MECHANICAL BEHAVIOUR OF POLYMERIC GEARS REINFORCED WITH RUBBER WASTES ANALYZED BY FINITE ELEMENT METHOD

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Abstract. *The vibrating screens are widely used in mineral processing industries to assess the particle size distribution. The constituent parts of the vibratory equipments exhibit a high cost of maintenance due to the intense wear caused by eccentric moments. The use of polymeric gears in contact with metallic gears is commonly used in the transmission of movement of eccentric weights, reducing the friction and the impact, besides being cheaper and easy exchanging. This work investigates the mechanical behaviour of polymeric gears, reinforced with rubber particles obtained from scrap tires, in contact with a metallic gear using finite elements analysis. The rubber particles into polymeric matrix provided not only moderate strength, but also high vibration damping, becoming a sustainable solution for gears used in vibratory systems. The composite C2, constituted of 25% of rubber particle size 20/30US-Tyler, exhibited satisfactory mechanical behaviour as polymeric gears of a vibrating screen.*

Keywords*: polymeric gears, composite polymeric, sieving machines, finite element method, rubber particles.*

1. INTRODUCTION

The minerals are the most basic raw material required by modern civilization. They are used in industries of steel (iron), ceramic (clay, kaolin, limestone, feldspar, phyllite, quartz, talc, etc.), cement and lime (lime, gypsum, etc.), chemicals (chlorides, phosphates, nitrates, sulfur, etc.), paper (kaolin, calcium carbonate, talc, etc.), as well as in construction (sand, gravel and crushed stone), and also the species considered for the jewelry industry inputs (gems).

These materials do not always present themselves in nature in the form that will be consumed by industry, sometimes because of its grain size or its chemical constitutions, which has no interest or are undesirable for the industrial process as intended. The mineral treatments are responsible to make the minerals suitable for several industrial applications.

The mineral classification process is that one which separates the particles by size or density. The most common equipments for particle's classification are the vibrating screens and cyclones (PORMIN, 2010). In the sieving process, the solids are placed on a surface with a given aperture size. Smaller particles, or fine, pass through the sieve openings, and larger particles are retained.

The vibrating screens are high capacity and efficiency machines, especially for thick materials. Vibrating screen presents structure subjected to mechanical vibrations provided by eccentric or unbalanced shafts with gears or pulleys, depending on the model. A common system used for transmission of shaft rotation is constituted by polymeric gears in contact with metal gears in order to reduce the friction. Besides the impact advantage, this system is economically viable providing an individual wear on the polymeric gear.

Composite materials have been widely used as an innovation and solutions for various engineering problems. According to Panzera *et al.* (2009), the addition of rubber particles into polymeric composites provides not only a moderate mechanical strength, but also high shock absorption and damping factor which are of great interest in the design of gears and structures of precision machines. The use of a polymeric gear in contact to a metallic gear reduces the maintenance costs, since the polymeric gear is the first to damage instead other parts of the system can be affected.

The growing number of vehicles coming into service each day leads to increase the amount of scrap tires. The final disposal of tires is a difficult problem, because they are objects that occupy a large volume and need to be stored in appropriate conditions. The difficulty of degradation and storage of waste tires are increasing environmental problems and the proliferation of insects and rodents, making a waste harmful to public health (Bertollo, 2002). Many researches have been conducted in order to develop new technologies for the reuse of scrap tires, not only as recycled rubber, but also as fuel in power generation; i.e. the addition of scrap tire rubber in asphalt and concrete mixes, burning tires to produce steam, and reuse of tire rubber in a number of plastic products and rubber (Chou *et al.*, 2007; Benazzouk *et al.*, 2008; Panzera *et al*., 2009).

This work aims to investigate the mechanical behaviour of polymeric gears, reinforced with rubber particles, applied for industrial vibrators through the simulations made by finite element method.

2. METHODOLOGY

The polymeric gear assembled with a metallic gear is used for transmission of motion in vibrating system, providing not only the rotation of eccentric masses but also reducing friction and wear. The polymeric gear (see Fig. 1) was taken from a vibrating screen system at Moinhos Gerais Inc. miner, situated in Minas Gerais state, Brazil.

Figure 1 Illustration of gear polymer under study.

The particulated composite can be classified as a two phase material: the dispersive phase and the matrix phase which is continuous and responsible for the adhesion and distribution of loadings. The epoxy resin, supplied by Resiqualy, was set as the matrix phase and the rubber particles, supplied by Mantiqueira Tire Company, were set as the dispersive phase.

2.1. Determination of acting force

The vibrating screens are used in grading as well as sieving purposes. These screens are composed of a main frame, electric motor, screen web, eccentric bock, coupler and rubber spring. These screens are designed primarily to separate the finer grains of thicker; presenting two outputs with different particle sizes (see Fig. 2). The vibrating system is fixed at the bottom of the sieve upon a sloping plane in order to achieve the correct force direction enhancing its efficiency.

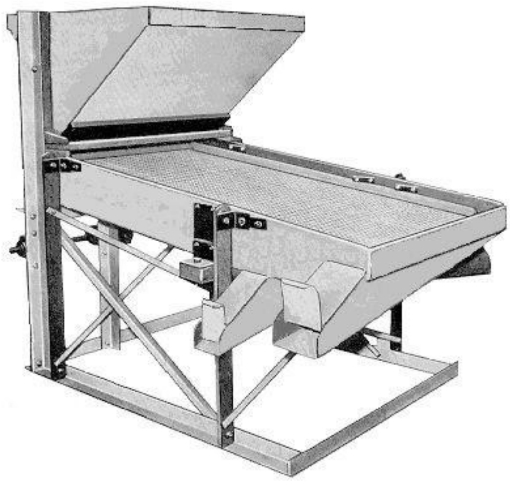

Figure 2 Illustration of a sieve machine

The eccentric shafts are rotated via gears or pulleys attached to the electric motor. In this case, the vibrating screen provides transmission of rotation to the shaft by two gears of 36 teeth and relative diameter of 198 mm. The engine that powers the system is the electric motor of 5cv and 1750 rpm. The illustration of Fig. 3 shows the assembly of the motion transmission system and the mechanical vibrator.

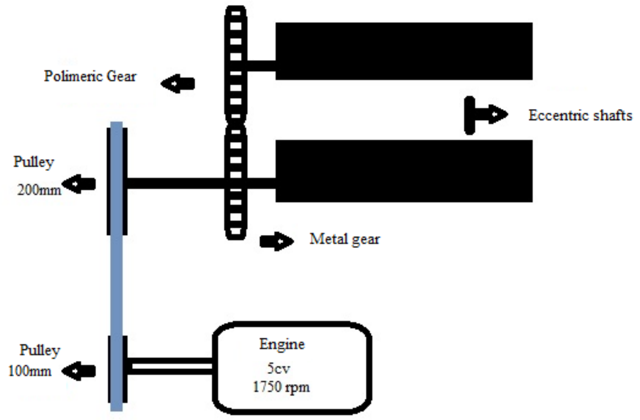

Figure 3 Motion transmission system for the mechanical vibrator.

The loading force of the gear was determined by the pulley transmission, Eq. (1), the axis torque obtained via electric power, Eq. (2), and the force from shaft torque, Eq. (3). We neglected the energy losses of the system.

$$\frac{n_e}{n_s} = \frac{D_s}{D_e} \quad (1)$$

Where,
n_e → input rotation (1750 rpm)
n_s → outlet rotation
D_s →outlet diameter (200 mm)
D_e →input diameter (100 mm)

$$M = 716{,}2 * \frac{N}{n} \quad (2)$$

Where,
M → torque
N → engine power (5 cv)
n → rotation of gear axis (875 rpm)

$$F = \frac{M}{d} \quad (3)$$

Where,
F → force on the gear tooth
d→ distance of force (0,198m)

The force applied on the gear tooth is 405.54 N.

According to Norton (2006), the global safety coefficient is chosen based on the largest of the three factors selected, as Tab. 1. Therefore, for a ductile material, it uses Eq. (4).

$$FS_{ductile} \approx MAX(f1, f2, f3) \quad (4)$$

Table 1 Factors used to determine the safety coefficient for ductile materials (Norton, 2006).

Information	Information quality	Factor
Data of material properties obtained from tests		**f1**
	The material was experimentally tested	1,3
	Representative data from tests of material are available	2
	Reasonably representative of material data are available	3
	Insufficiently representative of material data from tests are available	5+
Environmental conditions in which		**f2**
	The testing conditions are identical	1,3
	Typical laboratory environment	2

it will be used	Moderately challenging environment	3
	Extremely challenging environment	5+
Analytical models for forces and stresses		**f3**
	The models were tested in experiments	1,3
	The models represent precisely the system	2
	The models represent approximately the system	3
	The models are rough	5+

The safety factor of 3 and the gear loading of 1216.62 N were chosen to perform the structural simulation of the polymeric gear.

2.2. Material design

The particulated composite used to manufacture the gear was constituted of a thermoset matrix phase and a dispersive phase of rubber particles. The experimental factors were set as: the rubber particle sizes (20/30 and 50/80 US-Tyler) and the weight fraction of dispersive phase (10%, 25% and 50%). Table 2 shows the experimental factors and levels investigated in this work, establishing a full factorial design of $2^1 3^1$, providing six combinations.

Table 2 Experimental conditions, factorial design ($2^1 3^1$).

Experimental Conditional	Rubber particle size range (US-Tyler)	Fraction of rubber (%)
C1	20/30	10
C2	20/30	25
C3	20/30	50
C4	50/80	10
C5	50/80	25
C6	50/80	50

The specimens were manufactured using rectangular silicone molds of size 20 x 70 x 6 mm. After the curing period of seven days, they were polished (see Fig 4), avoiding the existence of sharp edges that could affect the results on bulk density and flexural testing. The flexural test was carried out following the recommendations of British Standard BS-2746 (1998).

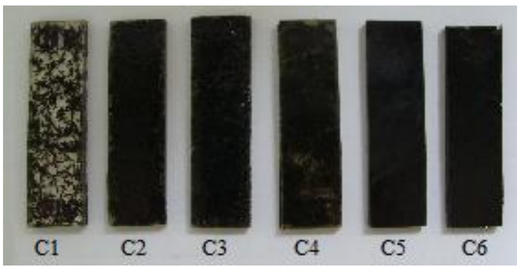

Figure 4 Polymeric specimens for bending test.

Five specimens for each experimental condition and replicate were set. The replicate is the repetition of the experimental condition, providing an estimative of experimental error of an individual response. The extent of this error is important to decide whether there are significant effects that may assign to the action of the factors (Werkema and Aguiar, 1996).

The composite namely as C2, which was manufactured with 25% of 20/30 US-Tyler rubber particles, exhibited a moderate flexural strength and modulus of elasticity, and also providing a significant reuse of rubber wastes (see Tab. 3). For this reason the elastic properties of this composite was used on the numerical analyses of the gear.

Table 3 Experimental results.

Setup	Bulk density [g/cm³]	Modulus of elasticity [GPa]	Flexural strength [MPa]
C1	1,12	2,10	37,65
C2	1,10	1,98	28,96
C3	1,01	1,16	21,10
C4	1,10	2,38	44,60
C5	1,09	1,81	39,43
C6	0,98	1,18	31,36

2.3. Finite element method

The Finite Element Method (FEM) has been used as an excellent tool to analyze the behaviour of materials for structural designs, as well as to evaluate the mechanical performance of these structures. The FEM can be considered as a technique of generating approach functions, which can be used to interpolate displacements, strains, stresses over the element domain. For the approximate solution of structural problems, the shape functions can be applied directly to the differential equation (weighted waste) or the energetic principles, such as the Principle of Virtual Work (Cheung *et al*., 2004; Christoforo, 2007; Góes, 2004; and Rigo, 1999).

The displacement of elastic structural problems is seen as an unknown variable obtained through the solution of linear equations, as followed in Eq. (5), and the mesh and nodes characteristics performed on the structure.

$$[K]\{U\} = \{F\} \tag{5}$$

Where:

[K] - stiffness matrix of the structure;
{U} - vector of nodal displacements of the structure;
{F} - vector of equivalent nodal forces of the structure.

3. RESULTS

The contact ratio of the gears defines the number of teeth in contact at a moment. According to Norton (2006) the contact ratio 1 means that the tooth leaves just when the other contacts the gear. This is undesirable due to the loading being applied at the tip of the tooth. So, the contact ratio was set as 1.7.

Gears can fail for basically two types of requests: (i) that occurring in the contact due to the normal stress and (ii) that one occurring in the tooth caused by flexural effect when the load is transmitted. However, the bending fracture is not common in a well-designed gear system. In general, what happens first is the failure by contact fatigue mode.

The *software* Altair HyperWorks 9.0 was used to perform the FEM. The gear modeling was conducted by creating a 3D finite element mesh. Tetrahedral elements were created with four nodes, each with a maximum size of 3 mm edge, suitable for quasi-isotropic materials.

The boundary conditions were set as restrictions of movement and momentum on the nodes of the pin hole of the gear. A 1D rigid element was created where the force was applied connecting all nodes. The failure criteria of Von Misses was considered for the material analysis. The Poisson's ratio used was 0,35.

According to Fig. 6, the polymeric gear exhibited a deflection of 0.155 mm under the maximum loading.

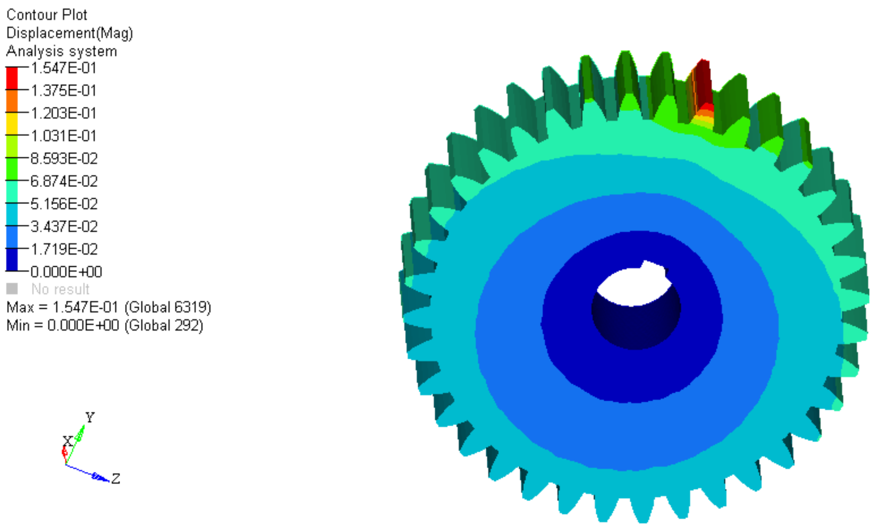

Figure 5 Displacement field of a tooth under maximum loading.

The maximum stress obtained via FEM was 7.72MPa, as seen in Fig.7. Based on the yield stress of the material, set as 28.96 MPa, the composite C2 support the structural requirements for the proposal use, making it a promising recycled material for this application.

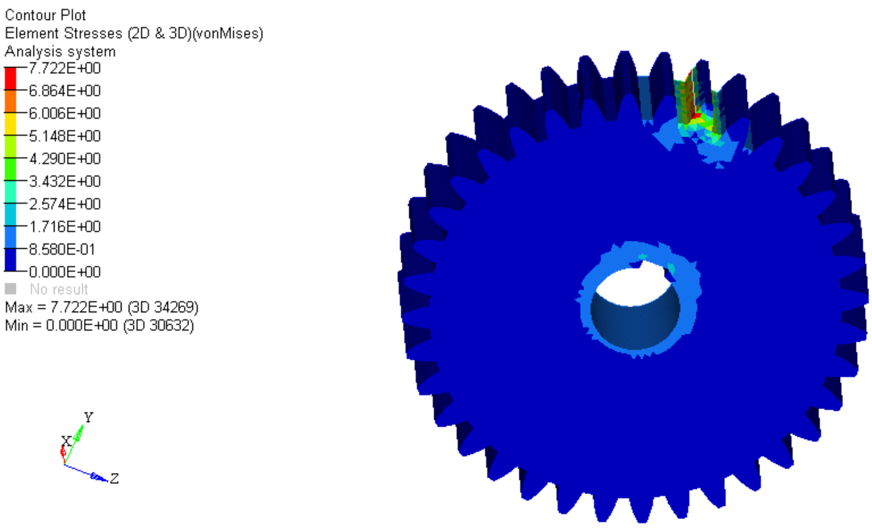

Figure 6 Stress Analysis

4. CONCLUSIONS

The study of new materials and their applications have been the focus of much research for new technologies. This study investigated the use of rubber composites as polymeric gears for vibrating screens in the mining industry. According to the Von Misses criteria, all composites made of rubber are accepted to be used as polymeric gear; however, the composite C2, consisting of 25% of rubber particle size 20/30US-Tyler, can be considered the best setup condition for this application, which can be attributed to the relevant structural performance and also contributes to the reuse of large percent of rubber wastes, becoming a good alternative to replace the standard polymeric gears made of Celeron.

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