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NUMERICAL MODELING OF A PLASTIC PALLET UNDER STATIC LOADING FOR SUSTAINABLE DEVELOPMENT

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Abstract. The present work proposed the improvement of a commercial plastic pallet project focusing its sustainability by reducing the amount of material, without compromising its load capacity. A numerical modeling was simulated in the SOLIDWORKS® environment, analyzing the mechanical behavior under static loading and using the properties of the Linear Low Density Polyethylene (PELBD) material during the resolution by the computational solver of the software. In the simulation of the original plastic pallet, a numerical analysis of the current model and the proposed new model was carried out, respecting the ABNT NBR 16242, ABNT NBR 8334 and ABNT NBR 8252 Standards. Initially, the structure of the plastic pallet was analyzed and a CAD file was generated, using the dimensions of the technical sheet of the product, then, the finite element model (FEA) was developed, with the creation of the geometric mesh, establishment of the material properties (PELBD) and application of the distributed load of 1500.00 kg, between the three support beams of the pallet as well as the support restrictions. Finally, with the results of the solver, the topology feature of the software can be used to generate an optimized model. In this solver, Intel Direct Sparse, carried out the analysis in the mass removal test, by the rigidity criterion of the PELBD material, incorporated into the pallet. Based on the results of the percentage removal of this material, it was possible to readjust the new plastic pallet, reproducing all the previous steps, to geometrically and structurally validate the proposed improvements. Results showed that the mechanical resistance of the new model was superior in relation to the commercial pallet, which proved to be adequate to reduce both the elastic displacement of the material and increase rigidity as well as controlling tensions during loading. Additionally, the new model promoted a material reduction of up to 25% of the total weight of the commercial pallet, improving its sustainability.

Keywords: Plastic Pallet, FEA Simulation, Generative design, sustainability, PELBD.

1. INTRODUCTION

The Pallete Padrão Brasil (PBR) was created in 1990, through the Brazilian Association of Supermarkets (ABS) and the Permanent Committee on Palletizing (CPP), in accordance with the Institute of Technological Research of the University of São Paulo recommendation (IPT - USP) (MARTINS, 2021). In addition, between 2017 and 2018, through the CPP and accredited brands, the PBR-NG pallet (known as "new generation") was developed, which have geometric and constructive characteristics and the same load capacity as the PBR of 1200.00 kgf. The Brazilian pallets follows several local Standards developed by Brazilian Normative Association (ABNT) to quote: NBR 16242 (ABNT, 2020), which indicates which are the requirements and test methods for plastic pallets; NBR 8334 (ABNT, 2014), that regards to the type of face; NBR8252 (ABNT, 2011) which mentions the basic pallet dimensions , in relation to the side of the upper face.

According to Chandran and Waigaonkar (2017), rotary molding is the preferred processing method, in which the polymers are molded by rotation, having zero or low shear and no residual stresses. Ogila et al. (2017), indicate that this process has some steps, which are: the polymer is added to the mold until it has its densification completed; the mold is then sent to the cooling station, maintaining its rotation; reaches the temperatures of the step that will unmold the product, the part is removed.

The present study proposes a numerical modeling of a PBR plastic pallet based on the technical sheet of the rotomolded plastic pallet standard PBR PL 078 monobloc, produced by Tecnotri®. This kind of pallet was developed for use with rolling forks and sliding sheets, for simple movement of the load without changing of the pallet place (figure 1).

Figure 1: Rollerforks® load lifting (available at https://rollerforks.wordpress.com/2010/02/04/palletless-handling-in-coldstore/). accessed on 06/23/23

2. METODOLOGY

The methodology proposed the development included the 3D modeling of the plastic pallet, with the aid of the software SOLIDWORKS® 2022 SP 2.0 and respecting the ABNT NBR 16242, ABNT NBR 8334 and ABNT NBR 8252 Standards. Initially, the structure of the plastic pallet was analyzed in CAD, using the dimensions of the technical data sheet of the equipment; then, the structural analysis criterion was set, for the creation of the geometric mesh, for the analysis in the Finite Element Method (FEM), for a distributed load of 1500.00 kgf, in the three pallet support beds. With the results of the solver, it was conducted a generative design in order to obtain a better solution. The solver Intel Direct Sparse executed the analysis of the mass removal, by the stiffness criterion of the PELBD material. Based on the results of the percentage removal of this material, it was possible to adapt the new plastic pallet, reproducing all the previous steps, to validate the improvements both geometrically and structurally.

3. RESULTS AND DISCUSSIONS

The technical dimensions of the original pallet followed the Brazilian PBR N Standard, with 1000.00 mm in width, 1200.00 mm in depth and 220.00 mm in height, with dimensional tolerance of 2% in the external dimensions of the product. The pallet, as previously reported, is made by rotary molding manufacturing process, which allows a single shell piece of 6 mm thickness to be created. There is no seams or welds, or even connecting elements such as screws, nails or any fixture element in its structure. The original plastic pallet model can be seen in figure 2
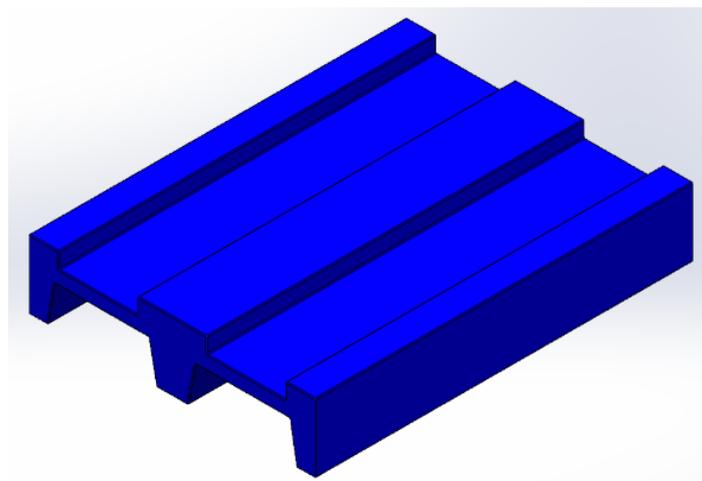

Figure 2: 3D model of the plastic pallet Tecnotri® PBR PL 078 (personal file)

The pallet is manufactured to support up to 1500.00 kgf of distributed load, on the ground. Also, it has three sparers, on its upper face, and two recesses for entrance of the fork system with rollers. The pallet weight is 23.00 kgf and it can be used at working temperatures from -35°C to +50°C. UV, antioxidants and antimicrobials were added in the

composition of the linear low-density polyethylene (LDPE) to make the material hygienic and non-toxic. Table 1 contains the mechanical properties of this material.

Table 1: Mechanical properties of PELBD material, for manufacturing in rotary molding.

Linear Low Density Polyethylene LDPE		
Properties	**Value**	**Unit (SI)**
Modulus of elasticity	676.00	MPa
Poisson coefficient	0.44	N/A
Shear modulus	59.40	MPa
Specific mass	935.00	kg/m³
Tensile strength	18.10	MPa
yield strength	24.20	Mpa
Conductivity	0.32	W/(m.k)
Specific heat	1842.00	J/(kg.k)

Chandran and Waigaonkar (2017) describe PELBD as the most widely used polymer for rotary molding due to its thermomechanical properties; capability to be reinforced with metallic nanoparticles, organic clays and metal oxides; low cost, stability and melting point.

The plastic pallet part built in 3D CAD was imported into the new SOLIDWORKS® Simulation environment and the study conditions were applied, which means the PELBD commercial material properties, the support conditions (resting on the floor) and the 1500.00 kgf load, distributed along the pallet main sparer. The mesh was generated with regular size tetrahedral elements, creating 159933.00 nodes and 78035.00 geometric elements in the whole volume. The degree of refinement of the mesh was considered adequate as it can see in Figure 3:
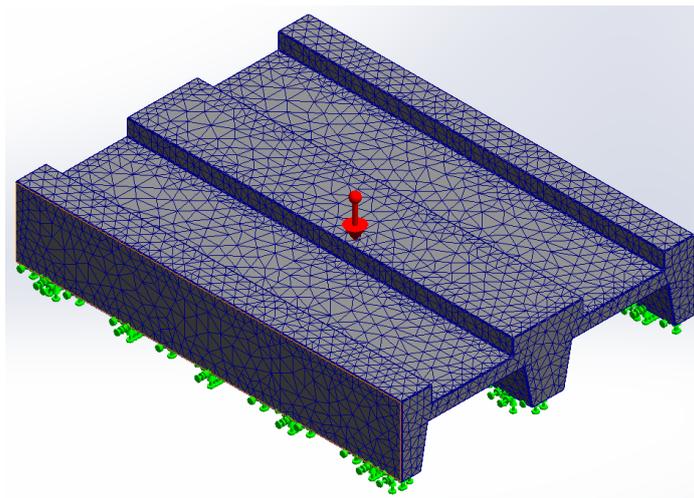

Figure 3: Mesh applied to the entire plastic pallet for static study (personal file)

The analysis was run and the results were shown in Figure 4 (a) and (b). The Von Mises stress maximum stress was 47.20 MPa located in the central spar of the pallet at the right notch of the roller fork inlet spar, being higher of the yield stress of the material. Also, it was indicated the maximum displacement, located in the center of the pallet, corresponding to 116.00 mm. This value caused above normal deepening in the upper part of the pallet.

(a)   (b)
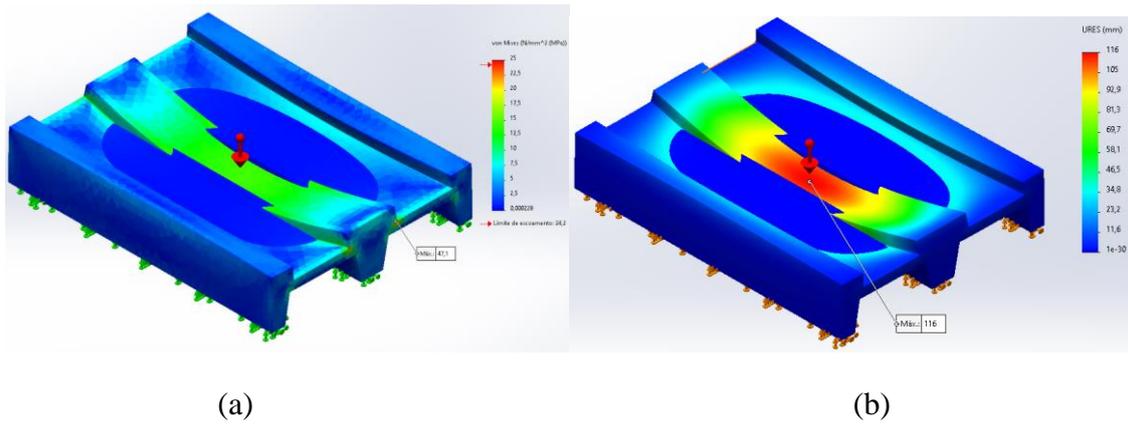
Figure 4: Von Mises Stress and Maximum displacement on the center spar of the original pallet (personal file)

After finishing the static analysis of the original pallet, the study was replicated with the Topology system, present in SOLIDWORKS®® Simulation to inspect areas where the mass could be removed. The computational analysis reached to a mass removal of up to 25%. Even reorganizing the analysis settings and imputing to a higher percentage, between 50% and 60%, the results of the numerical system accused failure in the product, since it was pre-established initial parameters of minimum15.00 kgf pallet weight, making the software work only in 25% of material removal at any point of the pallet. The results were shown in figure 5, where in blue and dark blue colors are the zones to remove mass without losing performance.
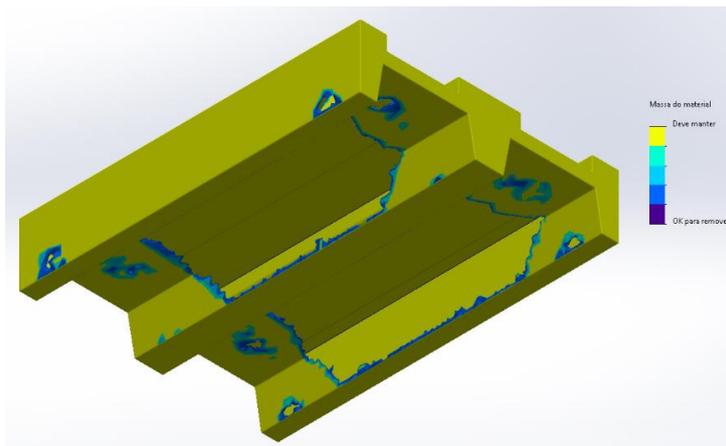

Figure 5: Result of mass removal, by topology analysis, at the bottom of the pallet (personal file)

Using the data from the topology simulation, we remodeled the pallet to have the restructured model of the plastic pallet PBR PL 078, which it can be seen in Figure 6.
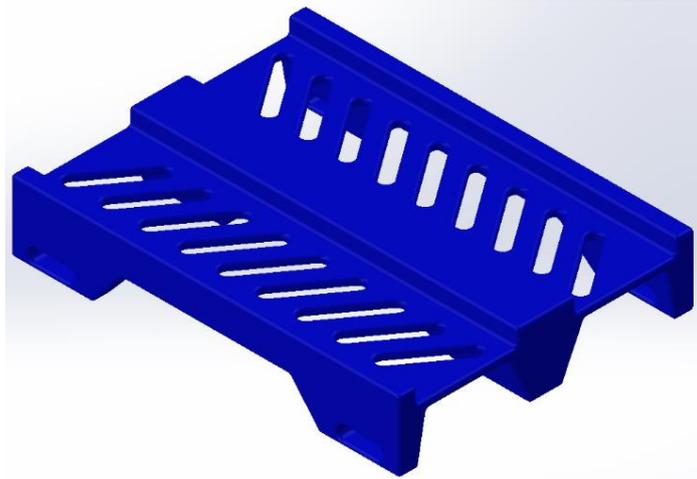
Figure 6: New model of the plastic pallet PBR PL 078 (personal file).

The new 3D model had significant changes compared to the previous one, to know:

- Increase of the two entrances of the plastic pallet, now with 310.00 mm, unlike the original pallet that had 250.00 mm. Following, the two upper lateral spars have reduced of 42% in their width, previously with 90.00 mm and now had 55.00 mm.

- The central spar, which was previously 220.00 mm wide, it now had a reduction to 180.00 mm. At the bottom of the plastic pallet enhancement, the lower central support spar had a slight variation in its opening angle, going from 103° degrees to 115° degrees.

- Several oblong openings were applied in the total length of the pallet. The sketch is 200.00 mm long, with an angle of 36° degrees in relation to the frontal face and has a radius of curvature of 20.00 mm

- A new pair of ribs was added, between the upper and lower face of the central spar, with a wall thickness of 10.00 mm, removing the void and improving the structure for the distributed load. This feature was shown in the red circle at figure 7.

- 10.00 mm inner fillets were applied to the upper face of the fork entrance to reduce stress concentration at the oblongs. It can be seen in the blue circle at figure 7.

- The last point to be considered, are the four lateral oblongs on the external faces of the pallet, located in the extreme load support spars of the right and left. It can be seen in the yellow circle at figure 7.
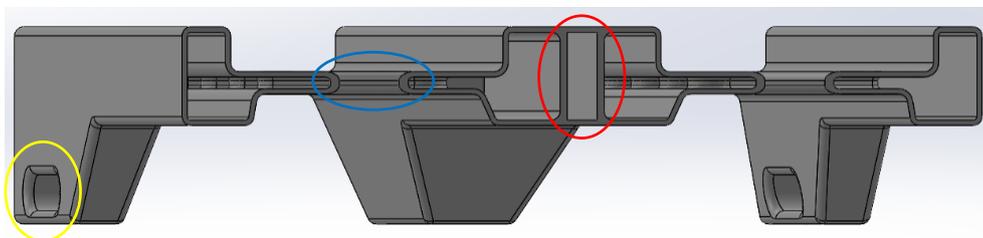

Figure 7: Partial cutting of the new plastic pallet, with the internal structural improvements in the shell pattern (personal file)

The new geometric properties resulting from the analysis and remodeling, also brought a total mass reduction of the pallet, which was previously 23.00 kg and became 17.18 kg.

A new static stress analysis was run, and the results can be seen at figure 8. The maximum Von Mises stress was located in the lower part of the pallet, precisely in the notch of the central spar, at 41.30 MPa level. However, in the upper part, the stress is at 23.00 MPa, below the yield stress of the material at 24.20 MPa and still in elastic zone.

Another comparative data was the maximum displacement, extremely high in the previous model, due to the presence of the shell and large voids. The displacement has decreased from 116.00 mm to 18.40 mm, which confirmed the stiffness improvement.
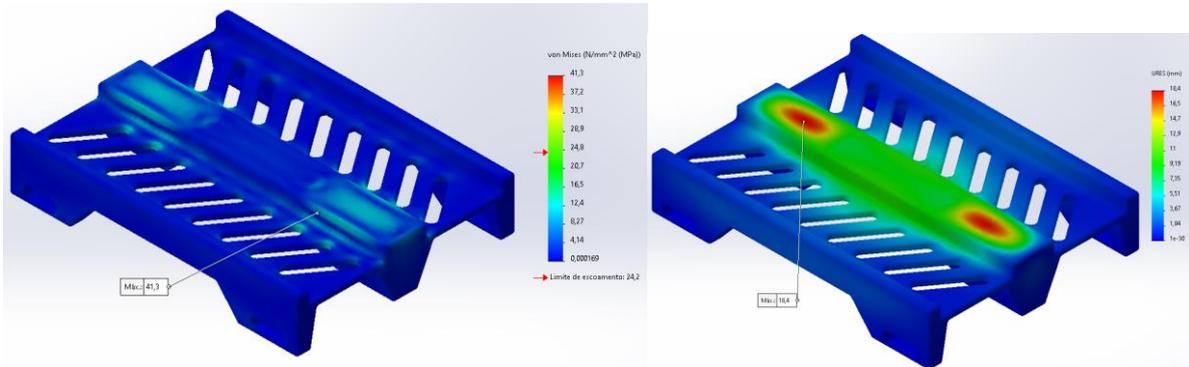

Figure 8: Von Mises Stress and Maximum displacement on the center spar of the new pallet (personal file)

For completeness, the pallet stiffness (CR) and mass pallet stiffness (CRfm) were calculated for both original and new models using Equation (1) an (2), respectively. The results were placed in the table 2.

$$CR = \left(\frac{\left(\frac{F}{A}\right)}{D}\right) \quad \frac{N}{mm^3} \tag{1}$$

$$CRfm = \left(\frac{CR}{m}\right) \quad \frac{N}{(mm^3.kg)} \tag{2}$$

where F, A, D and m were the loading force on the pallet in Newton, pallet surface area in mm², total displacement in mm and pallet mass in kg, respectively.

Table 2: Stiffness calculation comparative table

	Stiffness calculation	
Model	**CR**	**CRfm**
Original	$1,834.10^{-5}$	$7,975.10^{-7}$
New	$1,354.10^{-4}$	$7,882.10^{-6}$

The CR and CRfm for the new design are 738% and 988% higher than the previous one.

Finally, an estimative cost reduction was done. The original design value commercially is R$ 945,00 in the dimensions of 1000.00 mm x 1200.00 mm. By performing a simple comparison, with the results obtained from the new model with applied with the reduction of 25% of material, proportionally, it was obtained the value of R$ 708.75.

4. FINAL CONSIDERATIONS

The present work carried out a computational numerical study for the optimization and improvement of a consolidated project of a plastic pallet, specific for special movements, with the aid of the finite element method, to validate a new model and mechanical design of the product.

The result of this analysis followed by topological study led to a new pallet model, delivering 25% mass reduction maintaining the main dimensions, characteristics of 1000.00 mm x 1200.00 mm, due to current regulations. By reducing the quantity of LDPE per pallet, the new design is more sustainable.

The displacement of the pallet in plastic regime has decreased 84%, demonstrating than the new model presented greater stiffness as well as reducing stresses in the notches and oblongs. Studies of greater complexity are suggested, which can ratify and complement these research outcomes.

Finally, it was observed the increase of mechanical strength of the new plastic pallet compared to the original design, indicating the possibility of development of new sets of storage equipment, contributing to the field of goods logistics.

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6. RESPONSIBILITY NOTICE

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