

Combining the advantages of SolidWorks, Statgraphics and Matlab a novel alternative methodology, considerably faster and easier, for lightening solid parts by internal cellular structures was developed. The methodology, oriented to additive fabrication, allows reducing the mass but under certain restrictions defined by the user. The methodology overcomes the existing problems in CAD software, such as SolidWorks, where the optimization tools present some limitations for automation of the process when the geometry is complex as well as considerably processing time. Different sort of geometries for hollows cells were studied and compared.