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Optimisation of Recycled Thermoplastic Plate (Tile)

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ABSTRACT

The purpose of this paper is to perform a structural optimization of a flat thermoplastic plate (tile). This task is developed computationally through the interface between an optimization algorithm and the finite element method with the goal of minimizing the equivalent stress with specified target stress of 2 MPa when applied with a load intensity of 1000N. A 300 x 300 x 20 mm thermoplastic plate was selected for the optimization, which was performed with a tool in MATLAB R2012b known as genetic algorithm accompanied with static analysis in ANSYS 15. The results produced the optimum equivalent stress (δ_{opt}) of 2.136 MPa with the optimum dimensions of 305 x 302 x 20 mm. Also, the dimensions of the plate with the optimum value of the equivalent stress were discovered to be within the lower and upper bound dimensions of the plate. The thermoplastic plate object of the optimization was a square plate of 300 x 300mm, and 20 mm thick with isotropic properties and a particular load and boundary conditions were applied on the entire plate.

1. Introduction

The amount of solid waste is ever increasing due to increase in population, developmental activities, changes in lifestyle, and socio-economic conditions. Plastics waste is a significant

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portion of the total municipal solid waste [1] consumption of plastic products has increased dramatically over the past few decades; they account for more than 70% of total plastics market [2]. This trend results in the generation of a vast waste stream that needs to be managed appropriately to avoid environmental damage [3]. Many countries around the world are continuously faced with the problem of generation and disposal of plastic wastes. Governments around the world have funded hundreds of research projects to find efficient waste treatment technology [4]. Water sachet polyethylene is the most widely used polyethylene in developing countries especially Nigeria. Both licensed and unlicensed water sachet making factories can be found in virtually every street in cities, towns, and villages of Nigeria. During the dry season, about 70% Nigerian adults drink at least one sachet of pure water daily indicating that about 50-60 million used-water sachets are thrown into the streets of Nigeria on a daily basis [5]. The packaging of this sachet water is made of non-biodegradable synthetic polyethylene (polythene), which does not decay, decompose or corrode, and which when burnt, produces oxides of carbon, nitrogen, and sulfur which can harm man and the environment [6] and [7]. Waste recycling is often seen as an essential aspect of an efficient and effective solid waste management system; plastic materials can be formed into shapes by different processes: extrusion, moulding, and casting or spinning. Mechanic properties particularly stiffness, strength, and toughness of polymeric materials are decisive properties in industrial, technological and household application [8]. Several studies have been carried out on the recycling of polyethylene [9–12]. Since these water sachets still possess some properties of polyethylene, they can be used in a blend with pure polyethylene in making different polyethylene products like baskets, hats, ropes, bags, mats and for fabric sewing [13]. Andrei carried out a research on recycling of waste polyethylene into the thread but was not blended with pure polyethylene, and melt drawing was not carried out. This study is aimed at recycling polyethylene waste by converting wastewater sachets into threads for different uses thereby combating the problem of waste management.

The utilization of Genetic Algorithms (GA) in tackling engineering problems has been a significant issue arousing the curiosity of researchers and practitioners in the area of systems and engineering research, operations research and management sciences in the past decades. The vast areas of applications of GA optimization techniques in tackling problems that cannot be handled using the conventional methods and stochastic search are the focal areas of keen interest for consideration in this paper. GA is a type of evolutionary algorithm (EA) that is found useful in so many engineering applications which includes numerical and combinatorial optimization problems, filter design as in the field of Signal processing, designing of communication networks, semiconductor layout, spacecraft [14,15]. It is founded on the bases of natural biological evolution process which is used to mimic nature in searching for an optimal solution of a specific problem [16]. In the description of GA, the definition of chromosome and fitness functions is of paramount importance. Chromosomes are an abstract representation of candidate solutions. The fitness function is used in quantifying the desirability of a solution, which is closely correlated with the objective of the algorithm or optimization process. The fitness level is used in evaluating candidate solutions, that is, the values being generated to characterize the performance of candidate solutions [17].

In GA, the most promising search space areas are being explored through the utilization of probabilistic rule, hence minimizing the risk of convergence to local minima. This is achieved by simultaneously considering many points in the search space and favoring the mating of the fitter individuals [16,17]. GA is a robust search algorithm that enables the quick location of high-quality solution areas in a complex and large search space. The fundamental principle of GA includes selection, reproduction, population solution, encoding and decoding, fitness function evaluation and convergence [17,18]. This paper presents the optimization of the recycled thermoplastic plate (tile).

2. Materials and Methods

Optimization process

The optimization is performed through an algorithm which exploits the capabilities of the Optimization toolbox included in Matlab R2012b. It contains different functions among which Genetic Algorithm has been chosen as explained as follows.

The procedure is the following:

a. The Matlab R2012b algorithm is run, and the optimization starts;
b. An initial value is assigned to the variables and text file;
c. ANSYS15 reads the parameters present in the text file and uses them as input;
d. The static analysis is performed, and the total equivalent stress value is exported to another .txt file;
e. Matlab R2012b reads this value and continues to iterate in this way until a minimum (at least local) of the equivalent stress is reached.

3. Static analysis

The goal of the static analysis is to find the defects whether or not they may cause failure using the Finite Element (FE) method to perform a static analysis of the plate (tile) through the engineering tool ANSYS15. ANSYS15 is launched by Matlab R2012b at each iteration. In this way, the optimization process needs only to be started by the user in Matlab R2012b, and it continues to iterate until either an optimal solution is reached or a stopping criterion is satisfied.

Properties of material and Parameters used in the FE analysis

The property of the materials used for the FE analysis of the material is shown in Figure 1.

Properties of Outline Row 3: plastic

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	1106.9	kg m^-3		
3	Isotropic Elasticity				
4	Derive from	Young's M...			
5	Young's Modulus	141	MPa		
6	Poisson's Ratio	0.45			
7	Bulk Modulus	4.7E+08	Pa		
8	Shear Modulus	4.8621E+07	Pa		
9	Tensile Yield Strength	4	MPa		
10	Compressive Yield Strength	20	MPa		

Fig. 1. Properties of thermoplastic tile

The design variables of the plate are length (l) and width (w) which appear explicitly in this phase, and the thickness of the plate is specified but was not included as a design variable.

On the other hand, it is necessary to choose between triangular or quadrilateral meshes, which are the two possible choices when the mesh has to be defined over an area. In the optimization performed a quadrilateral mesh has been adopted because besides a better quality of the solution it speeds up the analysis time.

4. Boundary conditions and loads

In the optimization performed on the tile, the boundary condition adopted was elastic support of foundation stiffness $18N/mm^3$ with all the edges simply supported as shown in Figure 2. Also, a force of intensity 1000 N was applied to the plate before beginning the optimization as shown in Figure 3.

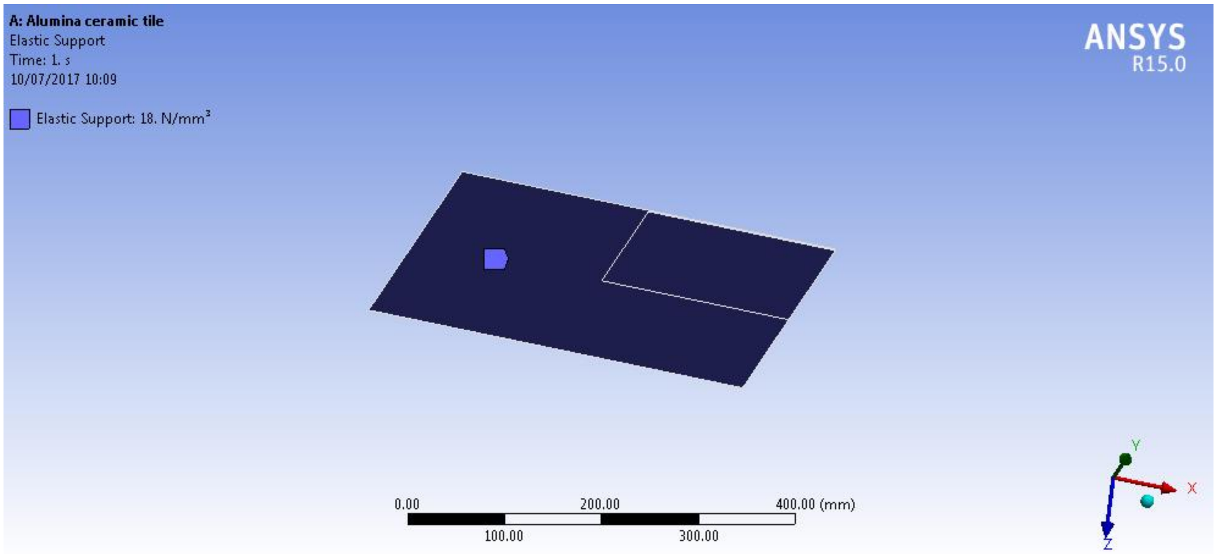

Fig. 2. Boundary conditions of material.

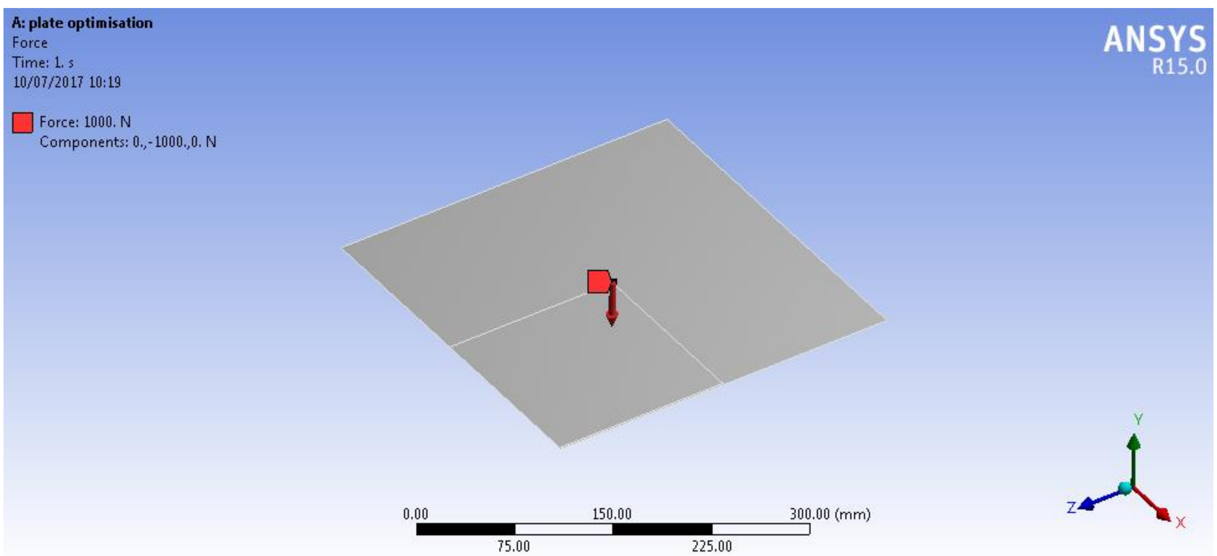

Fig. 3. Load intensity on the material.

Once the boundary conditions and the loads are defined in the ANSYS15, the static analysis is performed, and the total equivalent stress and deformation of the structure are calculated by summing the single equivalent stress and deformation values of each element that forms the panel. For this, the ANSYS15 element table of the post-processing step is used to obtain the equivalent stress and deformation of each element, and then each component of the table defined is summed in order to obtain the total value.

In the end, ANSYS15 writes the total equivalent stress and the total deformation value on a .txt file, and this represents the last step of the interface between Matlab R2012b and ANSYS15.

5. Results and discussion

Optimisations with *l* and *w* as design variables

Table 1 shows the optimizations done for different initial points, presenting, in particular, the minimum value of the equivalent stress reached, the optimal values of the design variables l_{opt} and w_{opt} are also presented in the table.

Table 1.
Various design points (iterations).

Design Points	Length(l_{opt})mm	Width(w_{opt})mm	Equivalent stress (δ_{opt})MPa
1	305	302	2.1381
2	300	302	2.1563
3	310	302	2.1251
4	305	300	2.1412
5	305	304	2.1300
6	300	300	2.1683
7	310	300	2.1402
8	300	304	2.1788
9	310	304	2.1344

In this case, the initial value of the thickness (t) is kept constant, and only the length and the width of the plate is changed because it turned out to be the most problematic in the convergence of the solution. The upper and lower bounds of the variables in these optimizations are presented in Table 2.

Table 2
Upper and lower bounds for optimization.

Bounds	Length (mm)	Width (mm)
Upper bound	310	304
Lower bound	300	300

From the optimization performed, targeted stress 2 Mpa was sought and rerunning the optimization program, it yielded three candidate points of which if a more refined optimization is performed, these three points will yield the targeted stress. These points are presented in Table 3.

Table 3
Candidate points for the sought target.

	Candidate points 1	Candidate points 2	Candidate points 3
Length(mm)	308.0189	308.0150	308.0250
Width(mm)	300.1763	302.0762	301.0762
Stress(MPa)	2.1282	2.1282	2.1282

From the FE Analysis performed in ANSYS15, the deformations and equivalent stress were determined as shown in Figure 4 and Figure 5 respectively. The result also shows that their maximum values were obtained to be 2.1683MPa and 0.0025mm respectively.

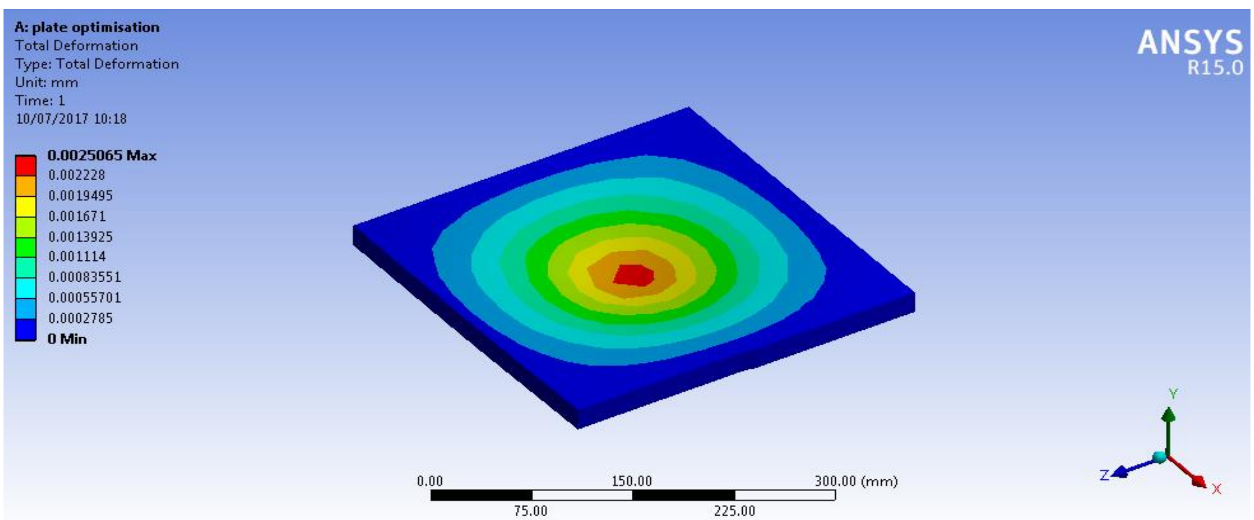

Fig. 4. Deflections of the plastic plate when analyzed.

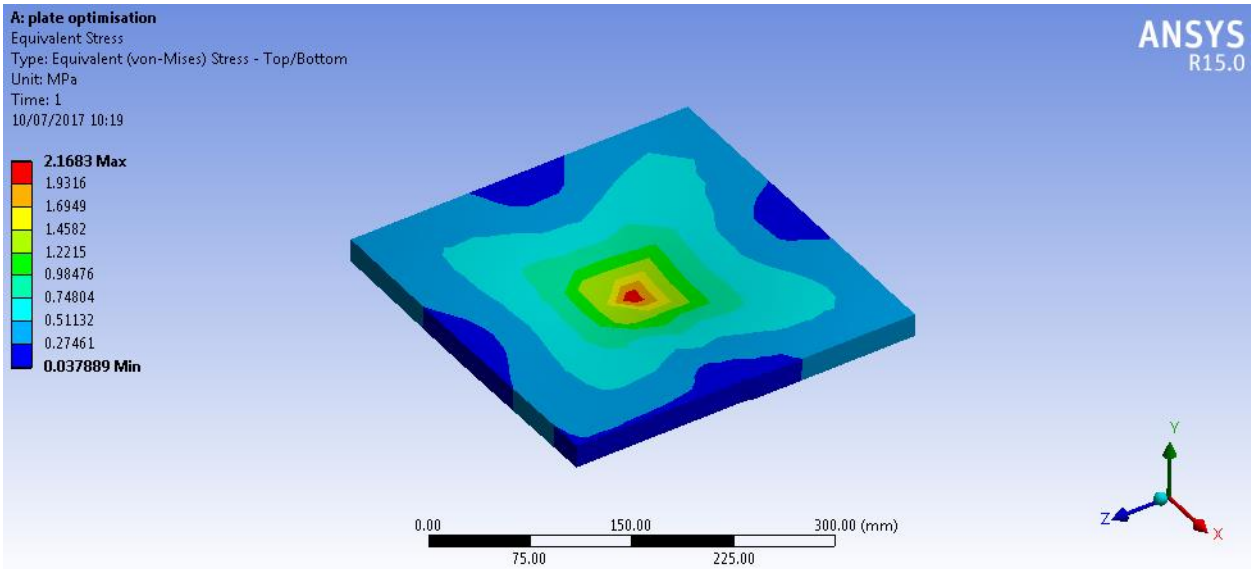

Fig. 5. The equivalent stress of plastic plate when analyzed.

However, from the optimization performed, the equivalent stress determined at each design point (iteration) was plotted as shown in Figure 6. Also, the maximum and minimum equivalent stress was determined at the design point 8 and design point 3 respectively.

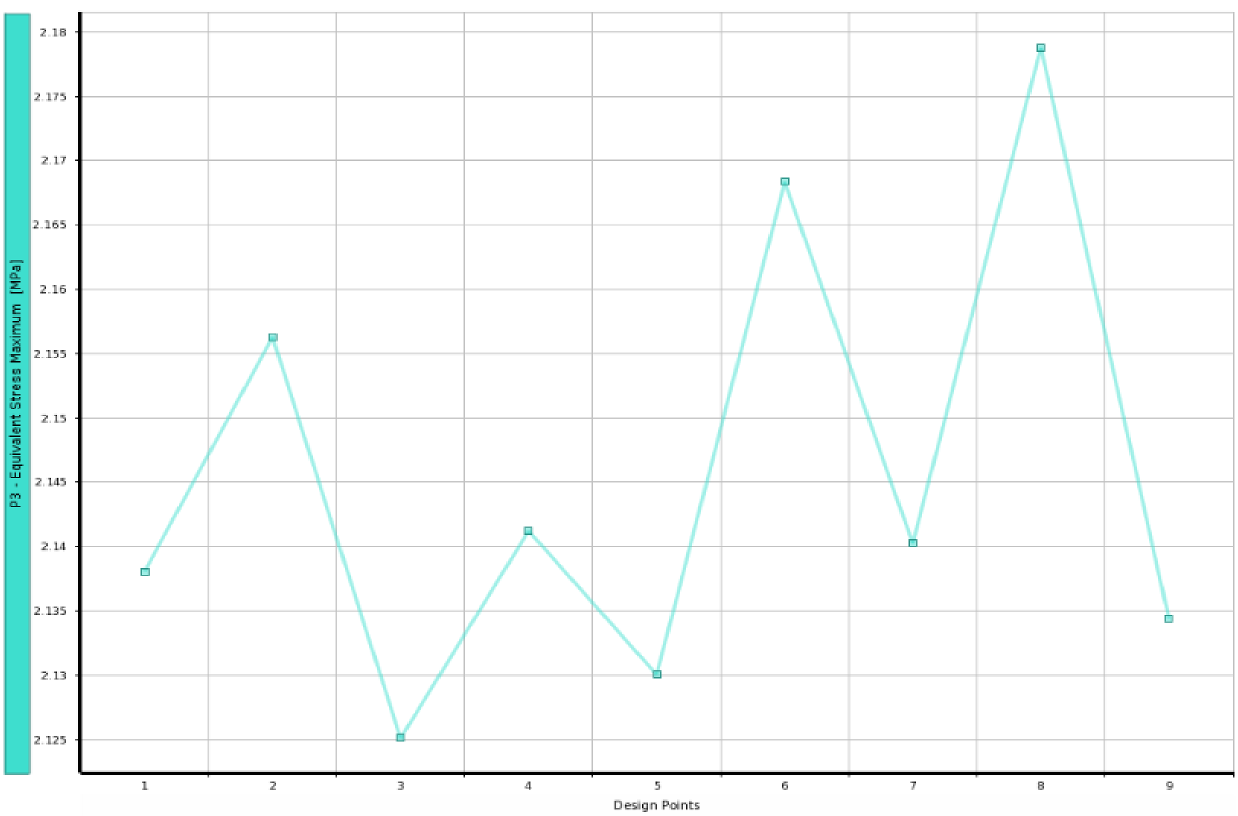

Fig. 6. Design points (iteration) against parameters.

Moreover, the dimensions determined at various design points were plotted against the equivalent stress (length and width) and the feasible points of the plate were found with a length of 305mm, the width of 302mm and the equivalent stress of this dimensions was 2.1364MPa. The graph of these feasible points is presented in Figure 7 for 2D and Figure 8 for 3D.

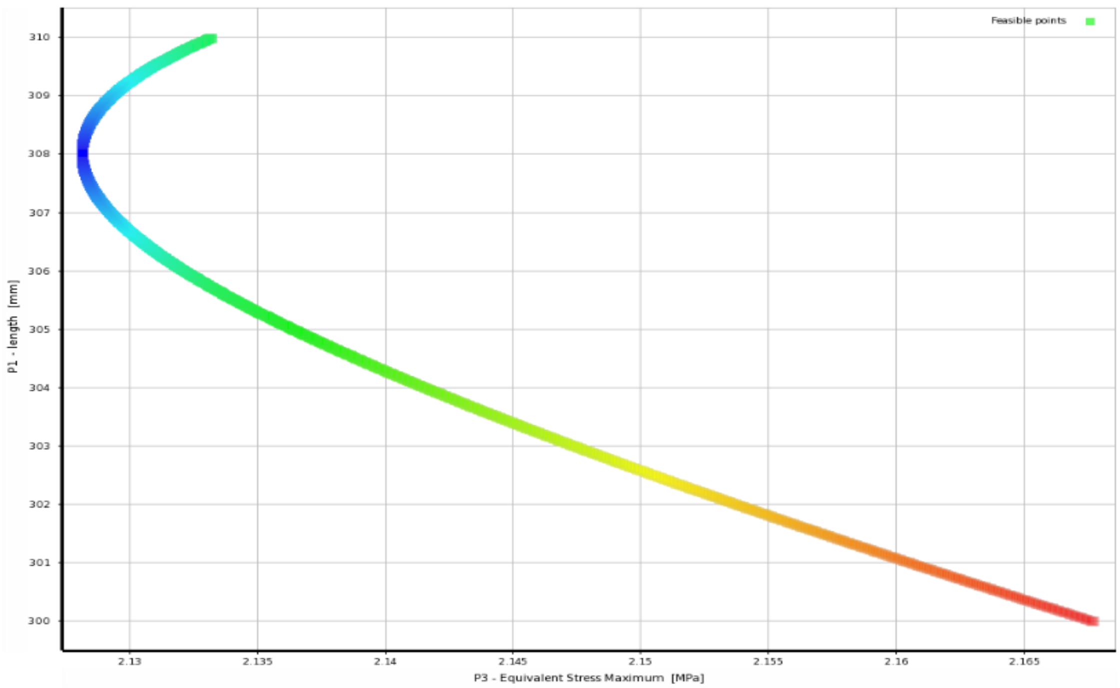

Fig. 7. Dimensions of the plate (mm) against Equivalent stress (MPa) in 2D.

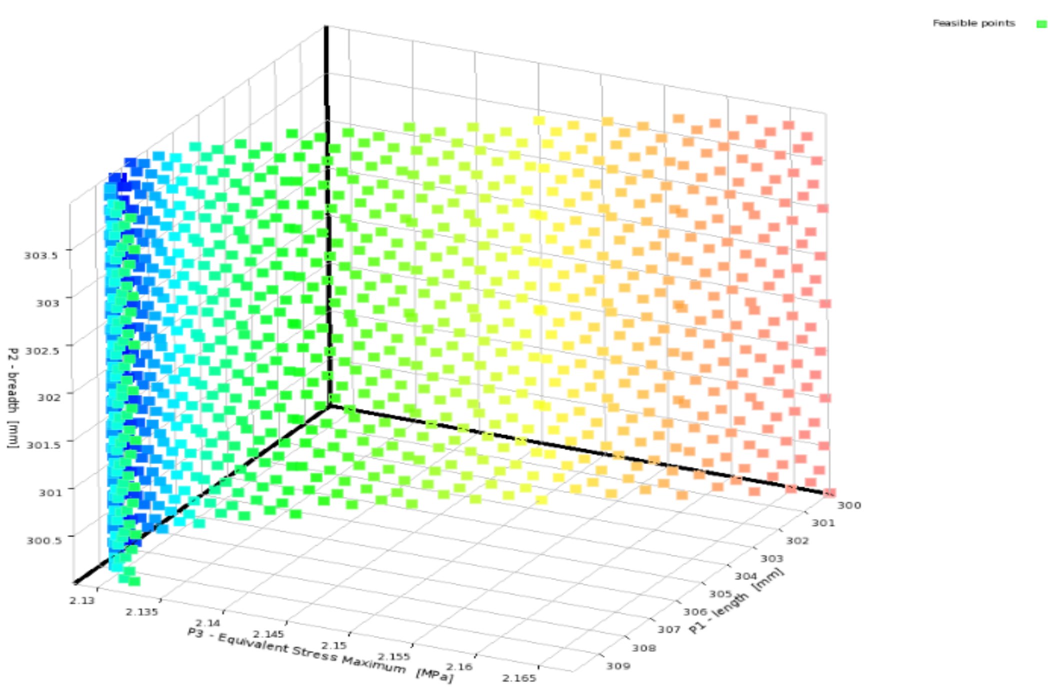

Fig. 8. Dimensions of the plate (mm) against Equivalent stress (MPa) in 3D.

The equivalent stress predicted from the response surface before performing the optimization was also plotted against the equivalent stress observed at various design points (iteration), and goodness of fit line was drawn for the best possible straight line which was found not passing through the origin as shown in Figure 9.

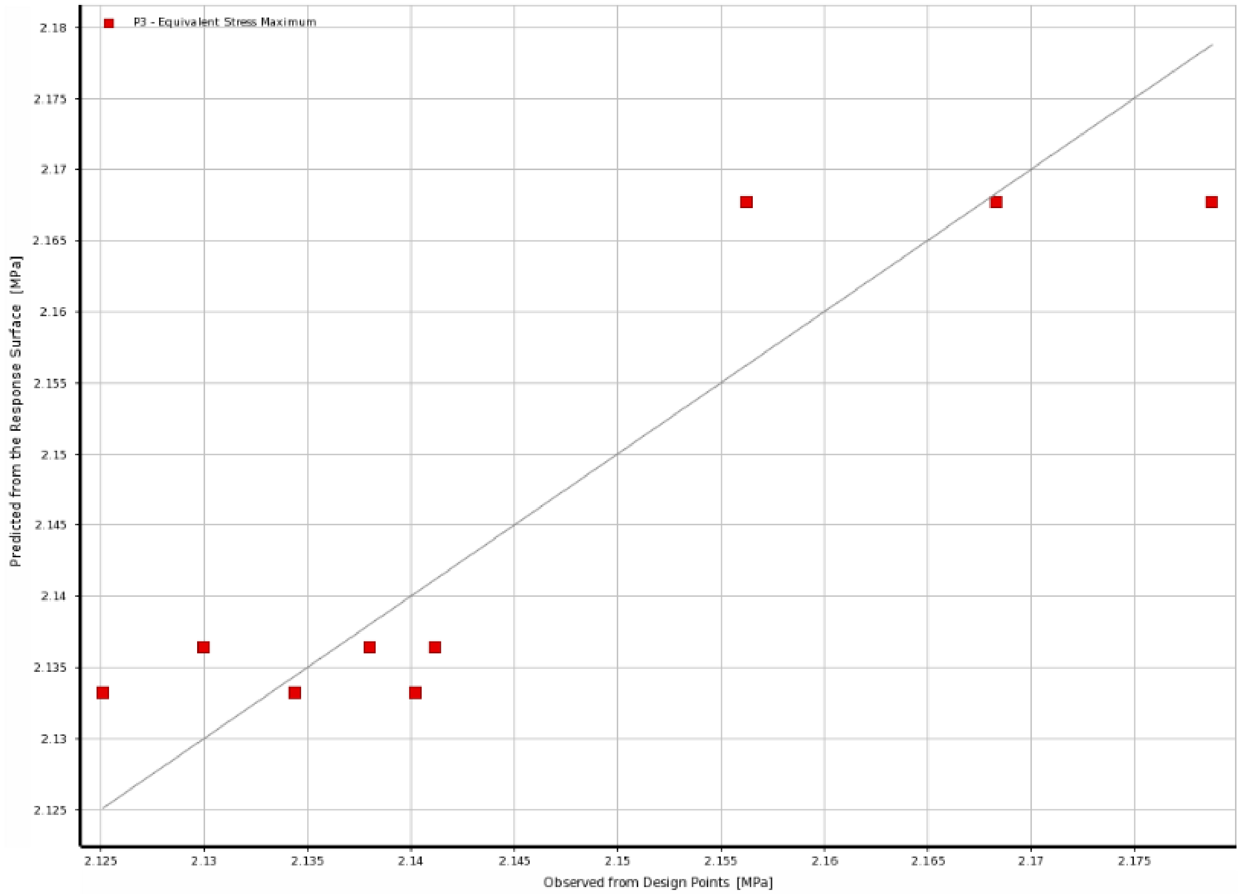

Fig. 9. Goodness to fit for predicted against observed values of the stress.

Moreover, the equivalent stress determined at various design points were plotted against the dimensions (length and width) which shows a cubic curve and which when interpolated with a length of 305mm gives the optimum value of the equivalent stress of 2.1364MPa as shown in Figure 10 for 3D and Figure 11 for 2D.

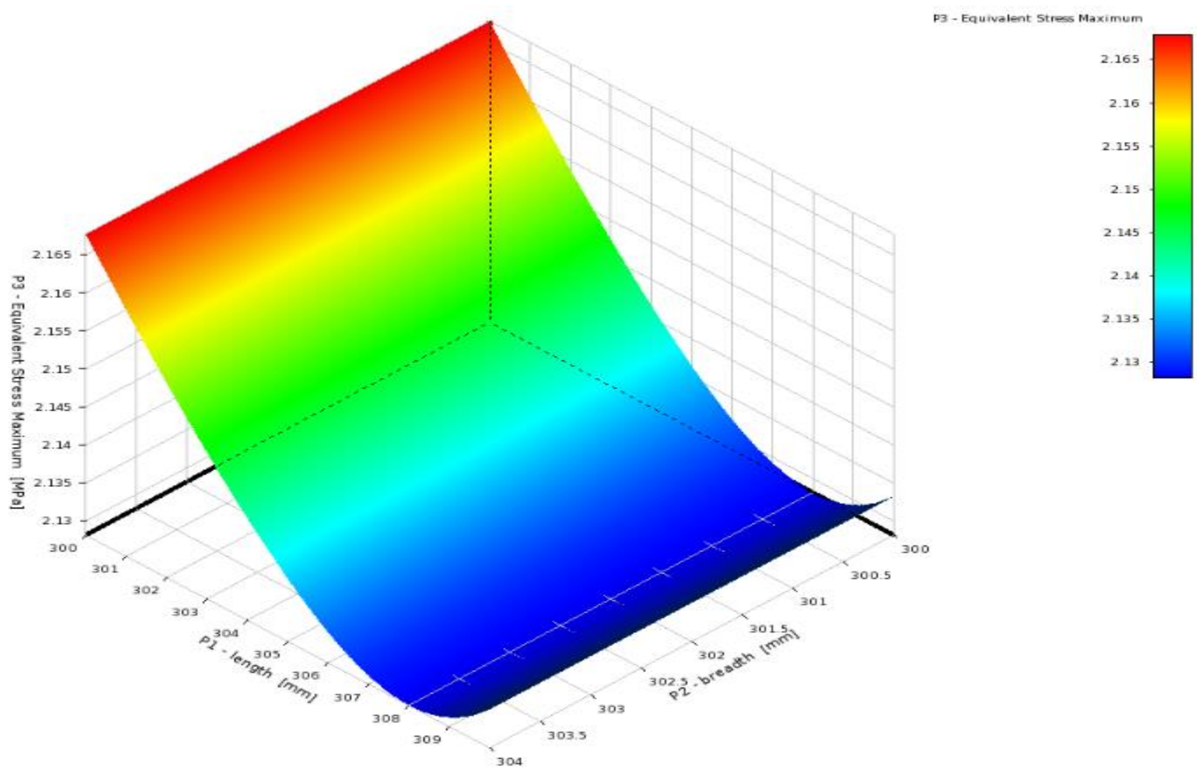

Fig. 10. Equivalent stress (MPa) against Dimensions of the plate (mm) in 3D.

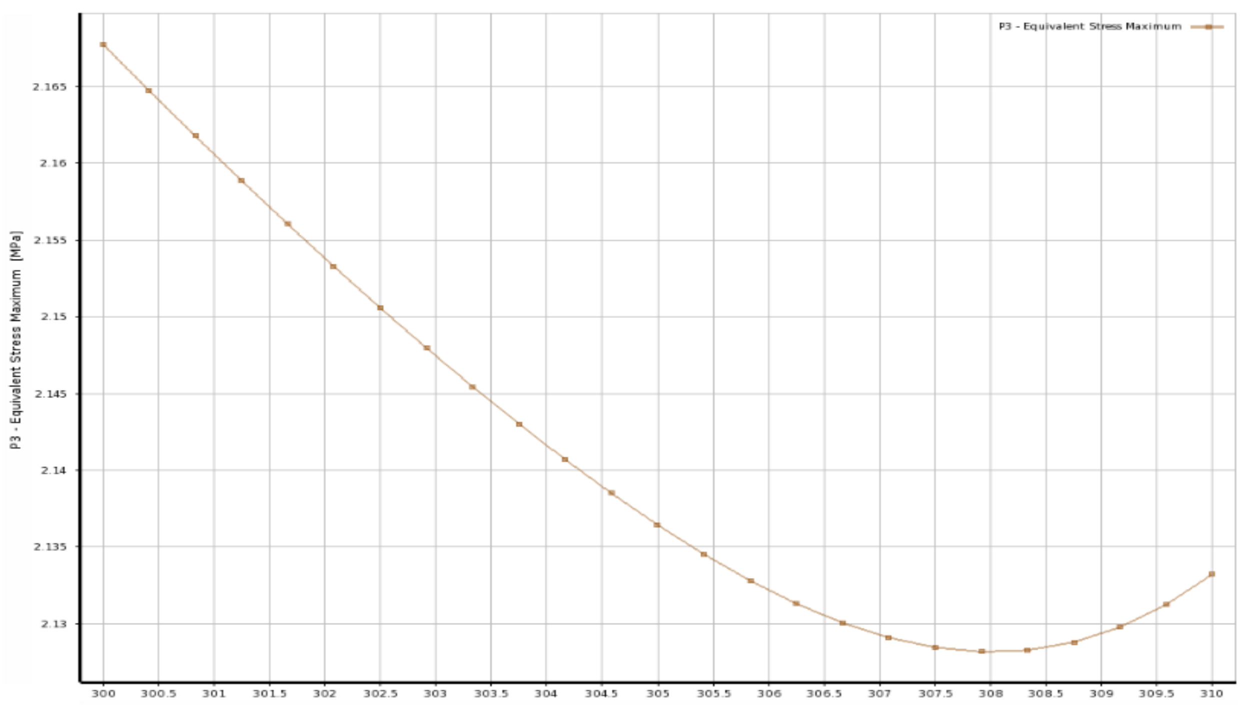

Fig. 11. Equivalent stress (MPa) against Dimensions of the plate (mm) in 2D.

The local sensitivity and the local sensitivity curves (LSC) were also plotted and indicated the same optimum value as in the previous cases. The equivalent stress is plotted against the LSC as shown in Figure 9; this allows not only to assess the overall accuracy but also to select the best threshold. With a very low threshold, everything will be detected but without specificity. With a very high threshold, there will be perfect specificity but will never classify anything as positive. It is possible to plot the specificity on the x-axis and reverse the direction, so it goes from 1 to 0 instead of 0 to 1. It is more intuitive with a specificity of 1, which is the rate of more false positives among all cases that should be negative. As we move along the curve, we get truer positive but also false negative. This description is best shown in Figure 12 and Figure 13. Note that, the point of intersection between the horizontal line and the curve marks the optimum point.

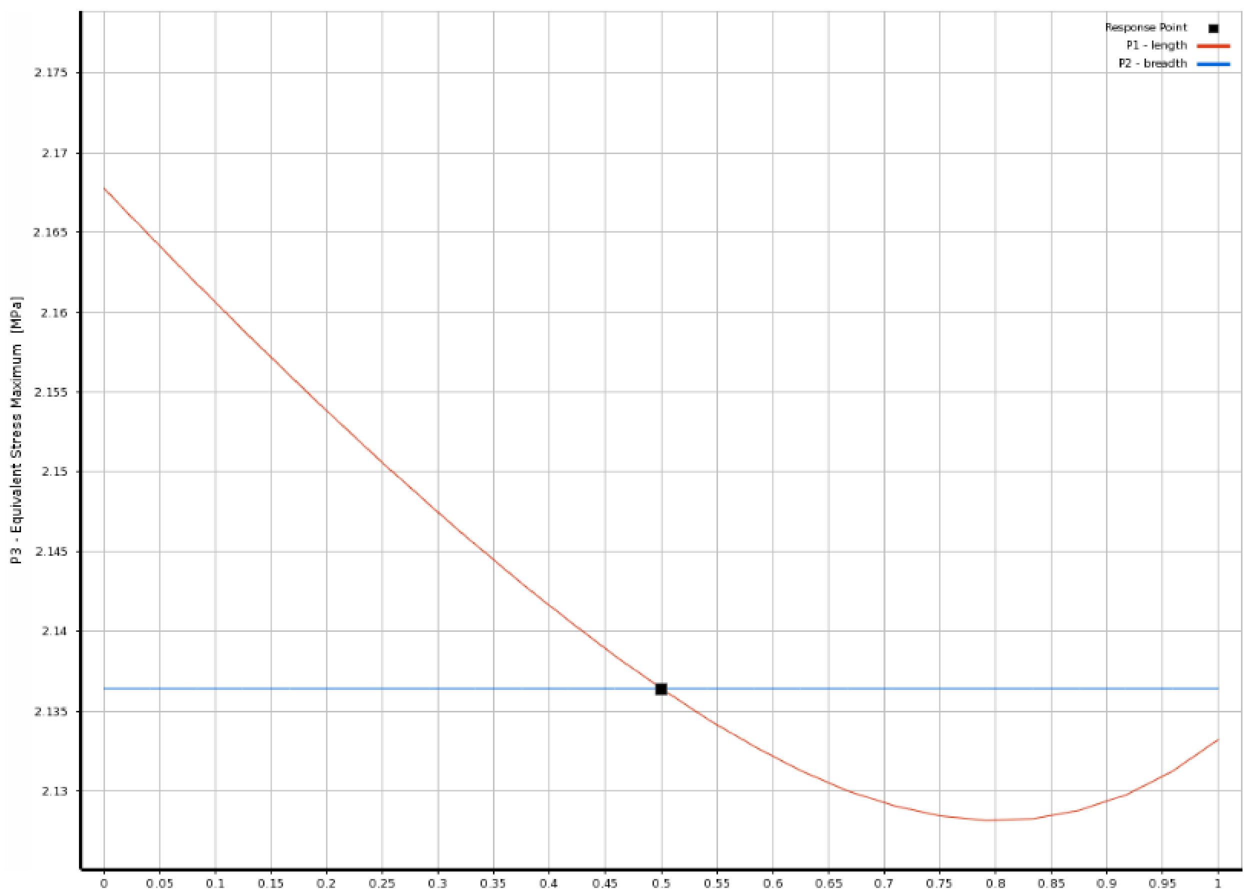

Fig. 12. Local sensitivity curves for Equivalent stress (MPa).

The parallel parameters chart was also plotted which shows the updated design points performed in the optimization. This chart also displays the lower and the upper bound of both the length and the width and also the minimum and maximum value of the equivalent stress performed during the optimization process. This chart is presented in Figure 14.

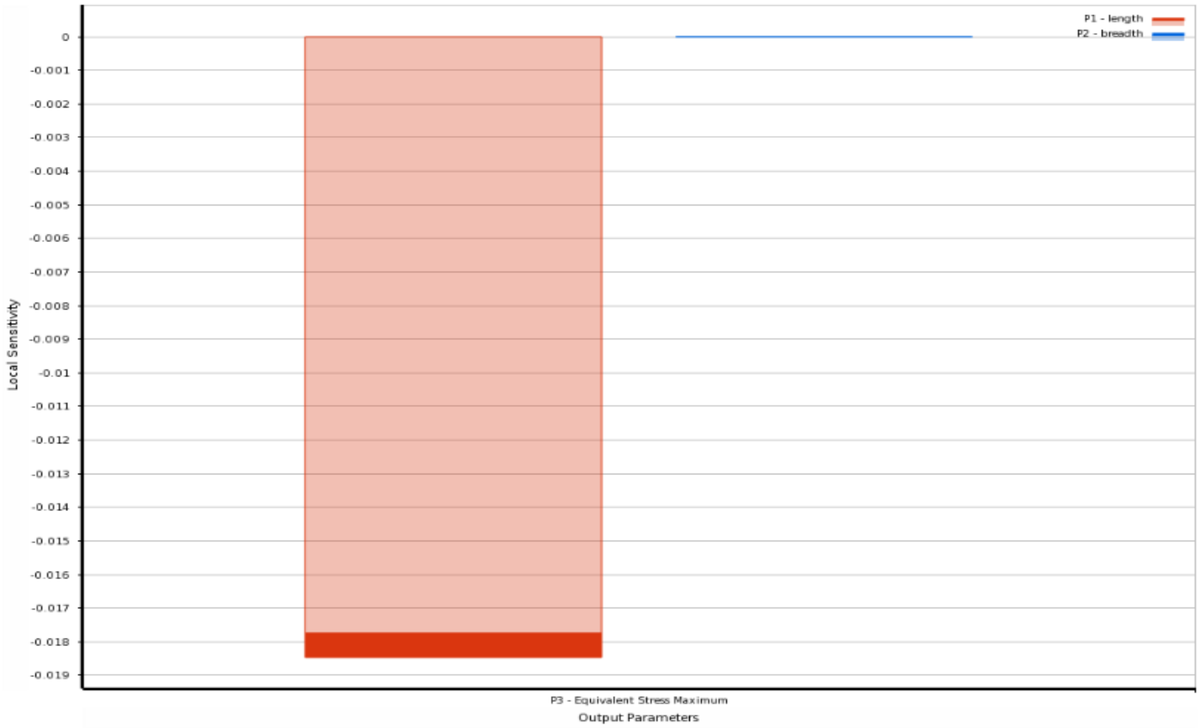

Fig. 13. Local sensitivity for Equivalent stress (MPa).

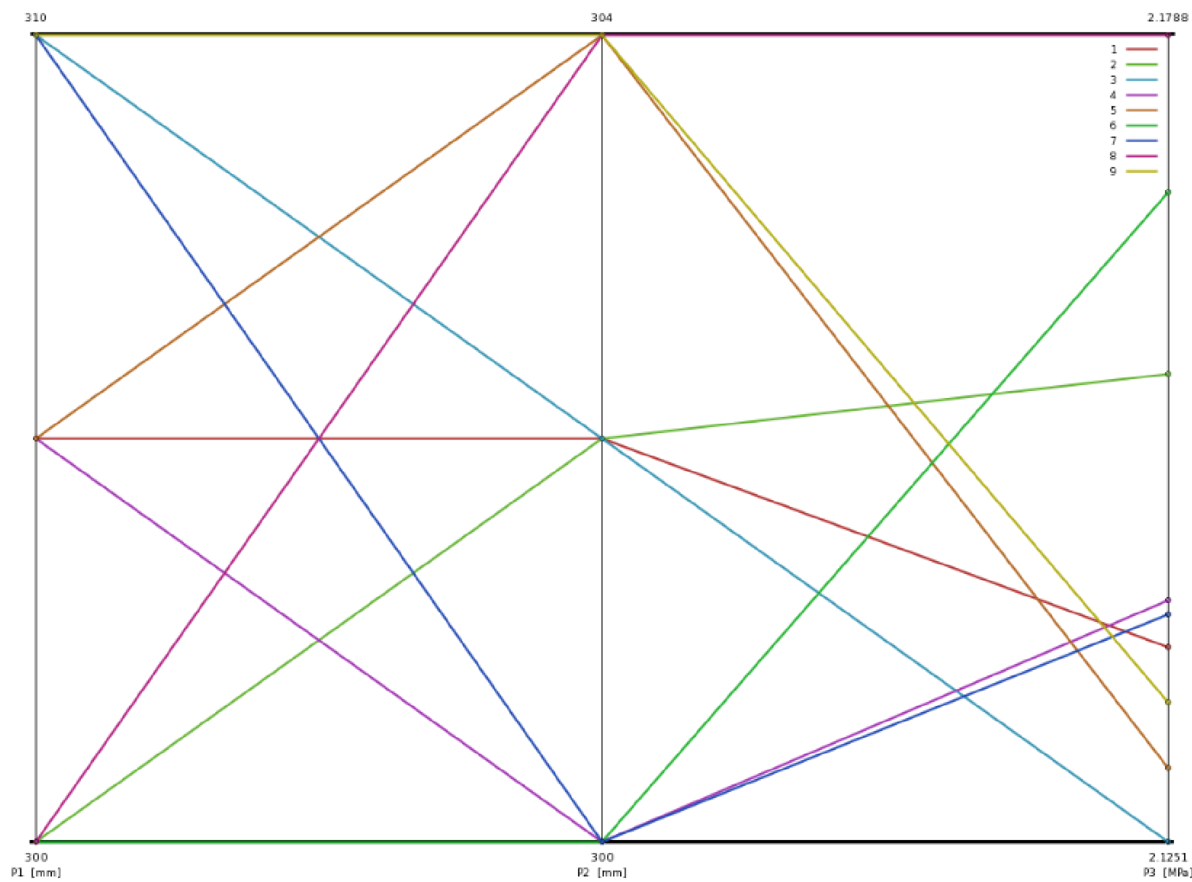

Fig. 14. Parameters parallel chart for the optimization.

As it is visible from the graphs plotted, all the simulations converged to the same values of length 305mm, width 302mm and with the equivalent stress of 2.1364MPa.

6. Conclusions

The goal of this paper was to build a computational model able to find the optimum value of a recycled thermoplastic plate (tile).

The thermoplastic plate object of the optimization was a square plate of (300x300x10mm) with isotropic properties, and a particular load and boundary conditions were applied on the entire plate.

In particular, the total equivalent stress of the plate was chosen as objective function to minimize, and the design variables were the length (l) and the width (w) of the plate for the first set of optimizations (the most relevant), only two design variables at once were considered in each optimization, because otherwise the computational effort would have been too big and the time required for each simulation as well.

An interface between the engineering tools Matlab R2012b and ANSYS15 was created to perform such optimization that adopted the *Genetic* algorithm from Matlab R2012b optimization toolbox, and an FE analysis to calculate the equivalent stress of the panel at each iteration, which the optimum point was reached and was found to be 2.1364MPa with the optimum dimensions of 305mm and 302mm for the length and the width of the plate respectively and a thickness of 10mm (fixed) with a load intensity of 1000N. Therefore, it can be concluded that for a tile of this type, the proposed dimensions of 300x300x20mm should not be used for the load intensity of 1000N but the optimum dimensions of 305 x 302 mm and 20 mm thick will be suitable for that load.

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