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ORIGINAL RESEARCH PAPER

Engineering

Designing a tire shredder machine to decide to import or build: A case study.

KEY WORDS: Used tires, machine design, import of machines, stress simulation.

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ABSTRACT

All over the world, used tires are a source of pollution, but several entrepreneurs have seen this problem as a business opportunity, for which the initial step is the acquisition of shredding equipment. The entrepreneur is faced with the dilemma of building locally or importing such equipment. This document shows the design of several mechanical elements for a tire crushing machine, verifies the simulations made by analytically calculating one of the elements and comparing the results obtained. Finally, the manufacturing costs are compared with the costs of importing the equipment into Ecuador. It is determined that the import cost exceeds the manufacturing cost by only 1% and it is concluded that local construction is not feasible.

1. INTRODUCTION

About one billion used tires are discarded worldwide each year and it is estimated that by 2030 this figure will be five billion. Due to their chemical composition, the inadequate management of these wastes constitutes a means of environmental contamination and, since they are capable of accumulating rainwater, tires become a source of transmission of infectious diseases such as encephalitis, zika, chikungunya, dengue, and malaria, among others. (ECO Green Equipment , 2018) (Pacheco, Yining, & Said, 2012) (Savari Antony, 2015) (tnu, s.f.).

The most efficient form of recycling is crushing, where the particle size depends on the application (Savari Antony, 2015) The costs of tire-shredding machines range from US$5,000 to US$80,000 depending on granulometry, production capacity, origin, and country of destination.

In Ecuador, there is no mass production of machines but rather prototypes are built and companies that wish to enter this business model must decide whether to build them locally or import them. This paper aims to determine the feasibility of building a pneumatic grinding machine from a process that uses computer-aided design (CAD) and computer-aided engineering (CAE) tools.

2. Method

The design was divided into the stages shown below.

2.1.1. Determining the operation

A tire crusher machine has disc blades arranged transversely on parallel axes that rotate in opposite directions at speeds between 28 rpm and 34 rpm. The blades are arranged in an alternating pattern so that when they rotate, they produce a pulling and tearing effect at the same time. Underneath the blades there is a screen that prevents material that does not meet a certain size from passing through, this material is fed back by the rotating action of the blades (EEUU Patente n° 4,757,949, 1988) (EEUU Patente n° 4,374,573, 1983) (EEUU Patente n° 4,052,013, 1977).

2.1.2. User requirements

They were obtained through surveys and were treated with the technique of quality function deployment (QFD) obtaining the results indicated in Table 1.

Table 1: Analysis results QFD.

Voiceofthecustomer	Engineeringvoice
Tiresize	RankingR12-R14
Crushingspeed	Capacity100kg/h
Particlesize	20mm
Tireentry	Tirecircum ference without bead ring

3. Availability of materials

A small market study is carried out to identify local suppliers and through their catalogs, the availability of materials, their properties, and cost can be identified. Characteristics that will be considered in the next stage. (Verma, Yadav, Quddusi, Sharma, & Tiwari, 2017)

3.1.1. CAD/CAE Stage

The prototype is modeled using CAD tools, as shown in figure 1, for each of the components a complex balance must be achieved between function, shape, materials, and available manufacturing processes.

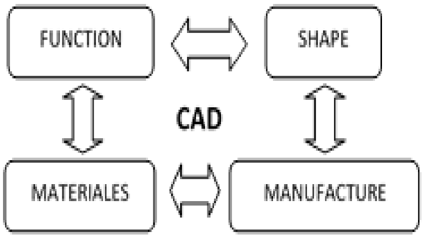

Figure 1: Relationships to consider in CAD

According to (Erazo Arteaga, Valencia Aguirre, Mejía Echeverría, & Terán Pineda, 2017), a design process does not need to be sequential. Therefore, the mechanical strength of the parts is checked at the same time as the dimensioning is done, thanks to the fact that CAD models allow the application of finite element analysis (Raj Tiwari, Alam, Pal, Ali Faiz, & Yadav, 2016).

According to experimental data, the force required to produce a cut in a RIN 14 tire is 2630N (Erazo Arteaga, Vasconez Jaramillo, Morales Davila, Ortiz Morales, & Mosquera Teran, 2019) Based on this, we start by modeling a positive cutting tool, with an incidence angle of 10° and a detachment angle of 12° the construction of this element will be utilizing water jet cutting, due to the availability of the process and the number of blades, which is why it was decided to make a hexagonal hole where the driveshaft will be housed. To reduce the stress concentration, a six-millimeter rounding is made at the bottom of the tooth, the measurements obtained are shown in figure 2.

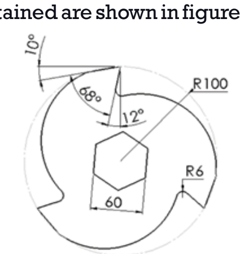

Figure 2: Cutting tool.

For the cutting tool, a 20mm AISI-D3 steel plate will be used, with the mentioned load the effort on the tooth is simulated and as shown in figure 3, a safety factor of 21 is obtained.

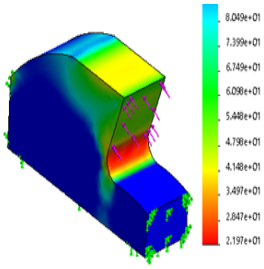

Figure 3: Tool safety factor.

If the cutting action is simultaneous on all the blades, the torque present on the shafts as well as the power required will be increased. It is decided to make a 20° offset so that the cutting action is always present on two pairs of blades, as shown in figure 4.

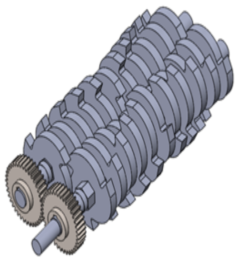

Figure 4: Position of the cutting tools.

A critical case is taken as the instant in which the two blades in the center are in cutting action, generating two loads on the drive shaft: bending of 2,630N and torsion of 263Nm. The torsion due to the gearwheel will be 526Nm causing a tangential force of 6.921N and a radial force of 2.520N. The shaft tip will transmit the movement from the motor with a torque load of 1,052Nm and a force of 4,893N due to the roller chain pulley that transmits the movement from the motor. As shown in figure 5, the shaft is simulated and a safety factor of 4.6 is obtained for an AISI-4340 material.

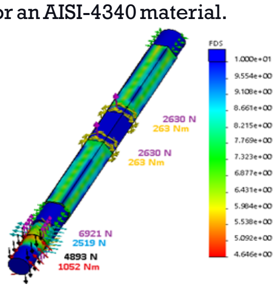

Figure 5: Shaft safety factor.

As shown in figure 6, the assembly will be mounted on ASTM-A36 steel plates of 10mm thickness and will be driven by a 3.730W motor coupled to an orthogonal reducer with a 50/1 ratio, in the lower part a duct will be placed for material discharge, the power transmission by chain will be covered with a metal sheet.

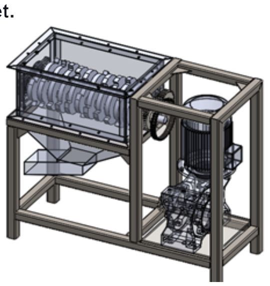

Figure 6: Crushing machine.

The structure is modeled using a 60mm square section tube and 4mm thick, the material to be used is ASTM-A500, the load due to the blade assembly is 3,432.5 N and the load of the motor-gearbox assembly is 981N. As shown in figure 7, the minimum safety factor is 2.

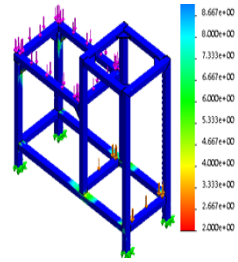

Figure 7: Structure safety factor.

3.1.2. Validation of simulations

To validate the results obtained by the software, the calculation of the stress present on the tooth of the gear is carried out, for which the equation is used:

$$\sigma = \frac{Ft * Cs}{b * m * J}$$

Where:
Ft: Tangential force
Cs: Coefficient of load increase
b: Face width
m: Module
J: Geometric factor

The Cs factor depends on the tangential speed of the wheel, so for speeds below 600m/min it will be:

$$Cs = \frac{180 + vt}{180}$$

The wheels are of module 5 and 31 teeth, the material chosen is AISI-4340, for this case the tangential speed is 16.2m/min, so the value of Cs is 1.09. The face width has been defined in ten times the module. The geometrical factor value is 0.39 and has been obtained from tables for spur gears and a 20° pressure angle with 30 teeth. A tangential force of 13,517.6 N is generated on the gears.

The stress obtained is 151.39N/mm2 and as can be seen in figure 8 the value obtained through the simulation is 150.45N/mm2.

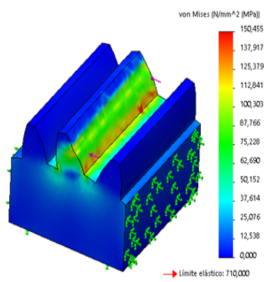

Figure 8: Gear stress.

4. RESULT

By analyzing each of the quotations that have been issued by local suppliers, the cost structure is made, which is summarized in table 2.

Table 2: Cost analysis results.

Cost	
Directrawmaterial	9.005,459
Externalprocesses	800,000
Toolsandmachinery	918,328
Directlabor	502,125
Indirectlabor	169,04875

Administrativecosts	1.899,000
Transportationandservices	9,837
Total	**13.303,797**

To know the import cost, we took as a base the design characteristics and we chose the crushing machine CSJ-600 of the manufacturer "Zumaque" whose capacity is of 300kg/h with a power of 11kW. The cost of this equipment is $6.000 so we calculate the cost of importing this equipment from China to Ecuador (Yauri Monteros, 2020). The summary of the import costs is shown in table 3.

Table 3: Importation costs.

Cost, insurance and freight	
Machine	6.000
Freight	1.500
Insurance	60
CIF	**7.560**

Table 3 (continuation): Importation costs.

Taxes	
ADVALOREM	1.890
Legalbase	9.450
BackgroundINFA	37,8
IVA	1.134
Total	**3.061,8**
Additional	
Token	50
Customsagent	350
Destinationcost	2.000
UnconsolidateCargo	500
Internalfreight	500
Portrate	150
Total	**3.550**
Totalimportcost	**1.4171,8**

5. CONCLUSION

The stress calculated analytically differs by 0.94 N/mm2 from the stress obtained by simulation, which leads to the conclusion that the percentage of error is 0.62%. However, the software must be used with criteria since there are more intervening factors in the gear wheel, in this case, the design has been considered as optimal because the safety factor is similar to 5.

The cost of the machine is around $13,500 for a capacity of 100kg/h, the cost of importing a machine with a capacity of 300kg/h is similar to $14,200, so it can be concluded that it is more beneficial to import.

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