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MODELING ADHESIVE STRENGTH OF A TEXTILE CONVEYOR BELT

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Abstract. *The present work is about simulation of a textile conveyor belt in order to calculate the adhesive strength between its constitutive parts. Some tests were performed, according to ISO-252/1-99 norm, with the purpose of determining the adhesive strength by experimental way. Some measurements were also made in order to be used in the mathematical modeling process of the belt's geometry. Used mathematical models are based on material resistance principles and numerical mathematic. Simulation process is based on finite element method. Obtained through simulation results were similar to tabulated limit values for peel stress.*

Keywords: *finit element, hyperelasticity, adhesive strength, conveyor belt.*

1. INTRODUCTION

A textile conveyor belt with a nylon core and a cover and filler between rubber layers is considered a compound material or composite. Consequently, the principles applied to these materials are those governing their mechanical behavior. The study of the adherence among the constituent elements of a composite turns out to be very complex as the phenomena of combined resistance and major strains appear, since both components have these characteristics.

This paper addresses the mathematical modeling of the geometric behavior of the phenomenon of the adherence among the constituent elements of a textile conveyor belt. In this connection, the experimental tests described are conducted (standard ISO 252/1-99, 1999) and then this phenomenon was simulated by the method of the finite elements.

The first steps for calculations in composites were taken several years ago (Goland and Reissner, 1944). That is the starting point or obligatory reference for all the works along that line to date.

That work intended to calculate the stress in joints, with the limitation that their model was based on simple and rigid joints, but taking into account the bending moment present and assuming a flat stress plane outlining that the thickness of the adhesive is very inferior to its length. The limitation of this is that the strains only stay in the elastic area of the material.

In 1973 Hart-Smith published a series of works for the calculation of adhesive bonded single lap joints (Hart-Smith, 1973c), adhesive bonded double lap joints (Hart-Smith, 1973a), adhesive bonded scarf and stepped lap joints (Hart-Smith, 1973b). In these works, account is taken of the development of plastic strain in different areas in the layers of the adhesive and of the adherent. These papers had already been prepared with the support of the computers, but they failed to keep in mind the normal stress or peel stress in the layers, and this becomes one of the major flaws in these materials and their unions.

Other methods of analysis for these failures are based on the mechanics of the fracture. In 1965, Paris-Sih (Paris-Sih, 1965) took a leap in the calculation of the stress in the formation of the crack, but their model considered that the crack growth was linear. There are models nowadays which outline another approach for the same type of failure. Methodologies are observed (Biel, 2005) for the analysis taking the fracture into account. Nevertheless, mathematical models are very complex, even for the traditional models developed by previous authors.

In a recent paper (Ozel, 2005), calculations of the effect of the thickness of the adherent are made in the failure of the joints, as well as the resistance of the joint under a bending moment. These papers adjust different models of finite elements and they compare it with experimental results. However, they lack a mathematical model that explains such behavior. Something similar happens to other calculations (Avila, 2004) and Venkateswara *et al*. (2008).

The calculation of the peel stress was revisited by Chen *et al*, (1979), including the dissipation of heat. This paper treats the adhesive as a hyperelastic material (Rodriguez, 2003), although its analysis was based on rigid (adherent) surfaces, there are aspects of that paper which is necessary to keep in mind. Recent studies (Makelev, 1999) and (Makelev, 2000), the calculation is addressed by the theory of the elasticity, which has been used in the analysis of failure.

In his work (Rivlin, 1950), an analysis is made of the flexion in large strains of the isotropic materials, where the stress is calculated through a function of elastic potential. It is necessary to mention that the calculations for these methods are very exact, but at the same time very complex. These methods are used by the current programs of finite elements since they are completed in a very short time with the help of the computer.

Very similar aspects are addressed in articles by Shigley and Mischke (2001) and Yang and Tromblin (2005), as they touch on the issue of the peel stress. They form the basis of the model that will be presented in this work.

2. MATERIALS AND METHODS

2.1 Characteristics of the band

The material used to do the work is a rubber belt with a nylon core. The nylon core is also known as the core layer. The belt is manufactured by Japanese company Bando Conveyor Belts. According to catalogue No. C-01170, the main specifications of the belt are as follows:

Resistance limit to the break of a layer: $k_t = 100$ kg/cm of width, number of layers: $i = 4$, layer thickness: $\delta_c = 0.9$ mm, material of the layer: nylon (both the warp and the weft), top and bottom covers, and filler layers: rubber, their characteristics are unknown, top cover thickness: $\delta_s = 4$ mm, bottom cover thickness: $\delta_i = 2$ mm, filler layer thickness: $\delta_r = 0.133$ mm, total thickness of the belt: $\delta_b = 10$ mm.

2.2 Experimental test adherence

This test is conducted in a station which has been prepared to these purposes. This test is governed by standard ISO 252/1- 99, which provides that the test can be carried out optionally with 2 types of test pieces and a total of 3 test pieces per test. Fig. 1 show a diagram of the type “B” test piece used in the test with their parts *I* and *II*, where *II* represents the part of the test piece that will detach from *I*. The results obtained in this experiment are shown in the Tab. 1.

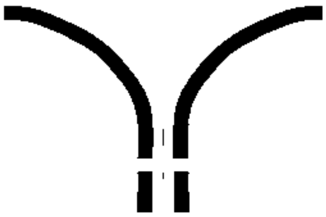

Figure 1. Type B test piece for adherence test

Table 1. Limit forces of adherence among the constituent elements

	Adherence resistance limit [N]
Top Cover	144.907
2 layer	137.468
2 layer	106.079

2.3 Determination of the neuter line and rigidity to the flexion of a composite

For future calculations it becomes necessary to obtain the values of the distance of the neuter line and the rigidity to the flexion of the parts and the system of the different models of test pieces. The determination of the location of the neuter line of a compound material starts from the following general expression:

$$\sum_{i=1}^{n} E_i \cdot y_i \cdot A_i = 0 \tag{1}$$

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where: E_i: Layer i elastic modulus [MPa], y_i : Distances from the center of the layer *i* to the neuter axis [mm] and A_i: Layer i area [mm^2]. Tab. 2 summarizes the values of the neuter line for each model, as well as for its two parts, *I* and *II*.

Table 2. Values of location of the neuter line.

Model	h_1 [mm]
M1PI	2.072
M1PII	1.966675
M2PI	1.04
M2PII	1.0333
M3PI	0.966675
M3PII	1.0333

The product of $(E \cdot I)$, is defined as rigidity to flexion, i.e., the multiplication of the module of elasticity by the moment of inertia. For a composite, the rigidity to the flexion is expressed as follows:

$$(E \cdot I)_{comp} = \sum_{i=1}^{n} E_i \cdot I_i \tag{2}$$

where n: Number of layer of composite, E_i : Elastic modulus of layer i [MPa], I_i : Moment of inertia of each referred to the neuter line of the composite [mm^4]. The values of rigidity to the flexion of the layer are summarized in Tab. 3 and those of the system are shown in Tab. 4.

Table 3. Models rigidity to the flexion.

Model	$(E \cdot I)_{(banda)}$ [Nmm^2]
M1PI	135200
M1PII	417.977
M2PI	16640
M2PII	15950
M3PI	49.636
M3PII	15950

Table 4. System rigidity to the flexion by each model.

Model	$(E \cdot I)_{(sist)}$ [Nmm^2]
1	416.689
2	8144
3	49.482

2.4 Adherence test model

With a view to simulating, in a program of finite elements, the resistance to the adherence among the constituent elements of the parts that make up the belt, it becomes necessary to determine a geometric model. This model will very accurately provide the geometry that the test piece takes before being subjected to the tractive force in the traction unit.

The development of the mathematical model is of crucial importance as it describes the behavior of the strain of the test piece. It is known that the test to the adherence carries 3 different models, and the break limit among the elements is determined in each test. Consequently, the initial geometry that the test piece takes will not be the same in each case.

The geometry of the model is of utmost importance in the simulation of any phenomenon since the greater similarity between the geometric model and the reality, the greater the accuracy and reliability of the results.

The determination of the geometric model that defines the geometric behavior starts from the general elastic equation of the beams subjected to flexion, which sets out that:

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$$k = \frac{1}{\rho} = -\frac{y''}{\left(1+(y')^2\right)^{3/2}} = \frac{M}{EI} \tag{3}$$

clearing y'' in Eq. (3) it is obtained that:

$$y'' = Ax + B\left[1+(y')^2\right]^{3/2} \tag{4}$$

where:

$$A = -\frac{R}{EI} \tag{5}$$

$$B = -\frac{Ax^2\sqrt{(y')^2+1}+2(y')}{2x\sqrt{(y')^2+1}} \tag{6}$$

$$y' = \tan\theta \tag{7}$$

In Eq (5) and (7), the value of A and y' are calculated through the values of R and θ which were obtained experimentally. Fig. 2 shows the cross sections of the two parts for model 2, which will be the used as an example of the test pieces used in the test of adherence. They also show the points of measurements of the different parameters. Tab. 5 indicates the values obtained in the measurements of the 3 test pieces.

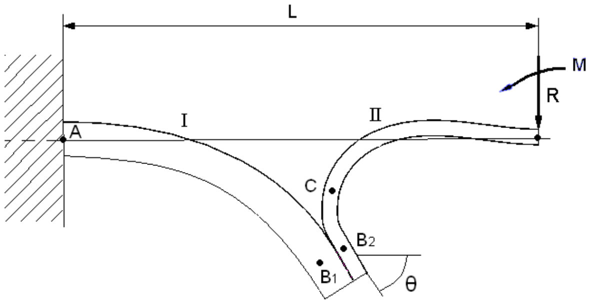

Figure 2. Diagram of the resistance test pieces to the adherence, model 2.

Table 5. Value of the parameters measured to each model.

	PARAMETROS								
MODELS	R [N]	L [mm]	Θ [°]	X_{B1} [mm]	X_{B2} [mm]	X_C [mm]	Y_{B1} [mm]	Y_{B2} [mm]	Y_C [mm]
Model 1	2	64	-12	39.5	40	36	-7	-4	2
Model 2	1	62	-60	34	36	35	-16	-13	-9
Model 3	0.030411	40	41	7	9	18	-25	-27	-7

Figures 2, 3 and 4 show the curves of the neuter lines of the models 1, 2 and 3 obtained when solving the Eq. (4) through the numeric method. It should be pointed out that these curves obtained mathematically comply with what is set out in the test. Please notice the similarity between the diagram in Fig. 2 and the curve of the Fig 4

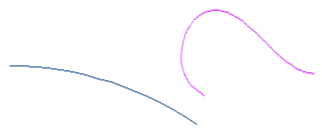

Figure 3. Curve of the neuter line of model 1.

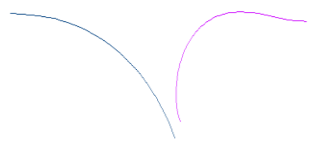

Figure 4. Curve of the neuter line of model 2.

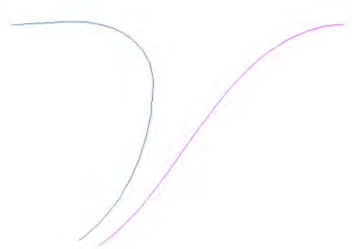

Figure 5. Curve of the neuter line of model 3.

2.5 Simulation of the test to the adherence between elements

For the simulation of this phenomenon, 2 types of elements are used. One is Plane 183, which is a two-dimensional element defined by 8 nodes and having 2 degrees of freedom at each node and translation in the nodal x and y directions. The element has to be used in 2-D geometry, it has a quadratic translation behavior, it is very appropriate for the meshing of irregular surfaces. This element is used for simulating deformations of nearly incompressible elastoplastic and fully incompressible hyperelastic materials.

The other element is the Hyper 84 (Mooney-Rivlin), which is used for 2-D modeling of solid hyperelastic structures. This element is applicable to rubber-like materials with large displacements and strains. Both compressible and nearly incompressible materials may be modeled. The element is defined by 8 nodes and has 2 degrees of freedom at each node: translation in the nodal x and y directions. The hyperelastic formulation is nonlinear and requires an interactive solution. Large strains have to be activated to be able to update the geometry in each step.

Due to the abovementioned characteristics, the Hyper 84 is used in the rubber elements and Plane 183 is used in nylon. The mesh used is the quad free with Smart Size 1.

Table 6 shows a summary of the values obtained for the layers of rubbers of the different models, which are the layers of the test pieces where the break is expressed by the peel stress.

Table 6. Value of equivalent peel stress in the adherence model.

Model	σ_{EQV} [N/mm^2]
1	1.922
2	3.426
3	3.473

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In this case of resistance to the adherence, a mathematical model to solve the problem in question is not achieved, but a model is achieved that describes the geometric behavior of the phenomenon. This is a very important element when simulating the phenomenon by a program of finite elements.

2.6 Comparison of the results of the resistance to the adherence between elements

Reference can only be made to the fact that the simulation values fall within the expected range as quoted by some sources. For example, Alphonsus (2004) established that for adhesives based on rubber the peel stress stays in the range of 1.8 – 7 MPa; and Shigley and Mischke (2001) stated that they are in the range of 0.88 to 3.5 MPa for warm fused synthetic mixtures of rubber.

If account is taken that the values obtained in the simulation are those shown in the Tab. 6 and that they are between 1.9 – 3.4 MPa, it can be said that these results are satisfactory. However, a comparison of the error cannot be made because an exact reference value is not available since it is not disclosed in the manufacturer's catalogue, as explained earlier.

As explained in the introduction, this phenomenon is complex and the models available have its limitations. The components of this belt are hyperelastic material, with big strains, with non-linear material behavior and with non-linear geometry too. As a result, the models analyzed fail to produce results with an appropriate or expected percentage. This is why the appropriate model should continue to be pursued.

3. CONCLUSIONS

1. Very satisfactory results are obtained when simulating, by the method of the finite elements, the adherence between constituent elements of the belt since the values obtained fall within the expect range. However, the error cannot be determined as an exact reference value is not available.

2. Geometric models as shown in the Fig. 3, 4 and 5, are obtained through a mathematical procedure that conforms to the test carried out.

4. ACKNOWLEDGEMENTS

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