ISSUES IN MODELING SLITTING OF MAGNETIC TAPES

by

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ABSTRACT

In order to quantify and understand the driving force for film layer fracture, delamination, and the cutting phenomena in general, an idealized two-dimensional "slitting" model was developed. The model includes two lower ("female") knives supporting the tape, through which a single upper ("male") knife is passed. The knife surfaces are modeled as frictional rigid surfaces and the displacement of the male knife is imposed. The tape is modeled as an elastic-plastic material with a critical shear strain energy and hydrostatic pressure criteria for element-localized failure. The model follows a "quasi-static" dynamic explicit formulation scheme that handles highly nonlinear responses very efficiently. This technique has been widely used in the modeling of metal cutting and is able to capture many of the major features of the slit edge morphology but shows a strong sensitivity to mesh resolution.

Criteria for success of the model includes invariance of the edge morphology with mesh scale and agreement between predicted and observed slit edge morphology. Results showed a strong dependence on tape materials properties. The major focus of this work is the interrelationship of mesh scale and the failure criterion imposed.

NOMENCLATURE

$\bar{\varepsilon}^p$ = equivalent plastic strain
$\dot{\varepsilon}^p$ = plastic strain rate tensor
D_c = critical damage
σ_h = hydrostatic pressure
σ_{eq} = equivalent Von Mises stress
L^e = element characteristic length
C_d = dilatational speed
ρ = material density
E = Young's modulus

INTRODUCTION

Many coated products are formed by first coating a wide but thin web or film then slitting, cutting, or punching the web to yield a narrow tape or other shape much smaller than the original. Examples include: thin polymer films coated with magnetic materials that are slit to form magnetic recording tape; thin polymer films coated with optically-sensitive emulsions that are slit and punched to form photographic film; paper multilayer structures that are slit, cut and punched to form adhesive labels; and metal-coated polymer-ceramic composite sheets that are cut and punched to form multilayer chip capacitors or semiconductor substrates. A general problem of the slitting process associated with these coated products is maintaining or achieving a defect-free cut edge. Such edges are crucial for yielding products that maximize the useful surface area of the slit component.

Shearing is frequently used as the separation process in many industrial fields such as metal forming, paper, and particularly, slitting of magnetic tapes. Mechanical shearing is still the most economical way to cut materials, despite the development of new techniques such as laser beam cutting. Furthermore, industry continuously raises standards in final quality of the product and, particularly, requires more uniformity in the output. These more strict specifications are met generally by "smart" trial and error procedures based on theoretical and empirical knowledge. Several studies of the slitting process, or its different versions, have been conducted to get a closer insight into its complex mechanisms and so, reduce the number of iterations needed to achieve the desired output. A considerable amount of work can be found in the literature about slitting technologies although most of it is related to metal and paper cutting. Research of slitting of magnetic tapes is not so often seen in scientific journals.

As mentioned, most of the work performed in the area of slitting of coated products is experimental in nature. Little work has been done using numerical models such as the finite element method to study this process. Most of these finite element analyses are 2-D representations of the actual physical phenomenon and none of them are applied to the specific case of magnetic tapes. Therefore meshes are too coarse for a good representation of the very thin magnetic tapes with their multiple layers. Furthermore, isotropic materials were considered in all cases, and also in this work, which constitutes another limitation as magnetic tapes are often composed of orthotropic materials. However, since similarities between slitting of magnetic tapes and metal and paper cutting are also important, references about the latter two can be used as background for the current work.

One of the first studies of the slitting process was performed by Stromberg and Thompson (1965), as reported by Viswanathan and Lu [1]. Bollen, Denier, and Aernoudt [2] studied the mechanics of the cutting phenomenon during the shear cutting of PET films using two rotating circular knives. The authors described four regions in the sheared edge: scales, split, and lower and upper flaps. From their observations they concluded that the scales regions are located in the upper part of the front face of the tape and in the lower part of the back face. The lower part of the so-called supported side and the upper part of the unsupported side are the two split regions. The space between these two regions is divided into two more regions: upper and lower flaps. According to the authors, the cutting process has four phases: the compressing, shearing, tearing, and damaging phases. Initially, the film is subjected to compressive stresses exerted by both the male and female knives. During this phase, there is no cut in either the lower or the upper sides of the film. The next phase, the shearing phase, starts once the shear strength of the material is reached and separation between the two faces begins. As the stretching of the film increases, two faces are formed and the film is torn following the path of minimum energy. Finally, the damage phase is due to friction between the knives and the film as web is transported past the knives.

Meehan and Burns [3] studied the effect of several variables on the cutting force. They concluded that the rate at which the material is slit and the tension on the web do not have a significant effect on the cutting force. However, they found that the relative angle between the blade and the web had an important impact on the cutting force. One of their more important contributions regarded the dependence of crack tip stresses and the cutting force. For the case of no applied force, crack tip stresses are well represented by the expressions obtained by solving the biarmonic differential equation with the corresponding boundary conditions related to the presence of the crack. These well-known expressions of traditional fracture mechanics give a singularity of the type $1/\sqrt{r}$. On the other hand, for problems wherein a cutting force exists the solution of the crack will have a singularity of the type $1/r$.

Strenkowski and Carroll [4] modeled the process of orthogonal metal cutting using the finite element method. The model followed an updated Lagrangian formulation employing plane strain two-dimensional solid elements. The separation between the chip and the workpiece was modeled using the slide-line capability. This feature consists in defining two lines (or surfaces for three-dimensional cases) whose nodes are connected with springs. These springs enforce the no penetration condition when there is compression and break if the effective plastic strain reaches a predefined value. Shih et al. [5] produced a more sophisticated model of metal cutting that includes the effects of elasticity, viscoplasticity, temperature, strain rate, and large strains. The separation criterion was based on the distance between the tool tip and the node connecting the two elements immediately ahead of the tool.

Rakotomalala, et al. [6] developed an arbitrary Lagrangian-Eulerian finite element model of material cutting. The model is based on the spatial discretization of the momentum equation and an explicit scheme to integrate the motion equations with respect to the time variable. The model includes thermal effects as well. A two-dimensional analysis of metal cutting was used to test the model. Bacaria et al. [7] extended this model to three dimensions and included a damage law as a separation criterion. They developed two- and three-dimensional finite element models to study the process of unsteady orthogonal cutting. In a similar but simplified fashion, Harish Viswanathan [1], under the supervision of Professor Hongbin Lu, presented a model of slitting of aluminum using the finite element approach. Their work focused mainly in the study of burr formation during the shear slitting process.

Wisselink and Huetink [8] developed a three-dimensional finite element model for the analysis of the steady state slitting of metals using an arbitrarian Lagrangian Eulerian (ALE) formulation. Goijaerts et al. [9][10] studied ductile fracture in blanking processes of metals to predict their final morphology. They used FEM to model the process and two strategies were used to account for the local ductile fracture: The first method employed blanking experiments and the second used a tensile test to characterize fracture criteria for the blanking process. Klingenberg and Singh [11] also investigated the blanking process by using a combination of analytical, numerical and experimental approaches.

In this paper, an extension of the damage approach to slitting of magnetic tapes will be presented. An idealized two-dimensional "slitting" model was developed to quantify and understand the driving force for film layers fracture and delamination and the cutting phenomena in general. The model includes two lower ("female") knives supporting the tape, through which a single upper ("male") knife is passed. The knife surfaces are modeled as frictional rigid surfaces and the displacement of the male knife is imposed. The tape is modeled as an elastic-plastic material The model follows a "quasi-static" dynamic explicit formulation scheme that handles highly nonlinear responses very efficiently. Two main failure modes are analyzed shear and tearing. A practical approach to obtain damage properties based on literature is used. Criteria for success of the model include invariance of the edge morphology with mesh scale, agreement between predicted slit edge morphology on tape materials properties and slitting geometry.

Characterization of a Ductile Fracture Model

The slitting process is represented in two-dimensions as a male knife punching the tape that is supported by two female knives. One of the fundamental differences between slitting and punching is the thickness of the tape as compared to the dimensions of the male knife. For the case of slitting, these dimensions differ by approximately two to three orders of magnitude. For punching, this difference is typically much smaller. Figure 1 shows a sketch of the two-dimensional representation of the slitting process and Figure 2 shows a close up of the cutting area along with graphical definitions of supported and unsupported sides. In addition, the composite tape system is depicted dimensionally in Figure 3.

The failure process considered in this study is ductile fracture. This failure mode, where shear effects are considered the cause of material separation, is frequently used in metal cutting. The authors believe that this failure mode can be extended to fracture of polymers like magnetic tapes. The process consist of three main phases:

- **Nucleation:** voids are formed at inclusions or particles due to loss of adhesion between particles and matrix, or due to cracking of particles because of large deformations.
- **Growth of voids:** driven by plastic deformation voids grow to a size larger than the particle itself.
- **Coalescence of voids:** when the voids reach a certain size the matrix breaks and voids are interconnected producing cracks.

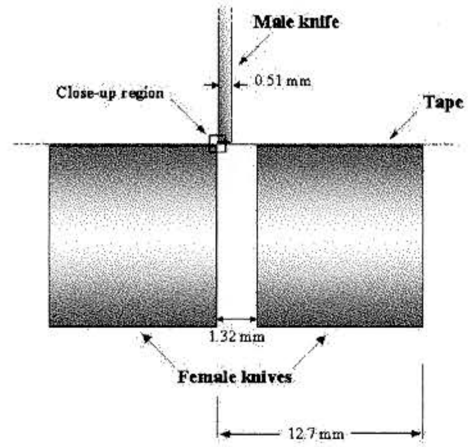


Figure 1. Sketch of the Slitting Process

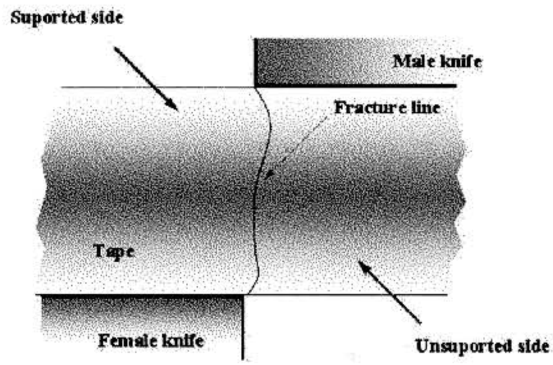


Figure 2. Close up of the Cutting Area

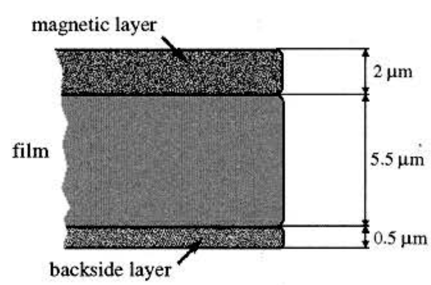


Figure 3. Sketch of a Magnetic Tape

In order to assess when the described process takes place, a damage approach is generally used. Damage is defined as the degree of degradation of the material properties. There are two types of damage models:

Coupled damage models: These models include the damage in the constitutive law; they are more precise because they allow incremental damage of the material.

Uncoupled damage models: These models compute the damage as a function of the stress and strain fields. Using these methods the damage affects the state of stress and strain of the material when the element is considered broken. This model was used in this work.

Fracture, or material breakage, occurs when a point in the domain reaches a certain level of plastic energy. This can be mathematically expressed as the integral of a certain function f over the equivalent plastic strain $\left(\bar{\varepsilon}^{p}\right)$.

$$D_c = \int_0^{\bar{\varepsilon}_c^p} f(\sigma, \varepsilon, \sigma_h / \sigma_{eq}) d\bar{\varepsilon}^p \qquad \{1\}$$

where $\bar{\varepsilon}^P$ is the equivalent plastic strain defined as: $\bar{\varepsilon}^P = \int \sqrt{\frac{2}{3}\left(\dot{\varepsilon}^p : \dot{\varepsilon}^p\right)} dt$

The damage law, therefore, takes into account the strain and stress history of the material to predict its fracture. The function, f, may depend on the stress, strain, and the triaxiality ratio $\left(\sigma_h / \sigma_{eq}\right)$; where σ_h is the hydrostatic pressure and σ_{eq} is the equivalent Von Mises stress. When this integral reaches a certain value, the material breaks and the equivalent plastic strain and the damage factor, D, are called critical.

$$D = D_c \Rightarrow \bar{\varepsilon}^p = \bar{\varepsilon}_c^p \qquad \{2\}$$

Several forms of this integral were proposed for the function in equation {1}. Clift et al. [12] made comparisons of the different functions proposed by combining finite element analysis and experimental work. Following are some forms of this function proposed in the literature.

$$D = \int_0^{\bar{\varepsilon}^p} \sigma_{eq} d\bar{\varepsilon}^p \qquad \text{Freudenthal [13]} \qquad \{3\}$$

$$D = \int_0^{\bar{\varepsilon}^p} e^{C_R \frac{\sigma_h}{\sigma_{eq}}} d\bar{\varepsilon}^p \qquad \text{Rice and Tracey [14]} \qquad \{4\}$$

$$D = \int_0^{\bar{\varepsilon}^p} (1 + C_0 \frac{\sigma_h}{\sigma_{eq}}) d\bar{\varepsilon}^p \qquad \text{Oyane et al. [15]} \qquad \{5\}$$

$$D = \int_0^{\bar{\varepsilon}^p} (1 + C_{G1} \frac{\sigma_h}{\sigma_{eq}}) (\bar{\varepsilon})^{C_{G2}} d\bar{\varepsilon}^p \qquad \text{Goijaerts [9]} \qquad \{6\}$$

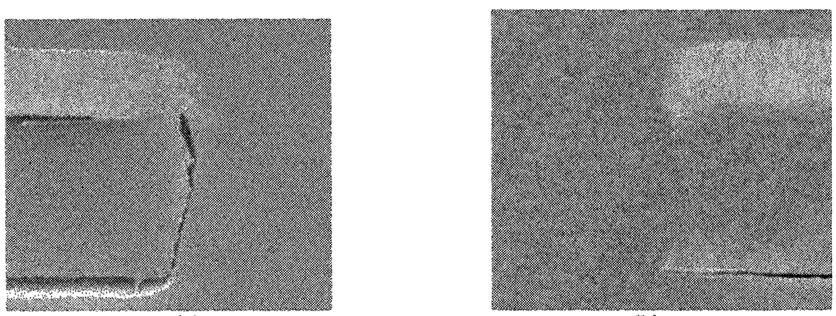
where C_0, C_{G1}, and C_{G2} are material constants.

All of these laws gave accurate results for the specific problems addressed but they are not applicable to all situations. The general conclusion from these studies is that the critical damage value is not a material property but it depends on the process. As a result of this, specific values have to be obtained for each case. Once these values are obtained each law is valid for small variations of the process, such as load, speeds, and small geometrical changes.

In this work the function, f, will be defined as a constant. The main reason for this is to reduce the number of parameters needed in the model. This is an important requirement since the goal of this project is to obtain reasonable results in a short time with limited experimental effort. Following this rationale, the expression below was employed.

$$D = \int_0^{\bar{\varepsilon}^p} d\bar{\varepsilon}^p \qquad \{7\}$$

For the slitting of magnetic tapes, experimental work suggests that failure is not only due to shear but also tearing. Evidence of this can be observed in Figures 4 and 5. These images were obtained by taking small pieces of tape embedded in a cast epoxy and sliced carefully until the cross section are clear enough for an SEM analysis.



(a) (b)

Figure 4. Cross-sectional SEM Image Depicting the Slit Profile: (a) Supported Side, (b) Unsupported Side

Figure 5 shows an SEM view of the slit edges of the supported and unsupported edges from two points of view; looking at the magnetic layer, and looking at the backside layer. These images are not from the same sample. However, they do represent an average view of the slit edges. In Figure 5 (a), (b) and (c) the reader can see tearing mode in the middle of the slit profiles. Figure 5 (d) shows a more pure shear mode of cutting that suggests that a combination of shearing and tearing or just shearing is the most probable mode of failure.

To characterize crack initiation due to shear failure a method proposed by Goijaerts et al. [9] is used. The idea is to obtain good estimates of the ductile failure properties by performing a simple test instead of a complex test to represent the slitting process. The method consist in the following steps:

- Perform a tensile test and record the maximum normal strain before failure.
- Simulate the tensile test using the method of the finite elements. The failure criteria chosen, in this case the equivalent plastic strain, is evaluated for all the elements and stored.

- From these stored values, find the maximum value of the equivalent plastic strain at the breaking point and choose it as the critical one; refer to Eq. {2}.

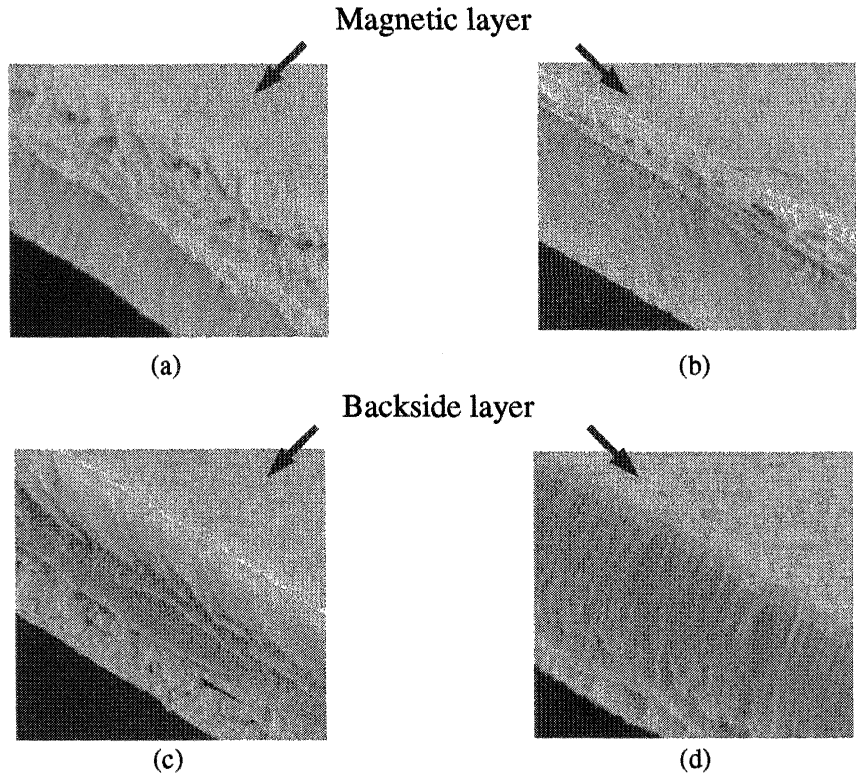


Figure 5. Slit Profiles, (a) Magnetic Layer Supported Side, (b) Magnetic Layer Unsupported Side, (c) Backside Layer Supported Side, (d) Backside Layer Unsupported Side

This method is suitable for industrial applications as it is fast and does not require sophisticated equipment. Moreover, it uses reliable and well known techniques that give results in a short time.

In order to model the tearing mode in ABAQUS [17], a critical value must be found and correlated to the hydrostatic pressure. A critical hydrostatic pressure is used to define failure by tearing because of software limitations within Abaqus {17}. The authors agree that a better criterion is needed. For example, a maximum strain or stress criterion, however this requires more complex modeling techniques, such as user subroutines, that will be subject of future work. The method is as follows: From a tensile test the maximum principal stress at failure was determined. In the present case, this was 350 MPa. Then a preliminary finite element simulation of the slitting process considering only shear failure was performed and values of hydrostatic pressure were obtained and recorded for elements located in areas wherein the maximum principal stress exceeded 350 MPa. The critical hydrostatic pressure was then determined by averaging those recorded values; this value was found to be 220 MPa. Table 1 shows the values of critical equivalent plastic strain and critical tearing found for PET films.

Table 1. Failure Criteria for PET Films

Mode of Failure	Critical value
Shear	0.4 (equivalent plastic strain)
Tearing	220 MPa (hydrostatic pressure)

In summary, the separation criterion applied in this work is a combination of tearing and ductile shear failure modes. Both modes are considered independently.

$$\text{if} \quad \bar{\varepsilon}^p \geq \bar{\varepsilon}^p_c \quad \Rightarrow \quad \text{material breaks}$$

or

$$\text{if} \quad \sigma_h \geq \sigma_{hc} \quad \Rightarrow \quad \text{material breaks}$$

If either of these conditions is true the material breaks no matter what the status of other condition. Once one of the failure criteria is met, the material can handle only compressive stress and all the other components of the stress tensor, tensile and shear, are set to zero. Therefore, broken elements are not removed but their properties are modified to carry only compressive stresses.

Modeling of Slitting of a PET Film

Description of the model

In order to quantify and understand the driving force for film layers fracture and delamination and the cutting phenomenon in general, an idealized two-dimensional "slitting" model was developed. The model includes two lower ("female") knives supporting the tape, through which a single upper ("male") knife is passed as shown in Figures 1 and 2. The knife surfaces are modeled as frictional rigid surfaces and the displacement of the male knife is imposed. The tape is modeled as an elastic-plastic material with critical shear strain energy and critical hydrostatic pressure criteria for element-localized failure. The model follows a "quasi-static" dynamic explicit formulation scheme that handles highly nonlinear responses very efficiently. This technique has been widely used in the modeling of metal cutting.

In this work, two-dimensional reduced integration plane strain solid elements are used. The mesh density increases near the cutting area. In this work, a mesh convergence study was performed and it was determined that a mesh of 12848 elements gives accurate results within a reasonable amount of time. The mesh includes 48 elements across the thickness and 100 elements along a 12 μm length around the cutting area.

Boundary conditions include contact surfaces between the tape-knife interfaces and equal displacements and rotations along the lines shown in Figure 6. Knives are modeled as rigid bodies to reduce the size of the system of equations. The process is simulated by displacing the upper knife until complete material separation. Abaqus Explicit [17] was used for the numerical computation and Abaqus CAE [17] for post-processing the results.

This approach has been used by several researchers, especially when modeling the punching and blanking processes where a damage approach assumes that large plastic strains lead to nucleation, growth and coalescence of voids in the material. As slitting of magnetic tapes include an important contribution of tearing, a component depending on the hydrostatic pressure was include in this work.

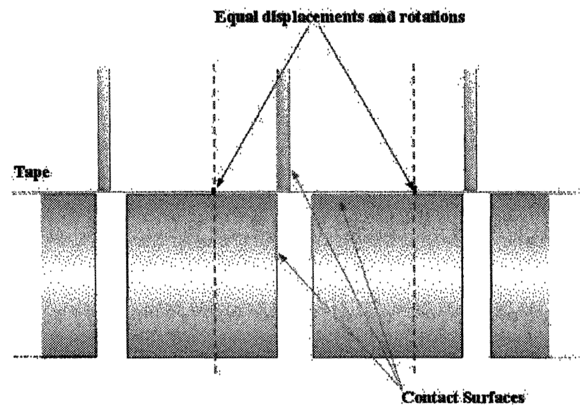


Figure 6. Finite Element Model Boundary Conditions

Formulation

All work presented herein was performed using a pseudo-static explicit formulation. This procedure has several advantages over the conventional finite element implicit formulation. In particular, an explicit formulation does not solve the differential equation for each time step provided that a lumped mass matrix is used. The solution process, shown in Figure 7, is reduced to a matrix multiplication. The drawback is that very small time steps must be used in order to obtain accurate results.

Even though this formulation was developed to solve dynamic problems, it can also be used in situations where inertia effects are negligible. This is performed in a convenient manner by reducing the loading rate or the mass involved. Although the selection of the formulation is a designer choice, for problems such as wave propagation or impact, an explicit formulation is the best alternative; and for linear or nonlinear-smooth problems an implicit formulation is more efficient in terms of computer time. There is, however, a trade off between implicit and explicit formulations. An implicit formulation requires fewer time steps but more computer resources for each time step. Conversely, an explicit formulation that requires more time steps but consumes less computer resources for each time step.

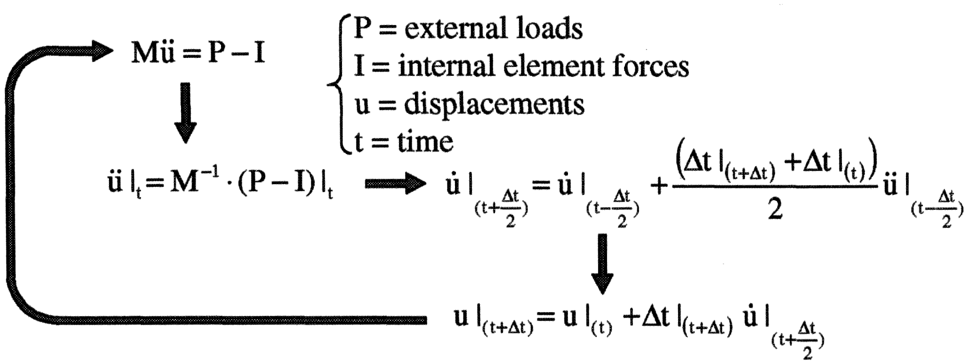


Figure 7. Explicit Formulation Flow Chart

Material properties

The film is made of polyethylene terephthalate (PET). This film is produced by the extrusion of a polymer melt that is quenched, oriented, and heat set. Orientation is performed by stretching the film in the longitudinal and transverse directions. The degree of crystallinity and its biaxial orientation, and the amount of amorphous areas determine the mechanical properties of the film. Although the material properties of polymers are quite complex, the film is assumed isotopic with elasto-plastic behavior. For plastic deformation the Von Mises yield condition was used and isotropic hardening was assumed. Material properties shown in Table 2 were obtained by a tensile test performed at low speed, so strain rate effects were negligible.

Figure 8 shows the stress-strain function for the one-dimensional tensile test of the PET film. The shape of the curve, monotonically increasing, indicates that there is no necking in the sample before fracture of the material. This means that failure occurs when the sample reaches its maximum strain condition. On the other hand, for cases wherein necking exists, failure occurs at the point where necking originates. Young's modulus was obtained from this test and Poisson's ratios from the literature [16].

Table 2. Mechanical Properties of PET Films

Young's Modulus	7258 MPa
Poisson's Ratio	0.33

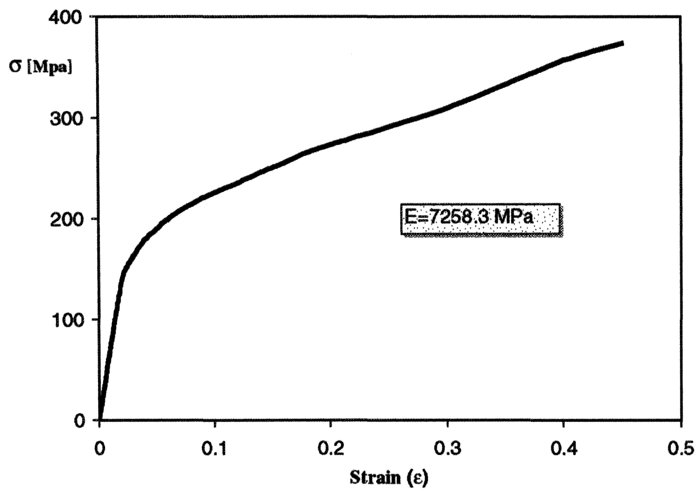


Figure 8. Stress-strain Relationship for the PET Film

Results

The numerical model was tested by simulating the slitting of a homogeneous PET film. As mentioned, both tearing and shearing modes were considered in these simulations. The inclusion of both modes seems to be crucial to obtain morphologies from the model that closely resemble the main features of the actual slit edge cross sections.

Since a pseudo-static procedure was followed, speed of the process and density of the materials do not influence the results. A view of the energy curves, see Figure 9, shows that the kinetic energy is small compared to the total external energy; this confirms that kinetic and inertia components are not important.

Values of Von Mises stresses are shown in Figure 10 before material failure occurs. At this stage the model simulates the elasto-plastic phase of the process just before any element fails.

Figure 11 shows cross sections of the slit edges for the supported and unsupported sides. In this figure, areas of shear and tearing modes are shown; this was done by manually checking the values of equivalent plastic strain and hydrostatic pressure for the broken elements given by the model at the different stages of the process.

Figures 5, 6, and 11 show that the model describes the main features of the slit edge morphology. It can be observed that the model gives a predominant tearing mode of failure in the middle of the profile and a shearing cutting mode of failure in the top and in the bottom. The differences between actual images and model predictions are attributed to the threshold values used in the failure criteria. In particular, the critical values describing the tearing phase need to be improved. In addition, it is known that failure occurs before the male knife touches the cutting area. This translates into smaller shear stresses and larger longitudinal stresses in the top of the film. As a result, the two-dimensional representation presented herein can not capture the opening effect of the knife penetrating the tape; this produces larger tearing, especially on the side facing the male knife.

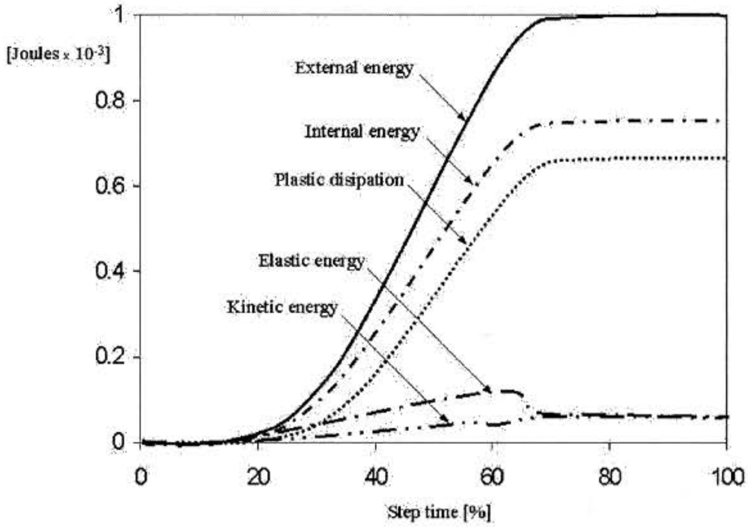


Figure 9. Energy Curves

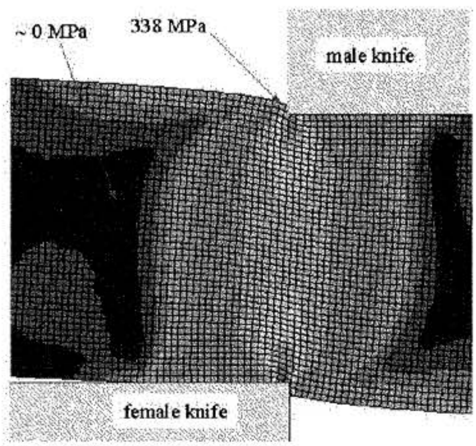


Figure 10. Von Mises Stress Before Element Failure

As mentioned, the process was modeled by using several mesh resolutions in order to determine if the results converge to a unique solution. The mesh shown in Figure 11 gives similar results than a mesh with twice its level of resolution shown in Figure 12.

The importance of selecting the right failure mode and the need to include all relevant modes, can be appreciated in Figures 13 and 14. These figures show the slit edge cross sections considering just shear mode, see Figure 13, and just tearing mode, see Figure 14;

all other parameters were identical to those cases previously discussed. It is clear that the slit edge morphology changes significantly depending on the dominant failure mode. A realistic evaluation of the failure threshold values was also found very important not only to obtain reasonable morphologies, but also to obtain mesh convergence. This indicates the paramount role of the material properties in the final morphology of the slit edge.

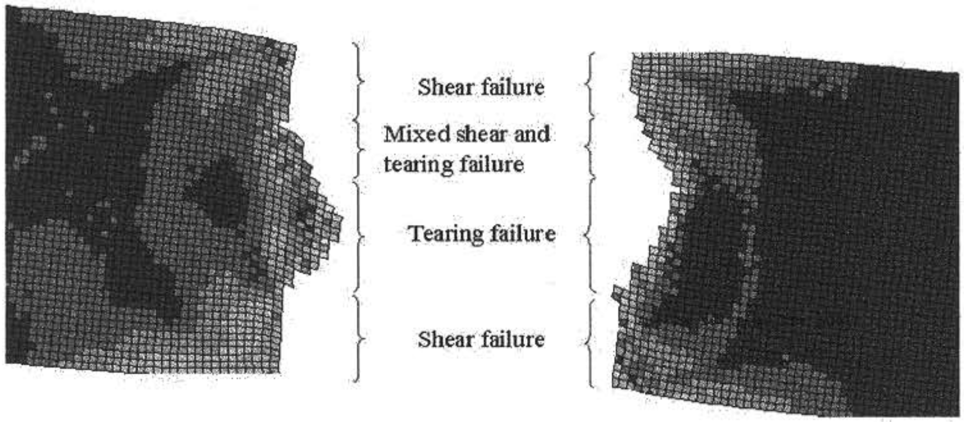


Figure 11. Slit Edge Cross Sections of the PET Film Including Shear and Tearing Failure Modes

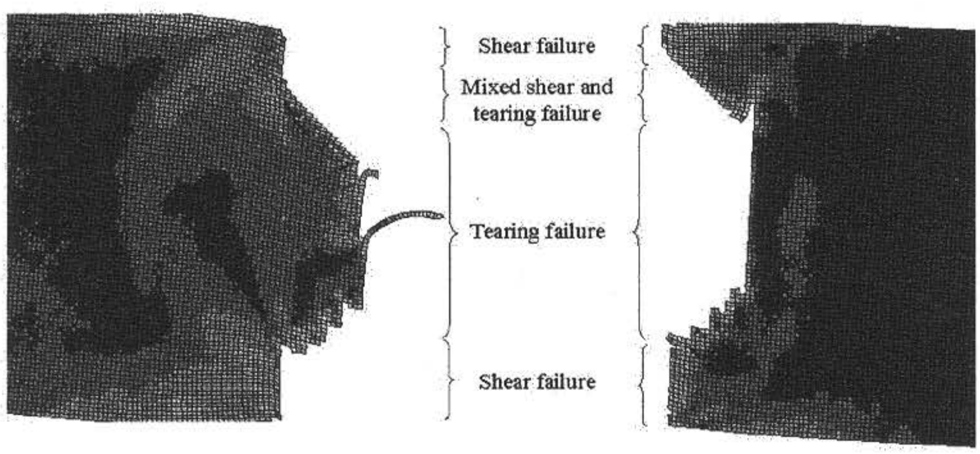


Figure 12. Slit Edge Cross Sections of the PET Film Including Shear and Tearing Failure Modes of Failure for a Finer Mesh

MODELING ISSUES

In the modeling of processes like slitting, cutting, blanking or forming, most of the researchers and engineers have used an explicit formulation for the numerical analysis and a damage approach to determine material failure. This section will summarize the main issues that the authors believe are important for a successful modeling of thin films such as magnetic tapes.

The largest problem of modeling magnetic tapes was the time needed for a simulation. This is due to the very small dimension of the film with respect to the other parts of the system, such as the knives. So a combination of the large elements and the very small ones dictates the minimum time increment needed to obtain accurate solutions.

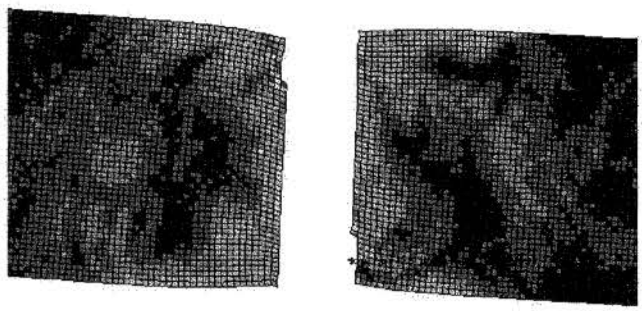


Figure 13. Slit Edge Cross Sections of the PET Film Including Shear Mode of Failure Only

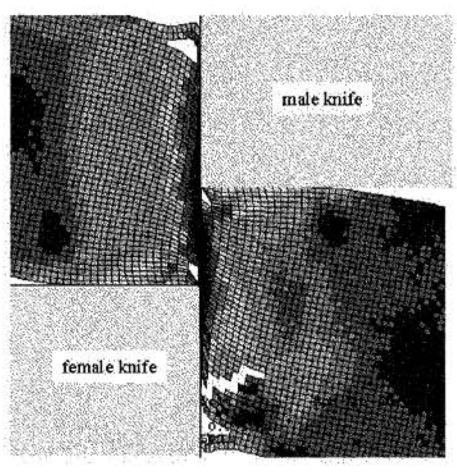


Figure 14. Slit Edge Cross Sections of the PET Film Including Tearing Mode of Failure Only

Mass scaling is a procedure used to reduce the solution time of the simulation. It consists of increasing artificially the mass of the critical elements, the smaller ones, so that the minimum stable time is also increased. The stability limit for a model is is defined as (Abaqus Manual, 2003)

$$\Delta t = \frac{L^e}{c_d}; \quad c_d = \sqrt{\frac{E}{\rho}} \qquad \{8\}$$

where L^e is the characteristic element length, c_d is the dilatational wave speed of the material, ρ = material density, and E = elastic modulus. Therefore, the smaller element densities increase but the total mass of the model does not change significantly and the results are still valid. This technique was used in this work successfully. Simulation times were reduced from hours to minutes using this feature.

Mesh refinement was accomplished with special attention to element size. Figure 15 shows a mesh with the same level of refinement as in Figure 11; however the area with the finest resolution is significantly smaller and the resultant slit profile is quite different from the one in Figure 11. This is due to the fact that damage methods are based on a maximum limit of energy density, large elements will tend to reduce this density which makes them more resistant to failure.

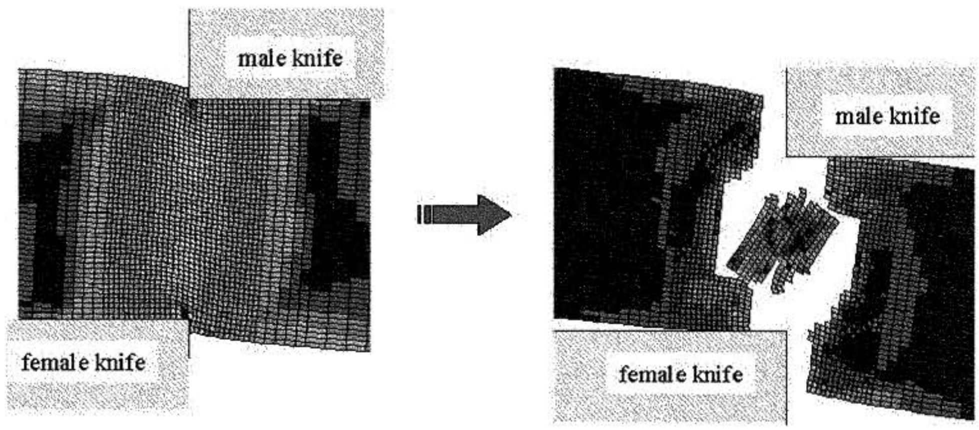


Figure 15. Von Mises Stress and Slit Edges for a PET Film Using a Too Small Finer Area in the Cutting Zone

Adaptive techniques are frequently used for modeling of slitting, cutting, forming, and blanking processes. Even though the commercial finite element package used, Abaqus (2003), supports adaptive meshing, this feature was not used to obtain the results shown in this work. Some simulations were run with this feature but results were not highly affected.

Another feature often used by analysts is element deletion. This is used to simulate the fracture of the material. The material is considered broken and the element is removed from the mesh when a certain variable reaches a threshold value. However, when this feature is used, part of the mesh may overlap some other part and the simulation reaches a physical inadmissible situation, as shown in Figure 16. An observation of Figures 11 and 16 shows the different edge morphology obtained if elements are totally removed of the model and contact conditions are not defined properly. In this work this situation was avoided by using a special condition that removed tensile and shear stiffness of the broken element but retained the compressive stiffness.

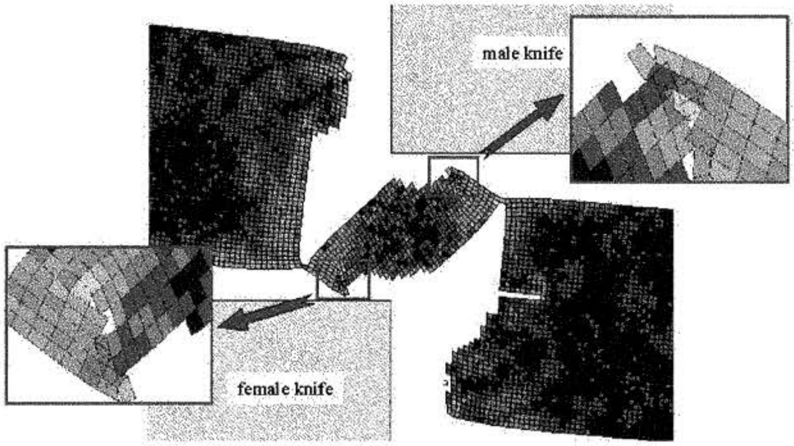


Figure 16. Mesh Overlapping When Element Deletion is Used

CONCLUSIONS

A finite element simulation of the slitting process of magnetic tapes was performed. The model simulated the slitting of the PET tape that is the supporting film of the magnetic coating. This is a preliminary step to the more complex modeling of the whole system that will include the multilayer structure composed by the coating and the substrate. Also, a three dimensional approach will be developed to represent more accurately the three dimensional nature of this process.

A damage failure criterion was used to determine when the material is broken. This approach requires dense meshes to obtain convergence of results. A mesh sensitivity analysis was performed and a reasonable mesh resolution was found for convergence. During this process it was found that there is a strong dependence on the material properties. A good evaluation of the failure modes and their threshold values was found extremely important.

Two main modes of failure were considered, shear and tearing. An approach formerly used for metal blanking was used to obtain threshold values for shear failure. It consists of performing a tensile test and recording some variable values at failure (maximum strain in this work); then the tensile test was simulated using a numerical model and values of the failure criteria at breaking were obtained (maximum equivalent plastic strain in this work). These values were the threshold values used in the slitting simulation. Tearing critical values were obtained from a slitting simulation and correlating pressure values with maximum stress at failure.

The slitting model simulates reasonably well the slitting process and the final morphologies captured several of the main features of the actual slit profiles. Differences are attributed to two-dimensional limitations of the model and the need of more accurate critical values of failure. It was found that convergence strongly depends on the failure modes considered and critical values used in the simulations. The following modeling issues were also discussed: element deletion, mesh refinement, adaptive meshing, and mass scaling.

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