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DESIGN, MANUFACTURING AND TESTING OF A LOW COST MECHANICAL RAW MATERIAL CARRIER FOR A RECYCLING PLANT

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Abstract. *Environmental friendly alternatives to work together with the sustainable development shows a crescent trend nowadays. Recycling plants enable this type of growth, however, as some of them employs people in many ages and education level, productivity analysis and working conditions should be evaluated and followed closely. The present work aims to analyze and detect points with low productive efficiency at a recycling plant, in the stage of recycled material sorting. One of the highlighted problems was the difficulty of internal material movement after being sorted and, due to the presence of people in old age working, the time and effort spent to manually drag the large bags of sorted materials is considered a downtime, since the workers earn per kilogram of sorted material and not per moved material. Besides, the energy required to drag the bags compromises the physical endurance of workers and consequently decreases the efficiency of their sorting process. In order to increase efficiency and individual productivity and to achieve better working conditions, this paper shows the project, simulation, manufacturing and test of a mechanical device solution. It must be able to assist the internal movement of sorted materials, taking into consideration the operating conditions, final manufacturing cost and customer experience analysis as an integral factor.*

Keywords: Recycling; Mechanical; Transport; Manufacturing; Simulation.

1. INTRODUCTION

It is remarkable that the concern with environmental preservation has gradually increased over the years. Even though there is a certain maturity in the mentality of citizens and government, there is still a lot of work to be done in order to promote efficient selective collection, since the process is costly and inefficient. On the other hand, it is known that the disposal of materials in dumps carries a serious social problem: the agglomeration of people in search of any type of income. In Brazil there are approximately 400,000 people taking their livelihoods with what is discarded by others (IPEA, 2013). A selective collection must be part of the culture in general, with the separation of the materials into categories (glass, paper, plastic). However, the recyclable material is collected completely mixed and needs to be sorted in cooperatives, present in 76% of the municipalities (Campos, 2013). Despite the growing presence of cooperatives in the national recycling scenario, more than half of them present very low levels of efficiency (Damasio, 2010). Reducing productivity leads to a number of other problems, such as: lower collection of the cooperative (inability to invest in shed infrastructure), loss of contingents (dropouts), excess material (silo overcrowding and sorting areas) and low quality of work. From this context, the present work focused its scope on the sorting stage of the recycled material, analyzing and detecting the points of low efficiency at “COOPESOL LESTE BH”.

One of the problems detected was the internal movement of the material after being screened, due to the presence of elderly people working, the time and effort spent to manually drag the large bags of sorted material is considered an unproductive time since they are paid per kilogram of separate material and not of material moved. In addition, the energy expenditure necessary to carry out the drag, compromises the physical resistance of the workers and consequently reduces the process efficiency. In order to improve working conditions and increase individual efficiency and productivity, this work shows the development since the simulation and design phase to the manufacturing and test of a low cost mechanical device capable of assisting the internal movement of the sorted material.

2. METHODOLOGY

2.1 Local Characterization

The Cooperative (COOPESOL LESTE BH) was founded in 2003, it has 35 cooperatives, with 2 people performing coordination functions and the others working on sorting, pressing and auxiliary services. Its average production, according to INSEA data, is 100 tons per month of recyclable materials sorted and marketed.

The production flow begins with the entrance of the truck compactor in the outside area of the shed. The truck is directed to a scale, according to Figure 1 on the left, for weighing the material inside. The truck follows back into the shed and dumps all its cargo in the silo. The silo is a storage place for the material in the form of a ramp, being supported by grids in its surroundings. At their lowest level these grids expand and are called "sorting windows", where the workers separate the recyclable material according to its composition, as can be seen in Figure 1, on the right.

Figure 1. On the left, outside area of the shed and, on the right, sorting windows

One of the consequences of the low productivity of the cooperative and its difficulty of production flow is related to the seasonality of the trucks number that discharge material per day. At commemorative dates such as Christmas and New Year, the number of material grows beyond the Cooperative processing capacity, often requiring the outside of the warehouse as a pre-storage area or even refusing to receive the cargo. Dumping of material in the silo beyond its capacity makes it difficult to slide the material to the sorting windows and excess weight hinders the removal process of the material due to its high compaction, which can lead to the breaking of the retaining grid. In addition, the larger the amount of material, the greater the presence of organic tailings and broken glass in the loading, compromising the physical safety of the worker and making the separation process difficult.

Figure 2 is schematically numbered from 1 to 6, showing the main sectors: starting with the number 1, where each worker in their respective window separates the materials into bags according to their composition and, when these bags are filled, the operator manually drag them to the scale (2) and then to the storage area (3). After separation, the material should be pressed and the worker must move the bags from the storage area (3) to the press (4) for the production of the bales. The produced bales are moved to a new storage area (5) where a forklift truck will transport it back to the shed entrance at the upper level for the truck loading. The location of each area shown by Figure 2 facilitates the visualization of the various unproductive movements and excessive physical effort that are necessary in the process of internal movement and flow of the production for the sorted material in the Cooperative.

Figure 2. Coopesol Leste Warehouse Interior

The internal organization of the warehouse directly influences its degree of efficiency. For example, if the storage of bags of sorted material is done indiscriminately, or even if the shed is overcrowded, the processing itself will act as an obstacle to the movement of people, bags and bales inside, compromising productivity.

2.2 Low Efficient Points Detection

Following the production routine, the bottlenecks were identified, which are the main problems and low efficiency points faced in the process of recyclable material sorting in the Cooperative. Initial solutions to the issues identified were thought together with some of the cooperators and based on their knowledge of the process.

The dragging of the heavy bags through the shed requires unproductive effort, since the time spent to move the bags to the stock area is significantly large and the physical effort as well. According to productivity theoretical analysis (Lima *et al*., 2008), there are cases in which the operator spends half of its working day only to organize the sorting activity.

In addition to the working condition depletion, the slow drag of each bag difficulties the work of the presser, who must move them full from the storage area to the press to produce the bales and carry out the production. With the delay to move these bags to the press, stock material is accumulated in a system known as FILO (First in last out), or first to enter last to exit, where the materials that were first sorted and arrived in stock will be the last to leave. Reducing this time of displacement results in more time and physical energy focused on material sorting process (which is the source of income of the workers in this function) and promotes an agile flow of production, which reduces overcrowding and idle material waiting time for weighing and pressing.

Taken this point of view, the present work aims to develop a conveyor to drastically reduce physical effort for the bag transportation enhancing the work conditions and improving the process efficiency as a whole. In order to function properly and fulfill its auxiliary function, the conveyor equipment under development has to withstand the operating conditions in which it will be submitted. For a generic project, consideration should be given to the weight the equipment will support, the area it will occupy, the ease of operation and handling, the required maintenance frequency and its cost of production.

2.3 Project Stages Definition

The bags supplied with recyclable material have different weights for different types of recyclable material. The dimensions of the bags are not standardized and their weight varies significantly, but in general it has been found that some can exceed 100kg. The surface area is relatively extensive and its diameter can reach up to 1,5m, according to Figure 3.

Figure 3. Sorted Paper Bag

For the sizing of the equipment, the critical case will be considered (100kg of load) and a safety factor defined by Ns=1,2 as well. Therefore, the load applied in the computational simulations will be of 120kg. The objective of defining this initial arbitrary loading is to correlate the dimensions of the equipment with the mechanical resistance required to withstand the applied load. Despite the small height of its base, the loaded bag will have to be dragged on top of it, which requires this vertical displacement be minimal in order to attend the physical effort elimination purpose.

The distance between the sorting area, the storage area, the pressing area and the loading location of the trucks varies from layout to layout between sheds. Therefore, the design must be able to meet both small displacement requirements and long distances, while maintaining the ease of operation of the equipment. In addition to the force required in moving the material, another issue that must be considered is the durability increase of the bags. These bags used in the recycling sheds are often industrial bags previously discarded, they already arrive with damages and significant level of wear. When they are dragged, the wear of the material is aggravated, so the project should promote an attenuation in the level of damage suffered by the bags as a function of their displacement.

Since the project under development is totally geared towards recycling cooperatives, there is no possibility of adding a high cost to the productive process of the sheds. This project should be as simple and intuitive as possible, aiming at the manufacture of low cost, easy to handle and basic maintenance.

2.4 Rolling Structure

After economic analysis and feasibility of implantation, a base was proposed for the bags where they can be sewn to ensure their fixation and avoid slipping and, on this basis, the presence of castors will aid the transport of the bag, according to Figure 4. One Advantage of this solution is that it does not need to change the existing internal handling process, since any bag in the shed can be installed in this equipment.

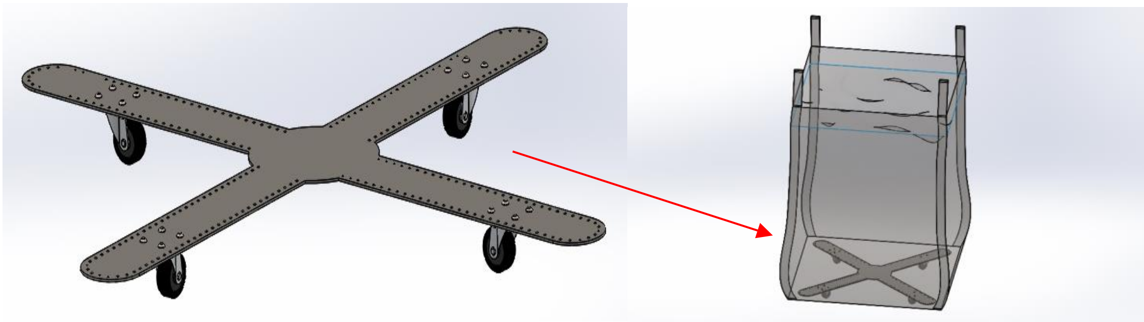

Figure 4. Schematic mounting for the rolling structure

Virtual analysis of the final proposal design of the modular roller conveyor, the main loads and deformations experienced by the project components were analyzed via computational simulation. In order to guarantee an acceptable reliability, the simulated operating conditions were the critical cases, which are represented by: A single roller bearing the total load of 120kg; the 120kg load fully transmitted to the roller bolt, which tends to shear the steel plate that serves as the structural support for the rows of rollers.

From the simulation analysis of the stresses under these critical conditions, it is possible to determine if the pre-dimensioning is in accordance with the structural requirements and what changes are acceptable in the project design without compromising its physical integrity.

The initial design is shown in Table 1 and is designed to require as little material as possible to maintain the low cost project concept, in addition to keeping the material as SAE 1020 material; the casters have been installed translated towards the center of the structure in order to guarantee its stability. In order to choose the caster, a workload support model was considered, which is easily accessible in the common market, facilitating its maintenance and guaranteeing lower prices, besides having a high robustness, since it will be used in irregular solos. The pre-selected model was the castor GL 210 NP Rotatory, which supports 45kg each, has a height of 76mm and a wheel of 50mm in diameter. After determining the measurements of the stems and their thickness, the software calculated their area, volume and total weight as shown in Table 1.

Table 1. Final physical configurations of the rolling structure

Component	Dimension
Number of rods	4
Length of rods	1000 (mm)
Central Geometry	Circular
Sheet thickness	3mm
Number of casters	4
Surface Area	5364,74 cm²
Volume	841,62 cm²
Total mass	6,548 kg

Following the determined dimensions, the actual condition of the structure was simulated and its behavior was investigated in relation to its flow limit and deformation. This means that the maximum tension in the equipment must be less than the maximum Von Mises theoretically calculated load. The suffered deformation must not be able to reach the plastic limit. Figures 5 and 6 show the results of the simulations.

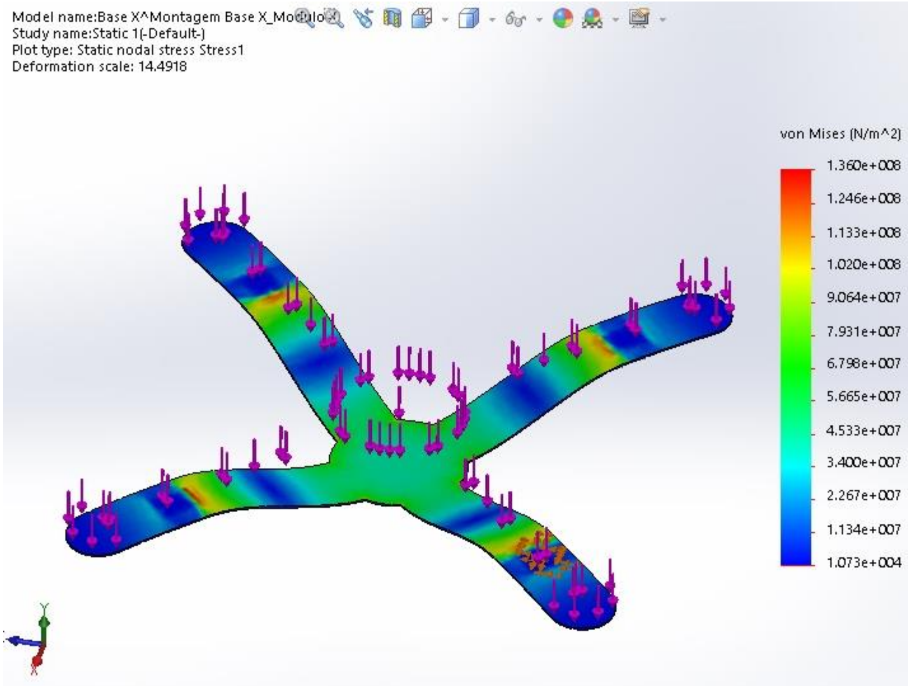

Figure 5. Rolling structure simulation (Flow Limit)

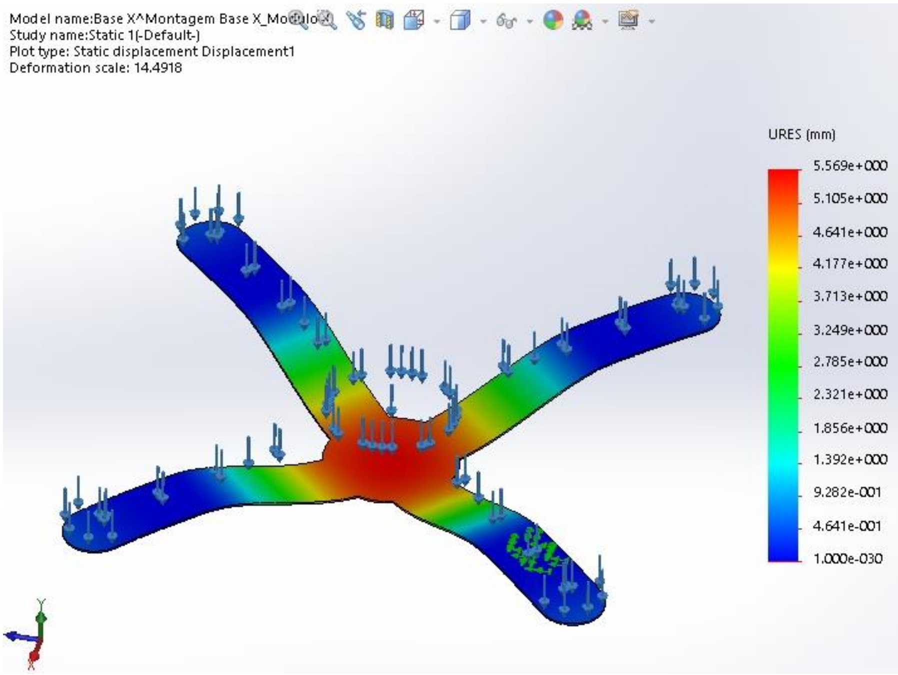

Figure 6. Rolling structure simulation (Deformation)

Analyzing the obtained results, it is noticed that the support is free of failures because it does not exceed the flow limit of the material specified. In the color scale, the highest detected load, is the critical region of the structure represented by the red color and has an absolute value of 136 MPa. In turn, there is no point under excessive high load and the most critical part, which is the center of the structure, has intermediate load requirements, shown in green on the color scale, with values around 67 MPa. The flow load of SAE 1020 steel is known in the magnitude of 350 MPa, approximately 2.5 times higher than the maximum load detected. Therefore, it is considered that with this initial design, the equipment is free of static faults.

On the other hand, when analyzing the results of the simulation regarding the deformation of the plate, it is noted that at its central point, the maximum deformation was 5.6mm. Although it is a low value, it is not advisable to disregard this displacement of the surface of the equipment, because after a certain time of activity, the part can present problems of fatigue, being able to occur cracks that could even lead up to the structural breaking. In order to overcome this situation, the thickness of the plate must be increased, being doubled, so the deformation of the plate will have a reduction of about 50%, reaching maximum peaks of 2.5mm which can be considered reasonable for such application. Finally, Figure 7 presents the final form of the product proposed to assist the process of internal movement of recyclable materials.

Figure 7. Final 3D version of the rolling structure project

2.5 Prototyping

After the virtual validation of the equipment, the prototyping phase was started and it was defined that, because of its greater simplicity and lower cost, the prototype of the rolling base for the individual movement of bags would be constructed. Thus, in order to correct the structural limitations detected during the virtual analysis of the equipment, small changes were made in order to guarantee the necessary mechanical resistance that the project requires and to enable conclusive tests. Figure 8 shows, schematically, the changes made to the initial design.

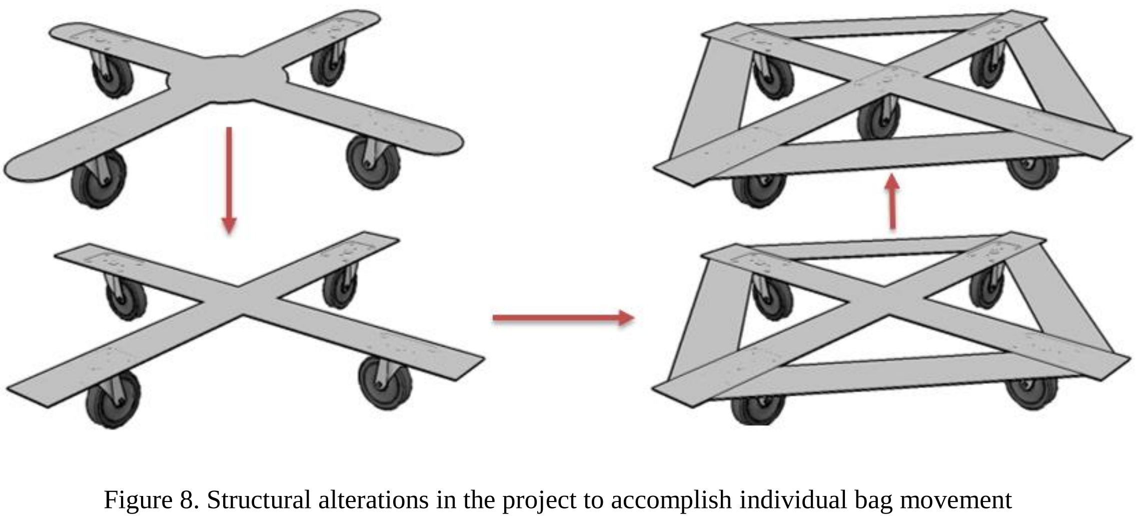

Figure 8. Structural alterations in the project to accomplish individual bag movement

Basically, a simplification was made in the geometric form of the equipment to make its manufacturing cheaper and a wheel was added in the center in order to avoid bending and possible breakage of the structure. As for the manufacturing value of the equipment, R$60,00 was spent on steel plates and R$25,00 on each carousel bought in retail, totalizing an investment of R$185,00. It is noteworthy that a single prototype was built with retail price of the pieces, in the case of building several of them, the price will naturally drop. Figure 9 shows the constructed prototype.

Figure 9. Constructed final version prototype

3. RESULTS AND DISCUSSION

After the construction, it was put to the test inside the Cooperative, for those who will actually make use of the equipment. The first test was done with a bag of 94.6kg, as can be seen in Figure 10. It can be noted that the height of the equipment is the same of the scale, eliminating the need to raise the bag to the platform, since only the horizontal displacement is enough to accommodate it on the scale surface.

Figure 10. Bag being weighted in balance with same level of the proposed structure. In detail, bag weight of 94.6kg.

In order to carry out this test, it was first verified the natural procedure of moving a full paper bag as it is carried out by the members. To move the bag shown above four operators are required to carry the drag from the storage area to the press, then the four raise the bag on the scale, carry out the weighting and return by dragging it to the stock again. This procedure is costly and mobilizes four operators who stops their processes of material separation, which is actually the source of their income.

When the same movement was performed with the prototype utilization for the same bag, only a single operator was enough to easily make the displacement of the bag of almost 100kg, and it is even possible to move the bag with the aid of only one hand. Such experience has gained significant approval and enthusiasm from the cooperates who participated in the test. Figure 11 below shows an operator performing the movement of the material with the the equipment.

Figure 11. Sorting worker transporting the bag utilizing the equipment

Another point tested was the ability to dodge obstacles, which was also considered satisfactory since it had 5 4-inch castors, the structure was able to transpose from drains to loose materials on the floor. It was also observed that the structure supported the load of approximately 100kg without flexing or damaging, being rigid enough to be used for the purpose in question, assisting satisfactorily the movement of the material, reducing the time released for this activity and the number of workers to perform the same movement, improving the working conditions in the process due to the drastically physical effort reduction.

4. CONCLUSIONS

The equipment to aid the individual movement of the bags served its purpose and was intuitive and easy to use, as well as being able to significantly reduce the physical effort, the drag time and the number of workers mobilized to carry out the same movement activity. It also withstood the expected load without cracking, crushing or damage.

Operators massive approval was granted regarding the inclusion of the equipment in the cooperative's work routine. However, an issue should be taken into account: the amount of equipment that will be available per shed, thus avoiding internal conflict among the workers at the cooperative. Equipment/hour analysis management calculation is required to determine the ideal amount of equipment per shed for sufficient availability for all workers. The reduction of the dragging bags activity on the ground will increase their useful life.

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