DETERMINATION OF VARIATIONS IN CERTAIN MECHANICAL PROPERTIES ACROSS THE WIDTH OF A FINISHED PRODUCT OF POLYPROPYLENE WEB

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1986

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
May, 1989

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ACKNOWLEDGEMENTS

I wish to thank Dr. Delcie Durham for all patience and help she has given me during the creation of this thesis. Also, many thanks to Dr. Lowery and Dr. Good for their serving on my graduate committee and the invaluable information they provided.

To my assistant, Dusty Pierce, go my deepest appreciation for the many hours of testing she performed. I wish to express my sincere gratitude to Craig Fuqua and David Davis for their help in proof reading and use of the printer. Without them, this study would have been much more difficult.

To my grandmother, Genevieve Allen, who was my source encouragement and support, my deepest thanks.

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CHAPTER I

INTRODUCTION

A web is a long continuous film of material with its length much greater than its width or thickness. Used in most high production rate plants, webs can be any material, from paper to steel, that can be processed on a continuous basis. This rapid handling of material benefits the user by reducing time of production, but the web form can sometimes cause serious problems.

Out of plane deformation of the web, e.g. waves, can ruin the finished product, costing the producer untold dollars in not only time but material. If some way can be determined to predict when waves occur, then methods of prevention could be investigated. Some base information has to be established before one can begin to predict such a complicated instability.

The aspects of the web that should be investigated include: yield strength, Young's modulus and anistropy. Usually, averages of these values are reported, but local values are also needed to determine how processing is affecting the web's properties. A profile of these properties across the width of the final product could provide useful information on the local attributes that may lead to waves and other instabilities.

It is proposed that the processing may cause variations across the web and that under certain conditions in handling or winding, these may be extremely harmful to the final product. This probe determines what variations in mechanical properties across the width of a finished product of web exist and develops techniques to measure as many of these variations in a static testing mode as possible to help prevent disastrous results. Once the techniques have been established and data is obtained, methods of presenting the information in a useful manner will be explored. Anistropy, local mechanical properties, and other parameters will be investigated to ascertain their effects, if any, on the onset of wave formation in association with the biaxial orientation process.

CHAPTER II

BACKGROUND

Material properties of polypropylene and polyester vary with respect to the history of their processing. Young's moduli of polypropylene range from 100 to 575 ksi [19]. The Young's moduli for polyester range from 280 to 3,500 ksi depending on the type of reinforcement. The maximum yield strengths are 4.5 to 5.4 ksi and 23 ksi for polypropylene and polyester, respectively [19].

"The glass transition is associated with the amorphous phase of a polymer and occurs at a temperature Tg at which segments of the main chain become mobile" [2]. Polypropylene is brittle below this temperature before the biaxial orientation is performed. The range of glass transition temperature for polypropylene is -30 C to 20 C, depending on tacticity and thermal history [2]. Polyester's glass transition ranges from 73 C to 81 C [19].

Biaxial orientation is the process that produces equal or balanced material properties in two perpendicular directions [21]. In polymers, this is achieved by heating the material above the glass transition temperature (to allow greater ease of chain disentanglement and slippage) while stretching in the MD until the desired MD modulus and yield strength are obtained. Then stretching the material in the CD is utilized until the desired MD and CD properties are equal. This stretching process is akin to work hardening, also known as strain hardening in metals. As the polymer is stretched, higher values for the properties are achieved (see figure 2.1). "Strain hardening continues by molecular alignment (sometimes called cold drawing) up to the fracture stress" [22]. From a random orientation, the polymeric chains are aligned approximately parallel to the applied stress [8]. This alignment brings the chains closer together where mutual attraction increases, especially when the chains are polar or symmetrical. As the stretching takes place, bond stretching or valence angle deformation also results. This is the elastic component of the biaxial stretching and is recovered when the applied stress is removed. Bond stretching, the viscous flow of molecular chains past one another, causes friction losses that cannot be recovered. All three molecular activities must be considered when determining the amount of overall elongation needed for the desired product. The main goals of the biaxial orientation process is to achieve molecular alignment of polymeric chains which increases strength, decreases brittleness and eliminates anistropy.

When dealing with polymers, viscoelastic effects must be examined. Viscoelasticity characteristics are between those of metals and viscous fluids. The models shown in

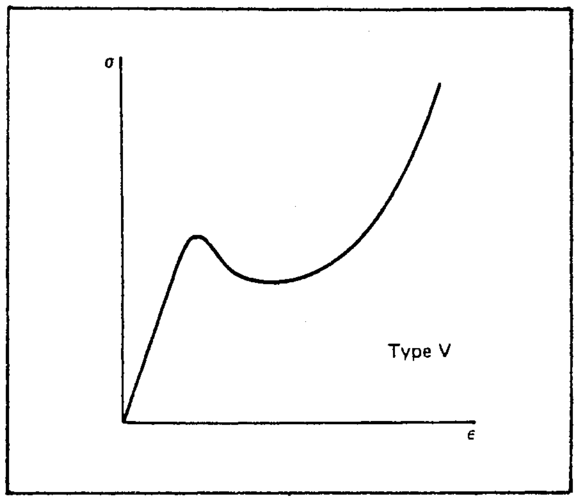


Figure 2.1 Stress-strain behavior usually found in crystalline polymers. [22]

figure 2.2 represent viscoelasticity. Keep in mind that this model is a highly simplified representation of the very complex polymer response. The springs, each with a different spring constant, in the models symbolize the elastic portions of the response which include bond stretching, crystallinity and chain rigidity [19]. Representing the fluid time dependent response, the dashpots each have a different viscosity. Figure 2.3 shows the standard time versus strain viscoelastic response. Stress and strain in this type of a model are time, rate of loading and temperature dependent. "Plastics have no true proportion limits" [19]. Most polymers have a curvilinear stress-strain curve. Depending on the polymer, test temperature and thermal history, length of the linear segment of the curve can vary greatly. Using moduli obtained from these linear regions, the prediction of deformation is very difficult. A polymer's yield point does not indicate the onset of "significant flow" as it does for most metals. The yield point is defined, in the case of polymers, in the general area of the "knee" in the engineering stress-strain curve. This "knee" is due to thinning of the cross-sectional area of the polymer in the tensile test. If true stress, based on instantaneous cross-sectional area rather than initial area, were plotted versus true strain, the "knee" would be much less defined. It is interesting to note that in general polymers' Poisson's ratios are much greater than those found in

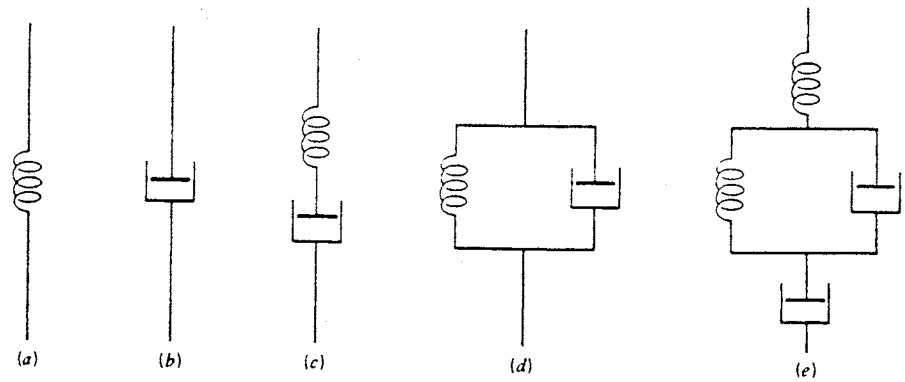


Figure 2.2 Mechanical analogs reflecting processes in polymeric solids: (a) elastic; (b) pure viscous; (c) Maxwell model for viscoelastic flow; (d) Voigt model for viscoelastic flow; (d) four-element viscoelastic model. [22]

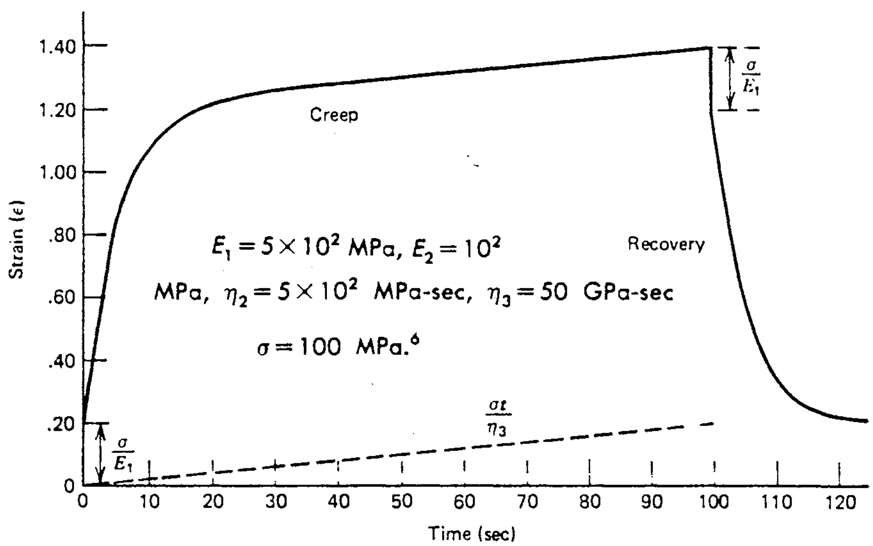


Figure 2.3 Creep response of four element model. [22]

metals resulting in much greater necking in polymers.

Figure 2.4 represents the Voigt model. At t=0, there is a step jump in stress due to the dashpot in figure 2.2 which appears to have infinite stiffness. As time progress from 0 to 100 seconds in figure 2.3, stress is held constant while strain continues to increase. This is called creep. "Creep curves generally show three continuous stages: a first stage marked by large and rapid initial deformation; a second stage where deformation continues at a relatively slow, constant rate; a third stage in which rupture occurs" [19]. At t=100 seconds, the strain is held contant while the stress drops in a stepwise fashion. Stress relaxation then ensues as strain is held constant. Stress relaxation can be approximated by:

$$\sigma(t) = \sigma_0 e^{-t/T} \qquad \text{...(1)},$$

where σ_0 is the initial stress before stretching is stopped, t is time and T is relaxation time defined by η/E. η is the viscosity and E is Young's modulus.

Detection of local thinning can be done with the use of circles printed on the surface of a deforming specimen. Figure 2.5 demostrates how changes in the circle as it becomes an ellipse can give information about thinning [21]. The major axis indicates the major direction and magnitude of stretching. The engineering strain, in the direction of the major axis, can be measured by noting the length of the major axis of the ellipse and comparing it to

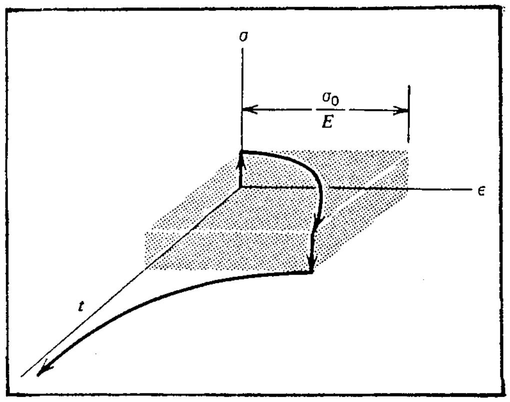


Figure 2.4 Voigt model's stress-strain diagram. [22]

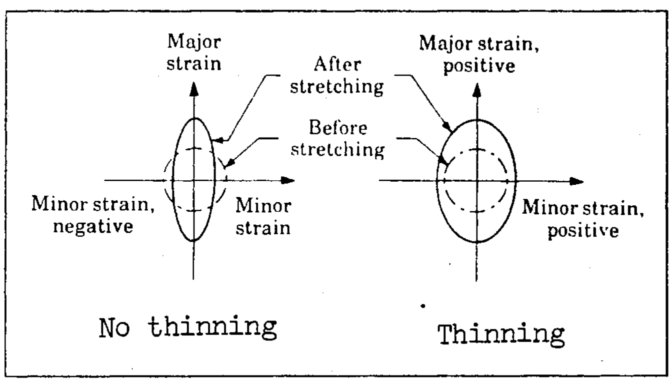


Figure 2.5 Ellipse deformation [21]

the major axis of the original circle. The same can be done for the minor axis and its direction, but where the major strain is always positive for the case of a tensile test, the "minor" strain may be positive or negative. In the tensile test, the minor strain is induced by the Poisson effect and the constancy of volume in plastic flow of a noncompressible material. If there is an area change from the circle to the ellipse then the thickness has changed. For example, if the area of the ellipse increases, the thickness must decrease to maintain the constant volume of the continuum. "This can be easily observed by experimenting with a wide rubber band" [12]. Notice when stretching the rubber band, an ellipse forms and the thickness decreases. If the continuum is to exist then constancy of volume must prevail.

Several methods of testing are available to obtain the needed mechanical property values. One method is optical. Using laser speckle interferometry, the in-plane elastic constants can be obtained [15]. The out-of-plane elastic constants are determined by conventional or holographic interferometry results and the Maxwell Relationships. Optical methods can only measure displacements and Poisson ratios. "Nevertheless, when combined with the necessary stress information (provided by other means), in-plane Young moduli and shear modulus can also be measured" [15]. Another method of measuring elastic constants is by acoustical means. Using ultrasonic waves, the constants can be determined by measuring the effects of the sound waves as they pass through the medimum in certain directions [12], [16] and [18]. This method can be used in dynamic testing, but the elastic constants are always higher than those produced by mechanical means. This is possibly due to the time involved in the two methods. In ultrasonic testing, there is very little time for viscoelastic relaxation to take place. Mechanical testing gives the material much more time for viscoelastic relaxation to occur. Mechanical testing, the last method examined for possible use, is accomplished by measuring extension, load applied and physical dimensions, from which a stress-strain curve is generated. The elastic contants and yield point can then be derived.

Waves are out-of-plane deformations. Several theories on their formation vary greatly. One theory is that the waves form similar to those in elastic columns in compression. Euler's formula [25] :

$$F_{cr} = \pi^2 EI / L^2 \qquad \ldots(2)$$

E is Young's modulus, L is the length of the column (the width in the case of films) and I is the moment of inertia of the cross section about the bending axis. Notice the critical force depends on E and geometry. In the case of thin films, a "critical" strain is caused by Poisson's effect. The tensile load applied to films causes a compression strain in the transverse direction that induces waves. It is possible that the strain that causes the waves is somehow related to the E, L, and I of equation (2).

The Von Mises stress defines the start of yielding. Von Mises stress is represented by

$$\sigma' = ([(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]/2)^{1/2} \qquad \ldots(3)$$

when a triaxial stress state exists where σ_1, σ_2 and σ_3 are the principal stresses [26]. Two specific cases can exist: plane strain and plane stress. Plane strain is where strain exists in two principle directions but not in the third principle direction. In the case of plane stress, the stress exists in two directions and does not exist in the third. Thin films under tension in a web handling process can be under plane stress. The above equation reduces to

$$\sigma' = (\sigma_1^2 - \sigma_1\sigma_2 + \sigma_2^2)^{1/2} \qquad \ldots(4)$$

for plane stress. Plastic deformation occurs when the von Mises stress exceeds Y (uniaxial yield stress of the material). The following is the relationship equation:

$$\sigma'^2 = Y^2 \qquad \ldots(5).$$

Figure 2.6 shows a 3-D stress element with stresses in the x, y and z directions with corresponding shear stresses. This is a triaxial stress state. The plane stress case is illustrated in figure 2.6. Notice there is no stress in the z direction. Figure 2.7 shows how one of the principal stresses relates to stress and shear. Figure 2.8 shows how a Mohr's circle, where stress is plotted versus shear for

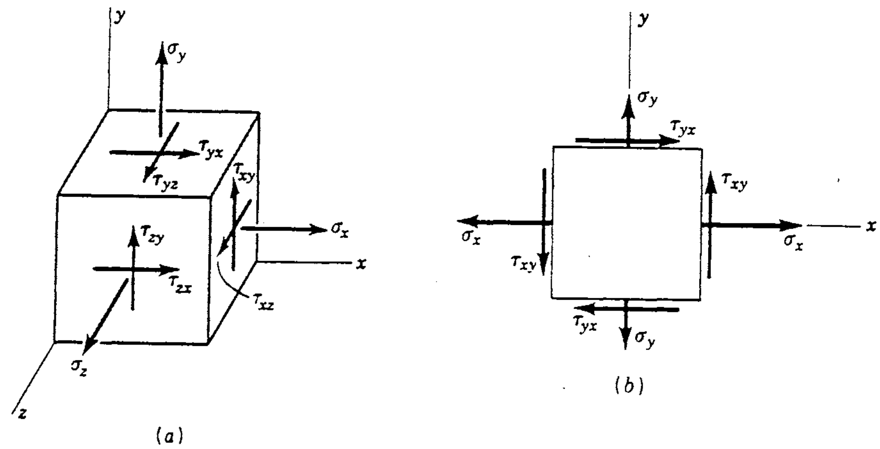


Figure 2.6 (a) 3-D Stress cube,
(b) plane stress. [26]

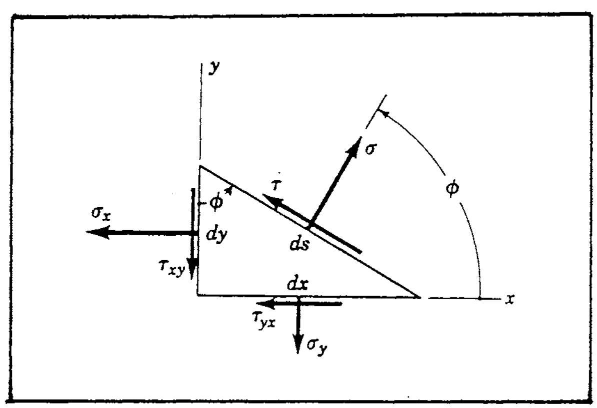


Figure 2.7 Relationships of stresses in 3-D stress element to principal stress. [26]

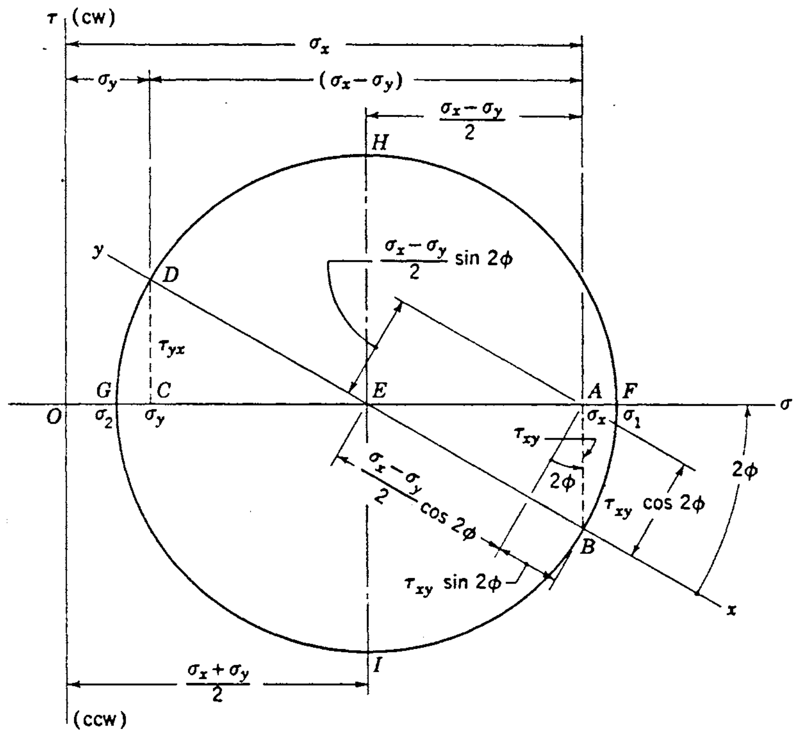


Figure 2.8 Mohr's circle diagram. [26]

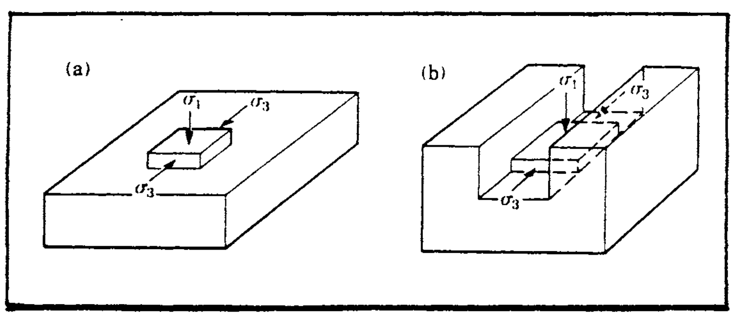


Figure 2.9 Two examples of stress
(a) Plane stress,
(b) Plane strain. [26]

the stress element, is constructed to yield the principal stresses. The principal stresses are those points of Mohr's circle where the stress is at its maximum and minimum. Plane strain is compared with plane stress in figure 2.9. Figure 2.10 shows Mohr's circles in various stress states.

Crazing can be an important part in the deformation of polymers. Yefimov, Bulayev, Ozerin, Rebrov, Godovskii and Bakeyev have done tests that show "crazing in polypropylene is accompanied by a considerable rise of polymer internal energy due to new surface created inside the crazes" [14]. They studied films of isotactic polypropylene 100 to 200 micrometers thick and 20 to 40 millimeters long at a relative elongation of up to 100 percent. The rate of deformation was 5 millimeters per minute. The samples were prepared by annealing oriented polypropylene at near its melting point. Using a microcalorimeter, they noticed heat was absorbed before crazes started forming. Small-angle X-ray scattering was used to detect crazing. A great number of crazes, 2.5×10^5 per centimeter, formed when the stress reached the "limit of forced elasticity", σ_f. After craze formation began, a "substantial" amount of energy was generated. "The energy stored in PP elongated to 100% amounts to 20-25 J/g" [14]. They concluded the heat dissipated was much less than the deformation energy so that the net internal energy increased during crazing. They also state that the change

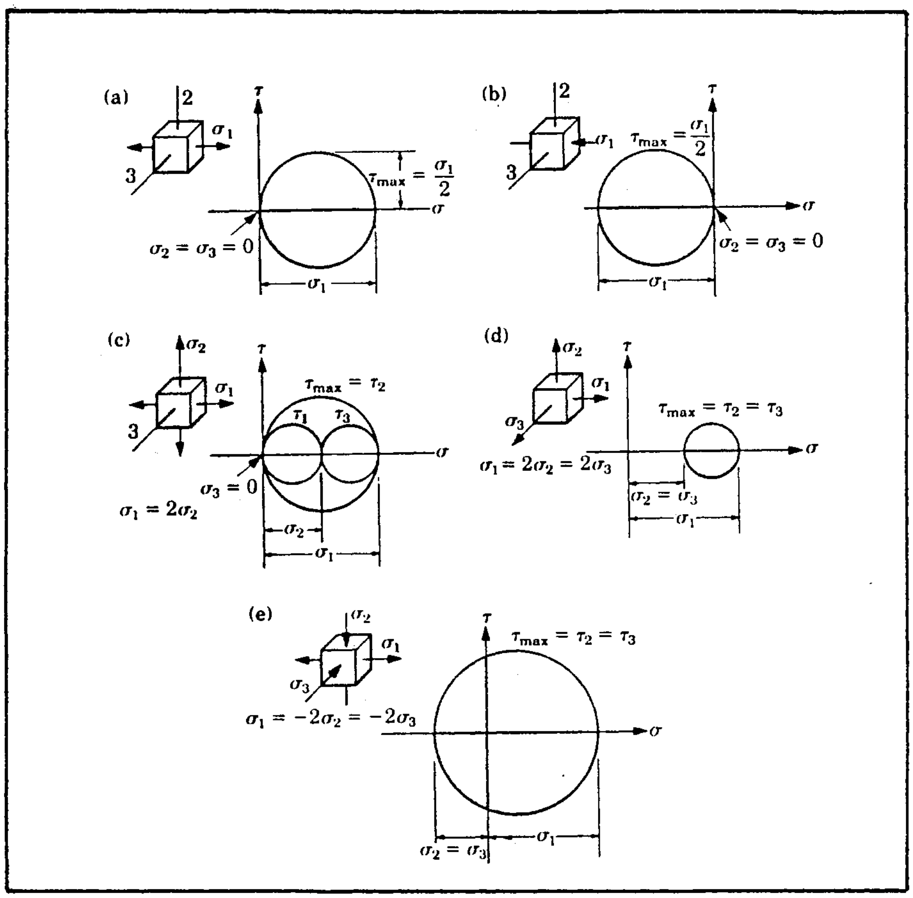


Figure 2.10 Mohr's circles for various states of stress.
(a) Uniaxial tension.
(b) Uniaxial compression.
(c) Biaxial tension (plane stress).
(d) Triaxial tension.
(e) Biaxial compression with tension. [26]

in internal energy increases linearly with deformation.

Jenkins and Jenkins studied the induction of a prefered orientation in a liquid crystal co-polyester by extrusion and drawing [10]. They found that the "rod-like" molecules of co-polyester tend to align themselves along the fiber axis during hot stretching following extrusion. But what they discovered later has a great importance, the stiffness peaked when the heat treatment was 170 C. At temperatures greater than 170 C, the preferred orientation would decrease. In other words, the stiffness in the preferred orientation would drop. They concluded that the mechanical properties are critically dependent on thermal and strain history.

In this study, the tentering process takes place at elevated temperate as well. The tentering region may be effected by this phenomenon.

CHAPTER III

EXPERIMENTAL

All experimentation was performed using an Instron tensile testing machine in correlation with specially designed grips and a load cell-tranducer-plotter arrangement (figure 3.1). Set for a constant displacement rate of 0.5 inches/minute, the Instron extended the sample positioned between the two roller grips. Each grip consisted of a steel bar bounded by "channel iron" supports. Down the length of the steel bar, a thin straight groove was cut at a depth of one half of the diameter of the bar. This groove is used to prevent the sample from slipping from the grip. Through the "channel iron" support and the steel bar, holes were drilled and removable bolts fitted stopping the bar's rotation during testing and allowing easy sample mounting and removal. The load cell-transducer-plotter set-up recorded voltage, proportional to load, versus time once testing began. System calibration was three-fold: first, measuring actual displacement of the Instron versus time; second, affixing a known load to the system and noting plotter displacement; third, comparing real time against plotter pin movement (see appendix for calibration results).

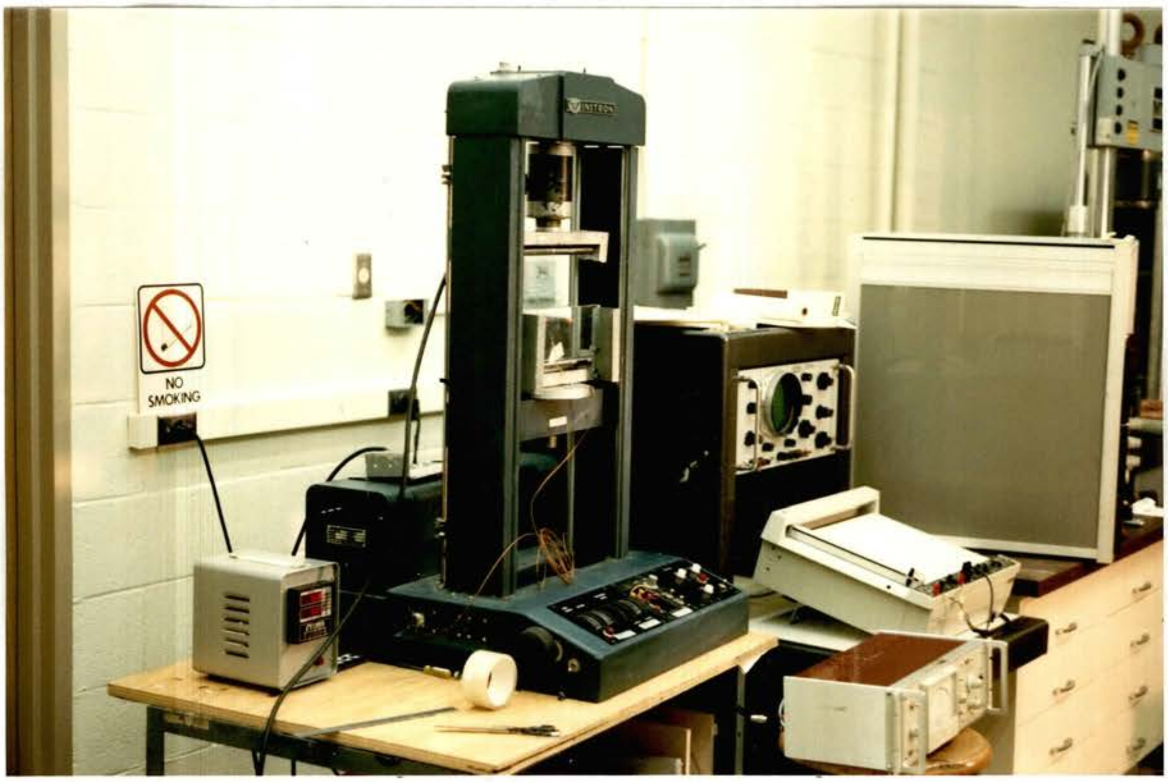


Figure 3.1 Instron and associated equipment.

The heating of samples to a specific temperature and maintaining that temperature (figure 3.2) during testing was achieved by the use of strip heaters, a Plexiglas heat reflector and a PID (Proportional Integral Derivative) controller (see figure 3.3).

Specimens of both polypropylene and polyester were tested. Polypropylene was taken from a "frozen" production line (figure 3.4) and samples were secured from sections of the finished product. Sampling along the length of the transverse direction orientation (TDO) (figure 3.5), provided information on the degree orientation or anistropy occurring as the polypropylene is being elongated in the cross-machine direction (CD). At ten foot intervals from the exit of the TDO, samples were cut in both the machine direction (MD) and CD to give data concerning change in anistropy as the material process attempts to approach desired biaxial material orientation. Specimens were also taken in the finished product across the width of the web to form a profile of data concerning uniformity (figure 3.6 & 3.7). Some samples were taken at a 45-degree angle to the MD to test biaxiality. Not knowing the past processing history of polyester and its size limitations, tests were run only in the MD. Experiments were also done at elevated temperatures to observe changes in material properties at different temperatures (figure 3.8).

Preparation of samples followed this format. First, the specimens were cut with a new razor blade after the

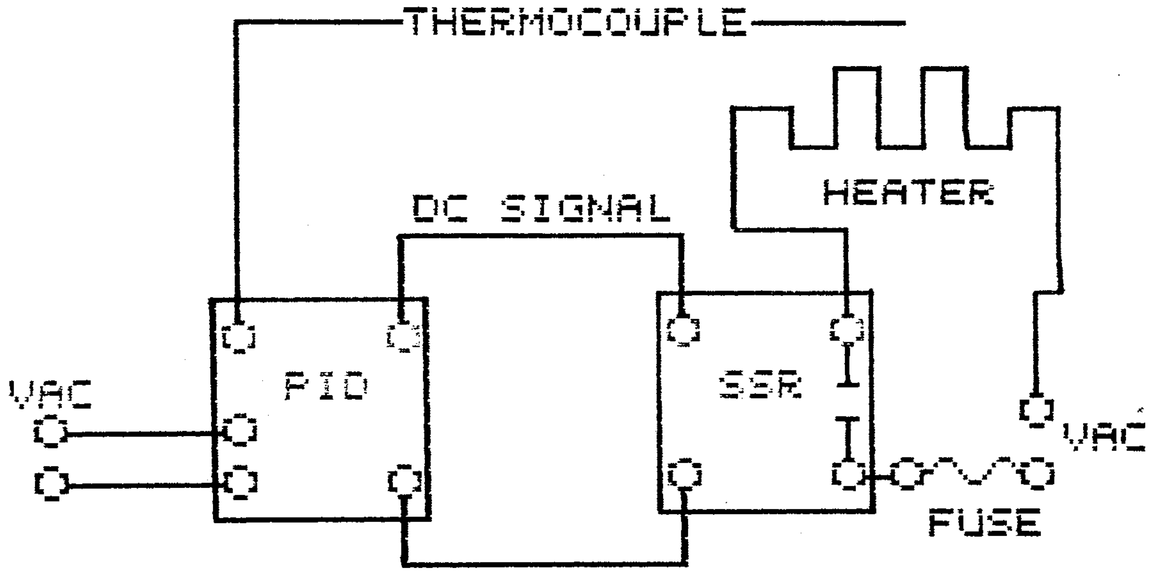


Figure 3.2 Schematic of PID controller and heater set-up.

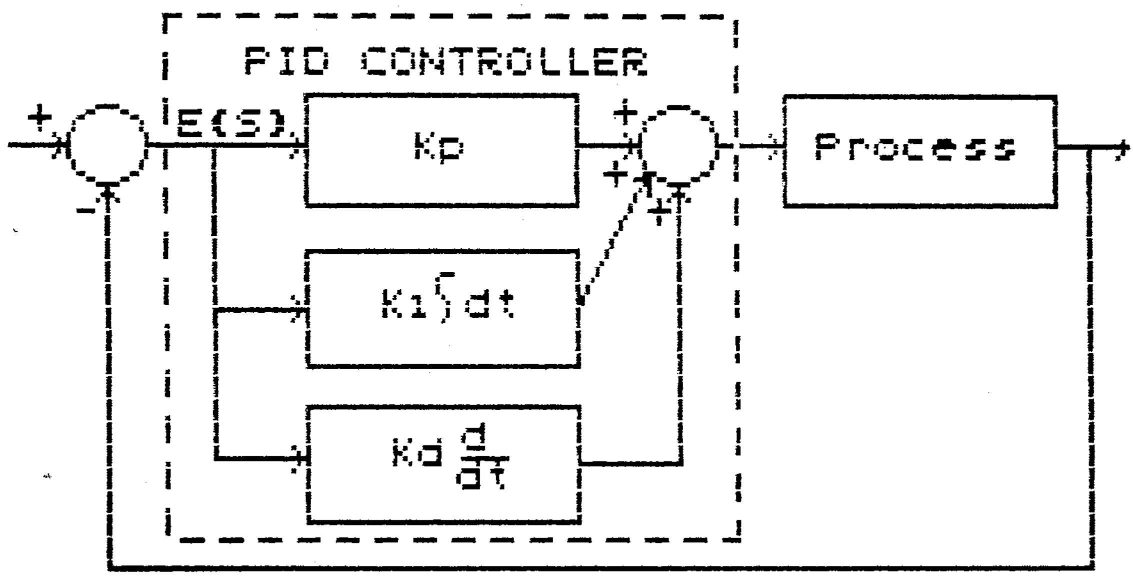


Figure 3.3 PID Controller.

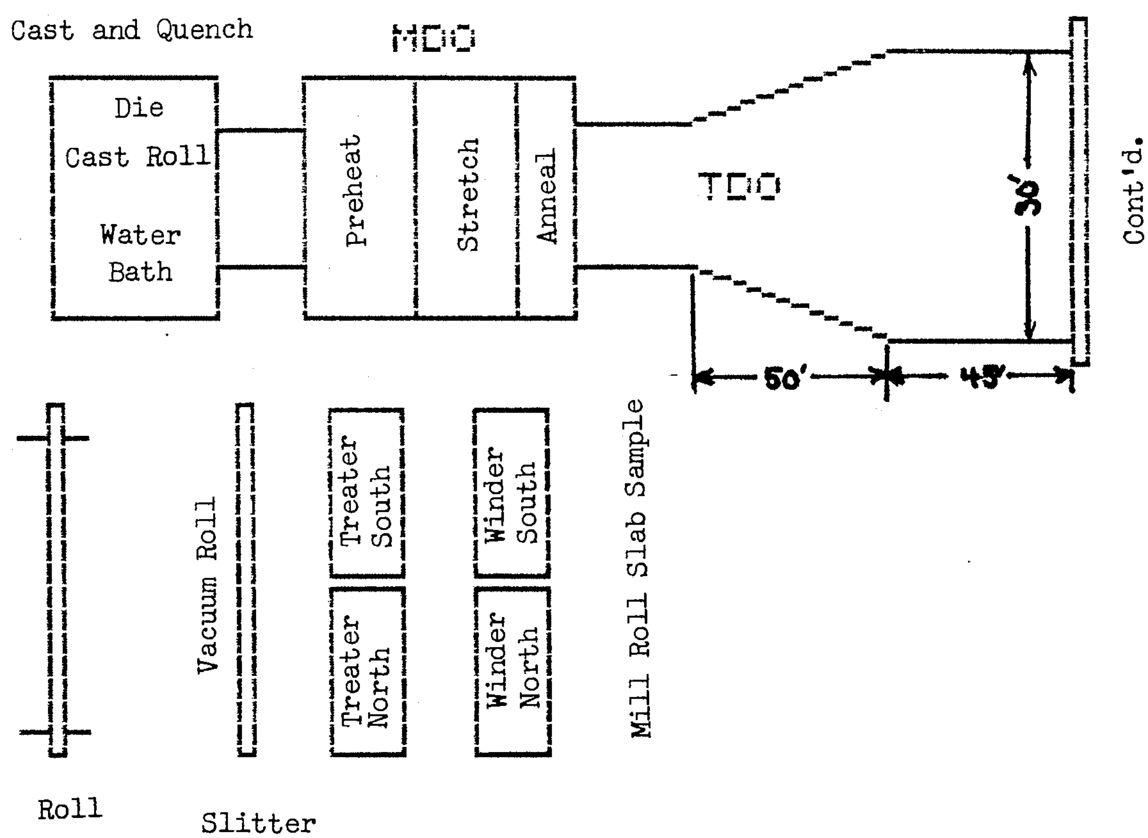
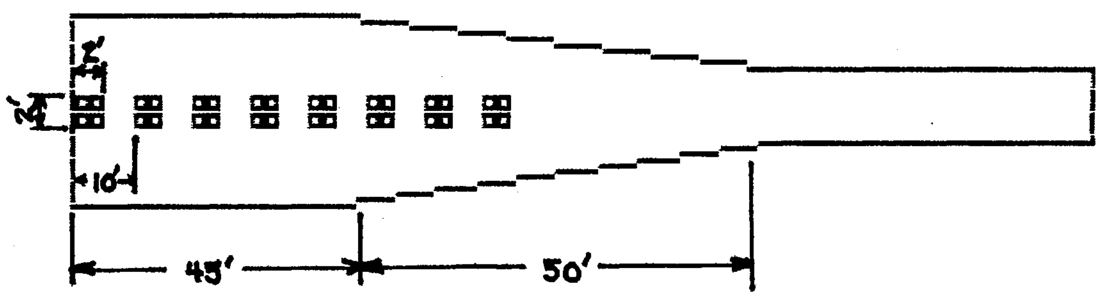


Figure 3.4 Polypropylene production line



8 SPECIMENS (4-MD, 4-CD)

Figure 3.5 TDO Sampling

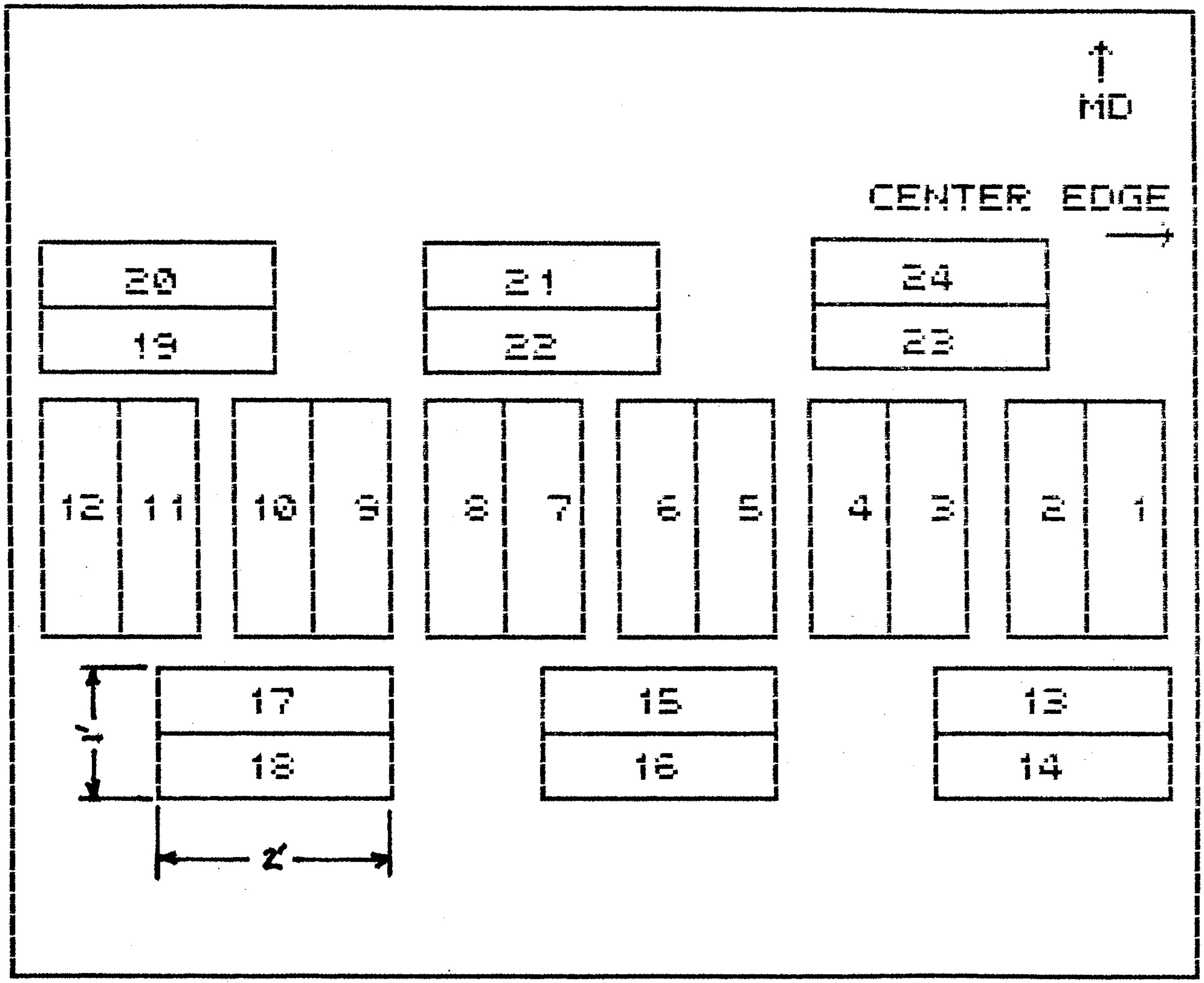


Figure 3.6 Across the web sampling between winder and treater.

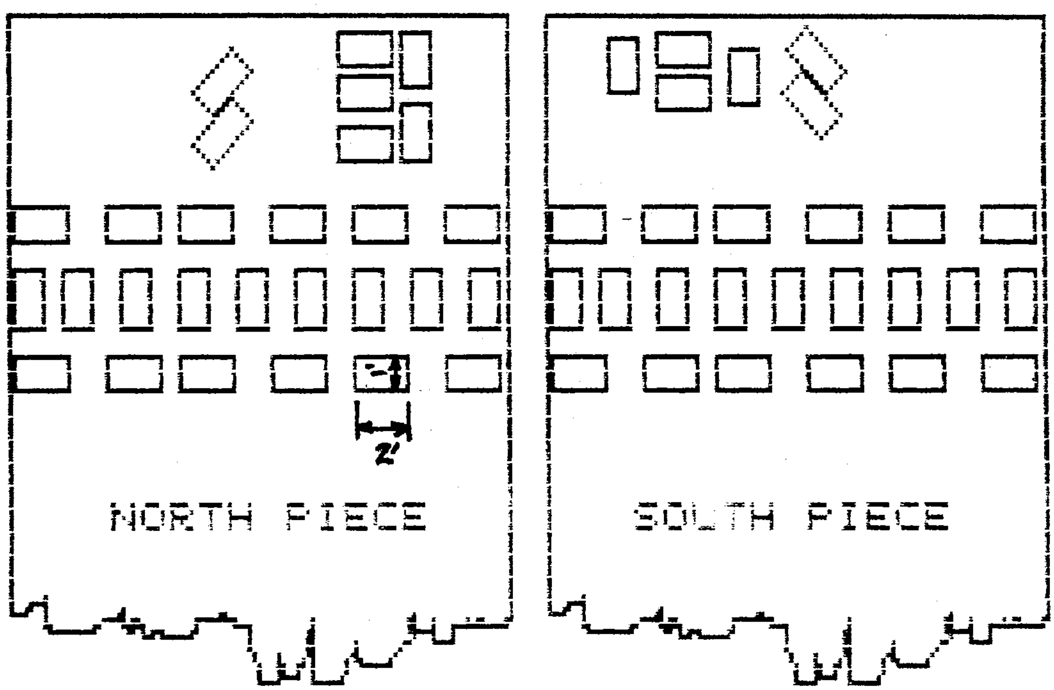


Figure 3.7 Sampling between winder and treater.

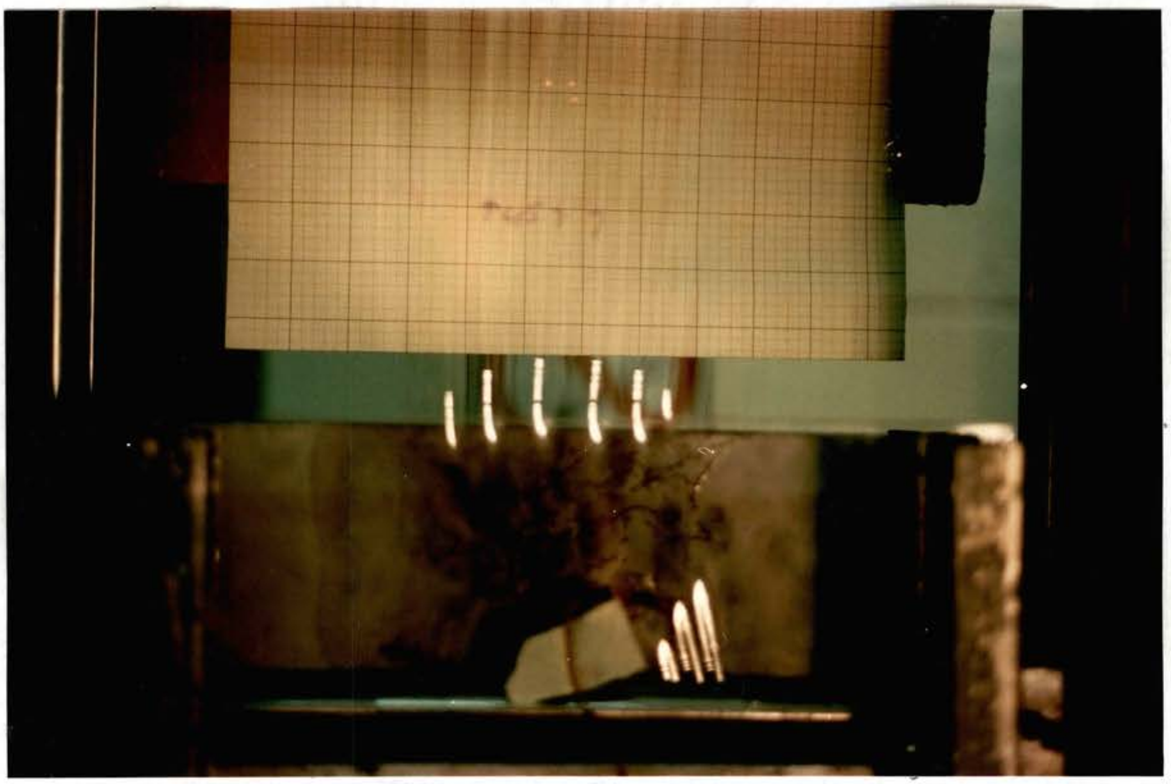


Figure 3.8 Polyester specimen being tested at an elevated temperature.

appropriate section and direction of the material was marked with a permanent marker. Care was taken not to damage the integrity of the material's edge. Specimen size was typically 6 x 24 inches, although final size may be altered slightly to remove sharp edge stress concentrations. Second, the 6 inch ends are covered with 1/4 inch of masking tape promoting sample mounting into grip groove. Third, using a permanent marker and a circle template, 1 inch diameter circles are drawn onto the surface of the specimen, again being careful not to damage the material's surface.

The samples are mounted by inserting the taped ends into the bar's slot and then rolling the bar until the specimen has been wound around approximately three times. (Note: on thicker materials, greater than 2 mils, adhesive can be applied onto the bar and specimen before wrapping to ensure traction as long as the adhesive is much stiffer than the sample.) This is repeated for both top and bottom grips. When winding the bar, care is taken to leave the sample in an unloaded condition. The bolts are then inserted through the "channel iron" and bar to prevent bar rotation.

Following mounting and before Instron start up, some pre-test data is recorded (see appendix for test blank) information such as width, gage length, test temperature, etc.

Testing begins with the starting of the Instron and the plotter at the same time. As the test progresses, ellipse dimensions, both major and minor axes, are measured and recorded on the plotter curve marking the location where the sampling was taken. Figure 3.9 show a typical MD oriented test with deformed ellipses. Width changes are also recorded in a similar manner to that of the eclipse data. Figure 3.10 shows typical test data. The onset of wave formation is noted by marking on the plotter curve as well. (Note: onset of wave formation was very loosely defined as that point in the test when out of plane deformation occured when all waves were no longer touching the grips. If the waves were still in contact with the bar then waves could be caused by a slack edge due to some minor misalignment.) Tests were taken either to failure or to two-thirds of the plotter's overall time range, then the Instron was stopped. If the sample had not failed, the plotter was allowed to run to its full time range, which recorded stress relaxation information on the sample.

Post-test data included final ellipse and minimum width dimensions in an attempt to measure elastic recovery after the sample is completely unloaded.

The following table shows number of tests run and their general location in the production line:

TABLE I

NUMBER OF TEST RUN

Material	Orientation	Number of tests
Polyester	[FP] MD	4
Polyester (300-D)	[FP] MD	8
Polyester (400-D)	[FP] MD	2
Polypropylene	[FP] MD	22
Polypropylene	[FP] CD	22
Polypropylene	[FP] 45	8
Polypropylene	[TDO] MD	30
Polypropylene	[TDO] CD	29

FP : Final Product
TDO: Transverse Direction Orientation taken every ten feet down the length.

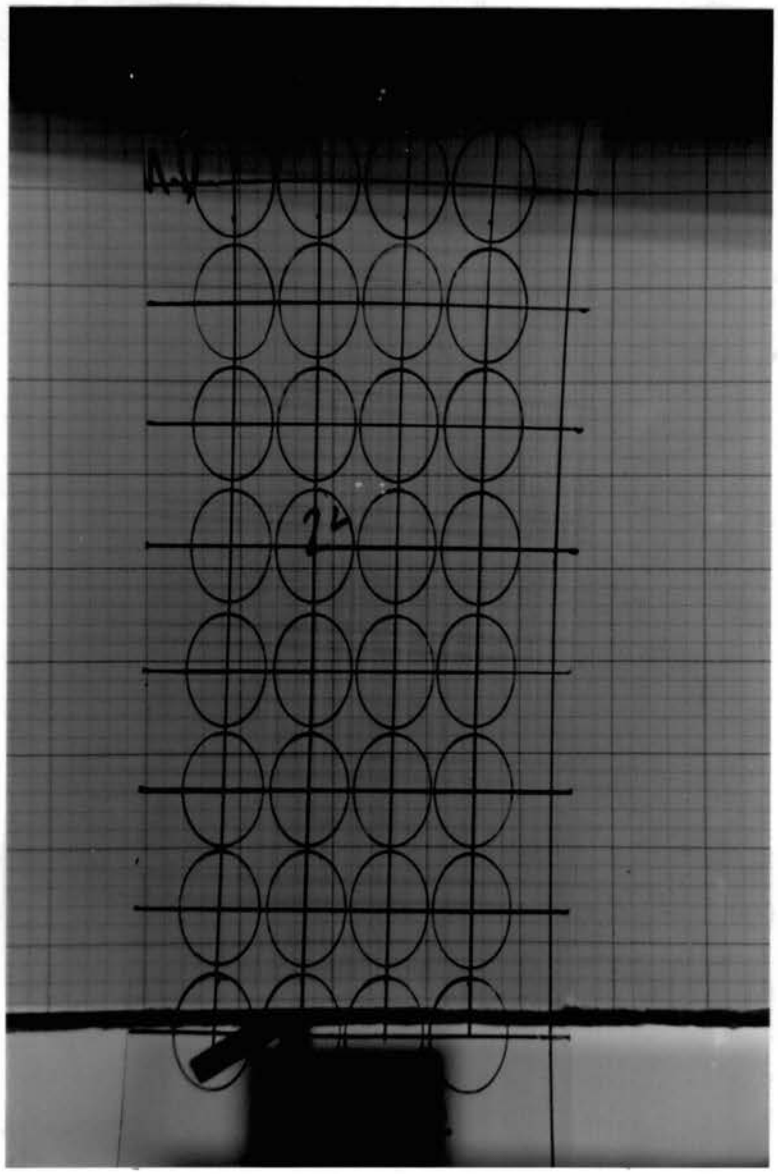


Figure 3.9 Polypropylene sample cut in the MD being tested at room temperature.

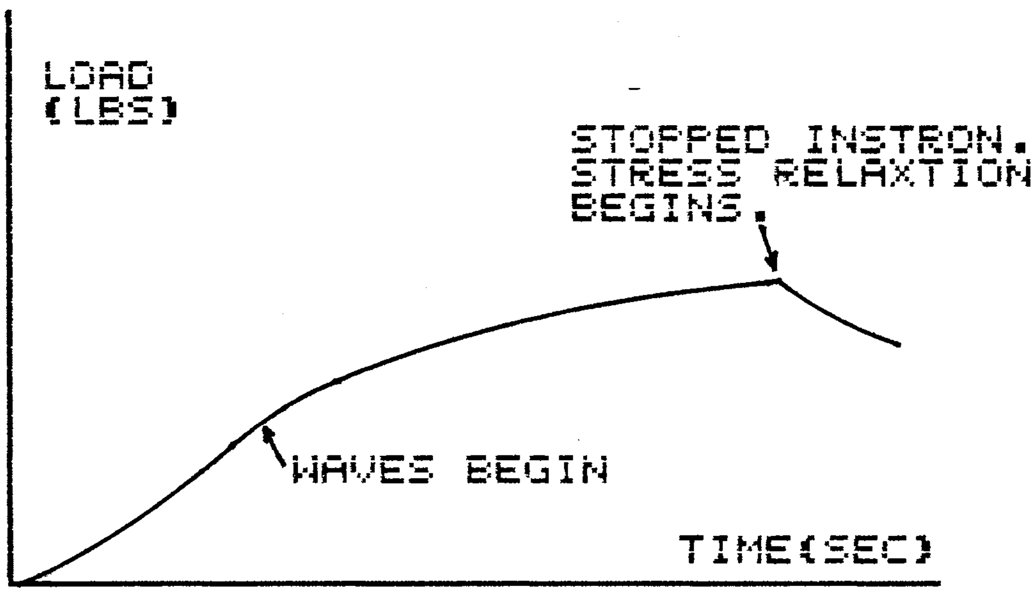


Figure 3.10 Typical time vs load plot for polypropylene in MD.

CHAPTER IV

EXPERIMENTAL RESULTS

Figures 4.1 - 4.3 show the MD specimen as it undergoes testing. Increasing length at a constant rate, the specimen deforms until failure. As it deforms, the test set up generates a load versus time plot, figure 4.4. The shape of the curve is typical for all of the tests that were run in the MD, regardless of the location of the sampling. The testing of the CD is shown in stages of deformation in figures 4.5 - 4.7. CD curves all have similar load/time curves as recorded in figure 4.8. Points were entered from the load/time curves into a computer program (see Appendix C) that converted the raw data into a more useful form. The beginning and ending points of the linear elastic regions were entered to establish Young's modulus for the test. Using the load and time points at which the test became plastic, the yield point was established. Points from the load/time plot were entered to determine the stress at specific strains. Neck dimension data was entered to yield stress information, as well. If the test specimen provided stress relaxation information, the appropriate load and time points were entered to yield relaxation time. After unloading or

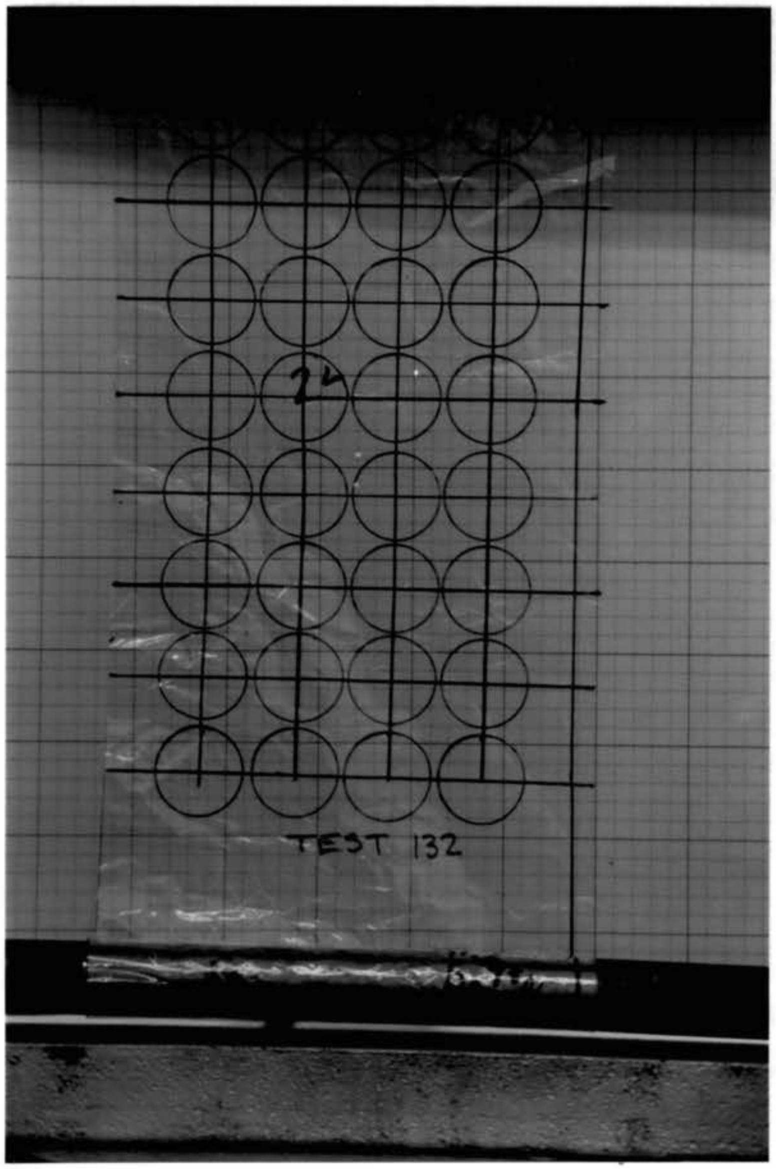


Figure 4.1 Polypropylene sample with MD orientation awaiting loading.

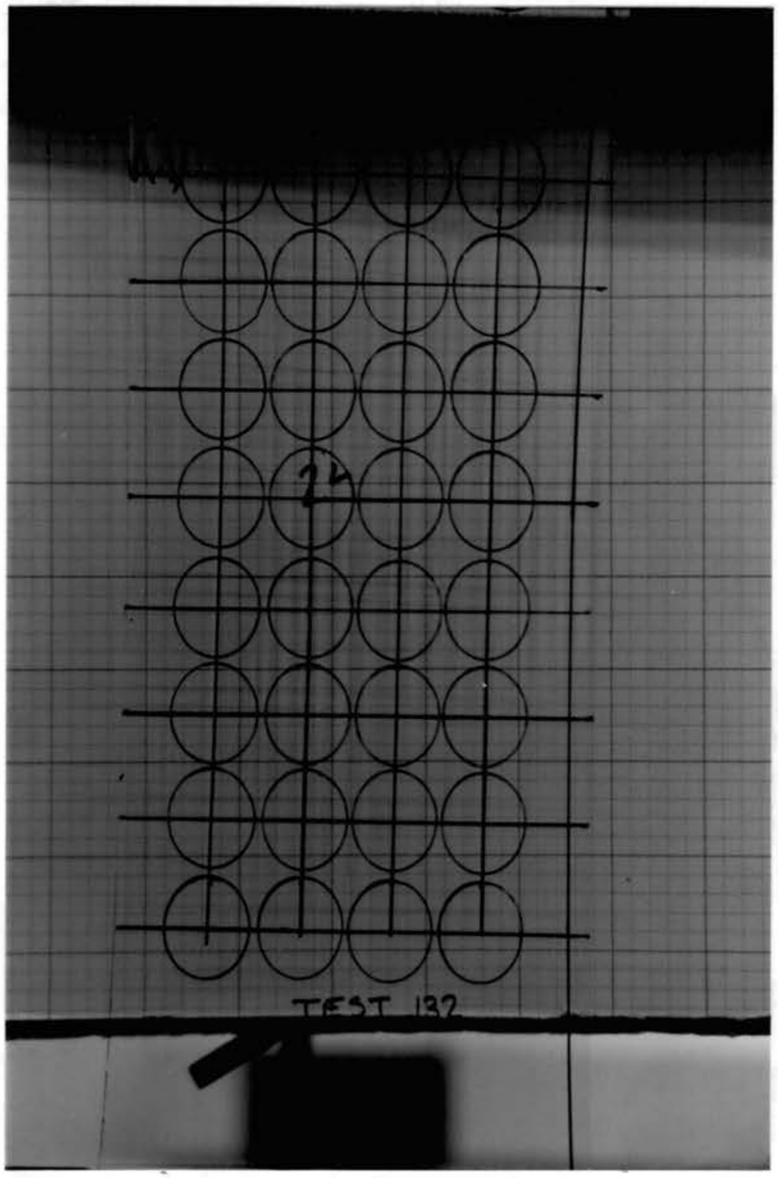


Figure 4.2 Polypropylene sample with MD orientation under tension.

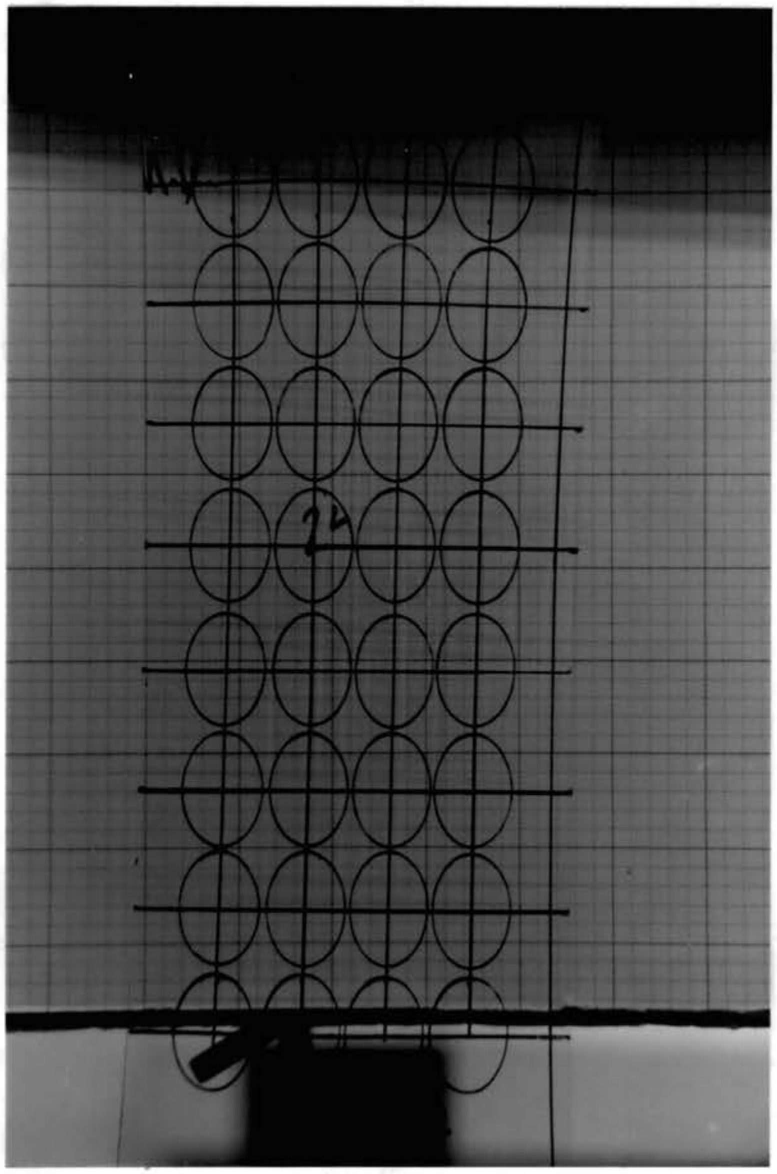


Figure 4.3 Polypropylene sample with MD orientation before failure.

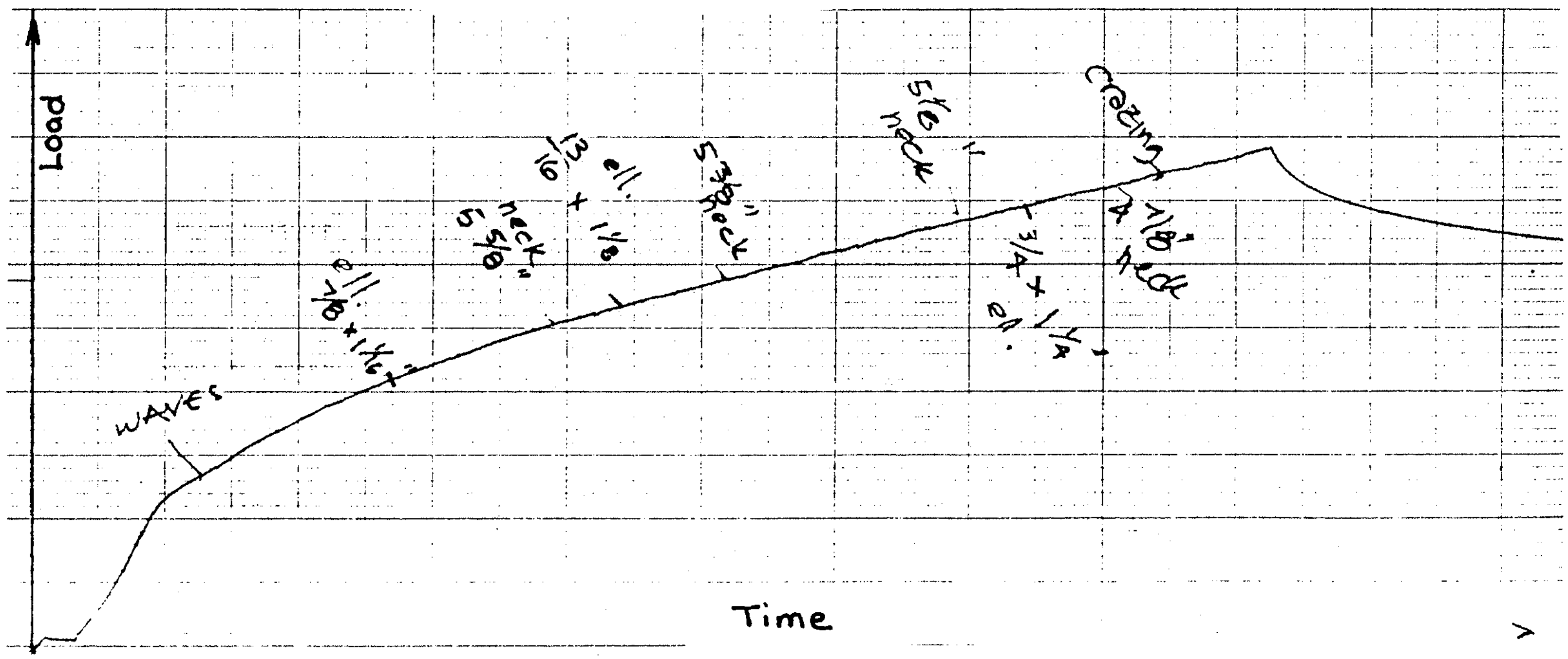


Figure 4.4 Typical MD test plot of time vs load.

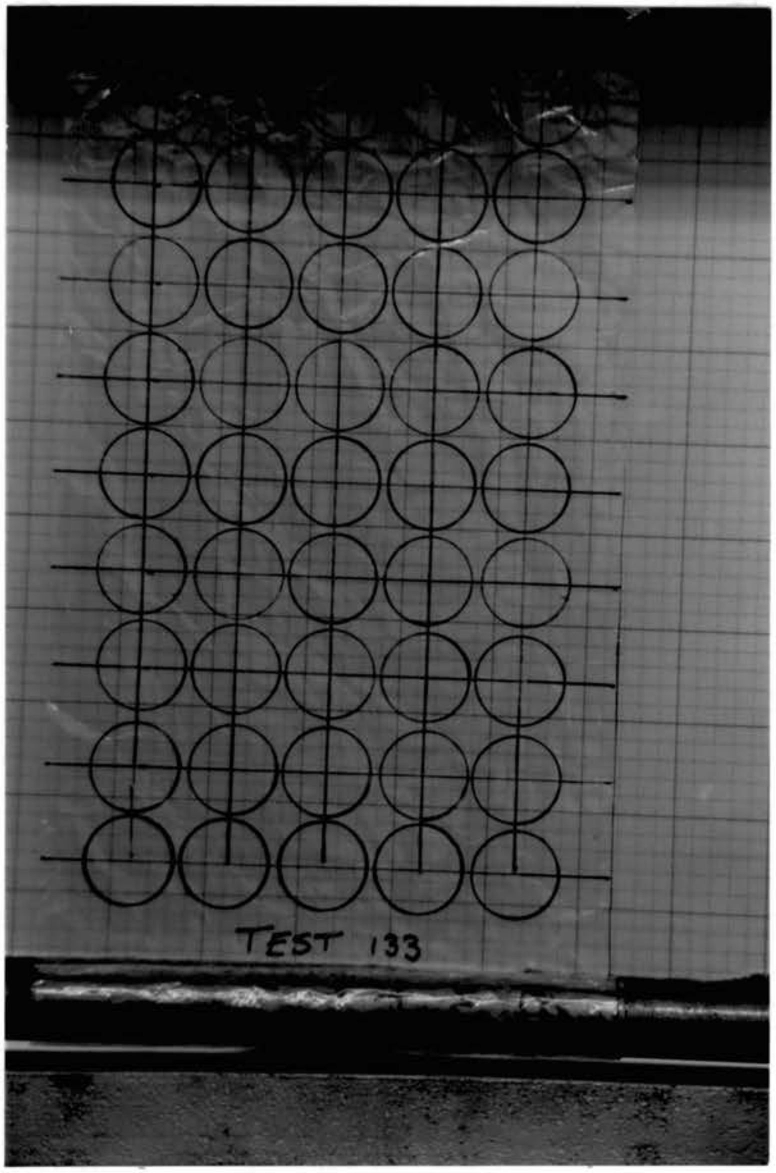


Figure 4.5 Polypropylene sample with CD orientation before loading.

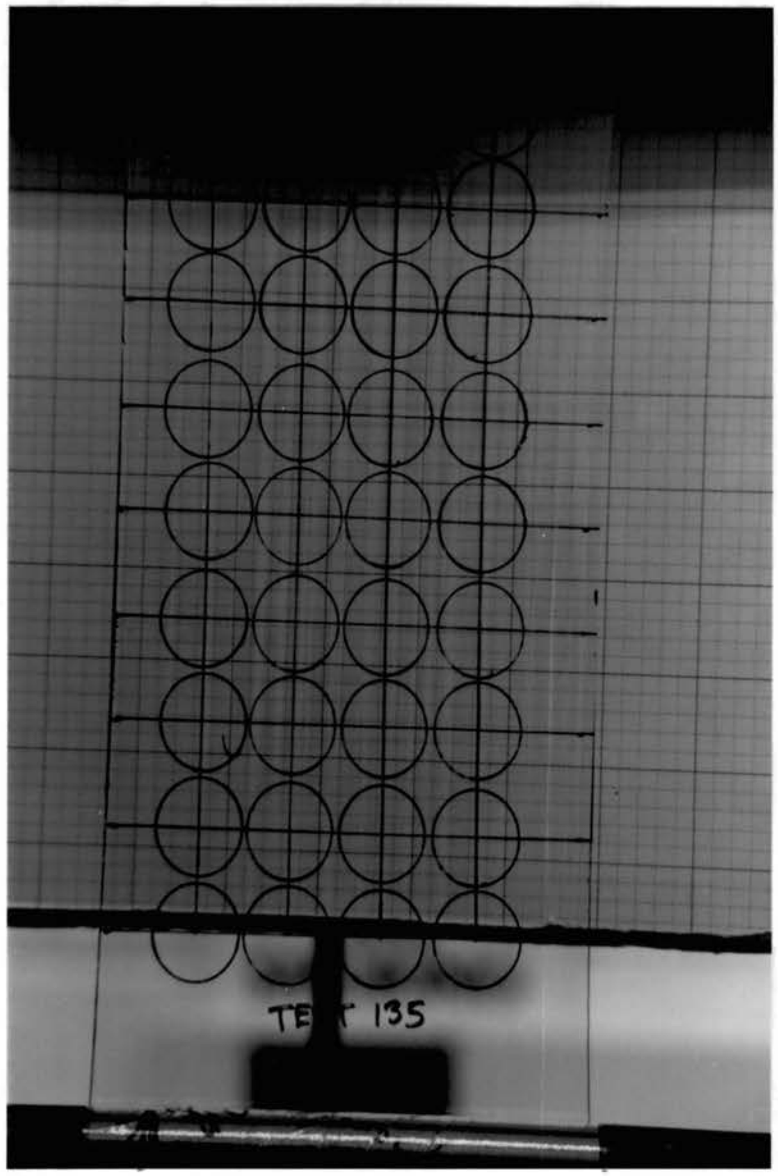


Figure 4.6 Polypropylene sample with CD orientation under tension.

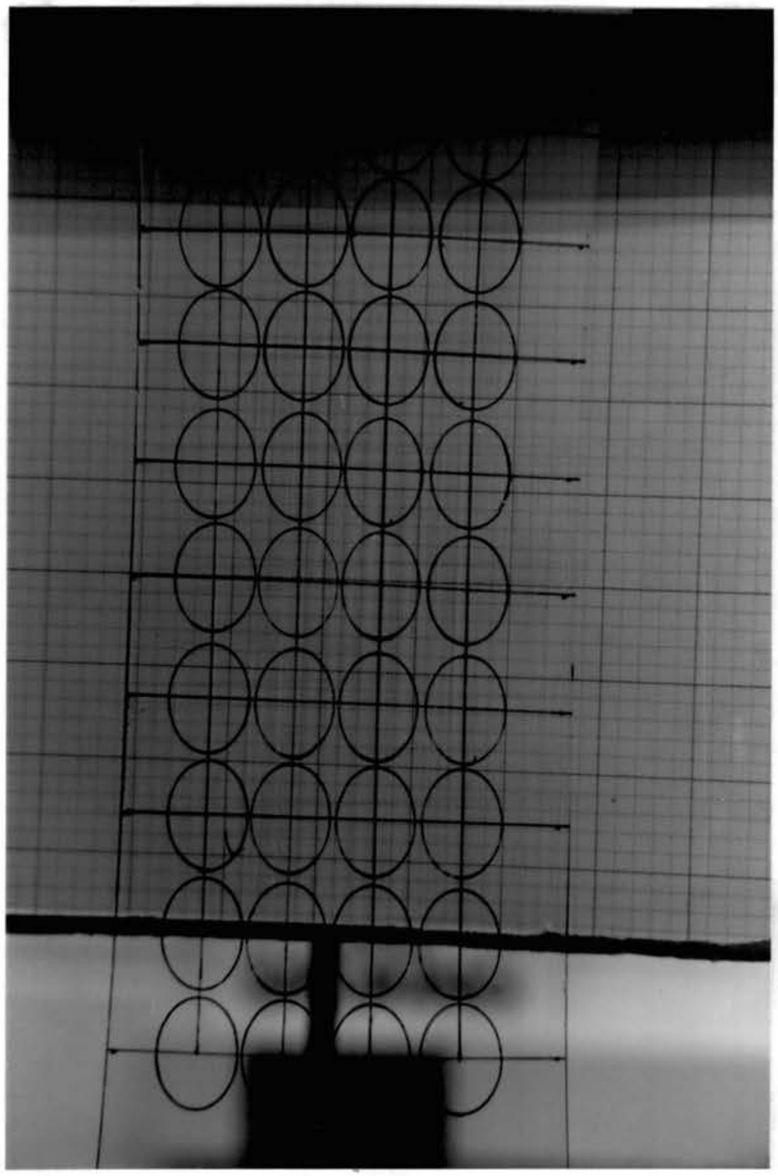


Figure 4.7 Polypropylene sample with CD orientation before failure.

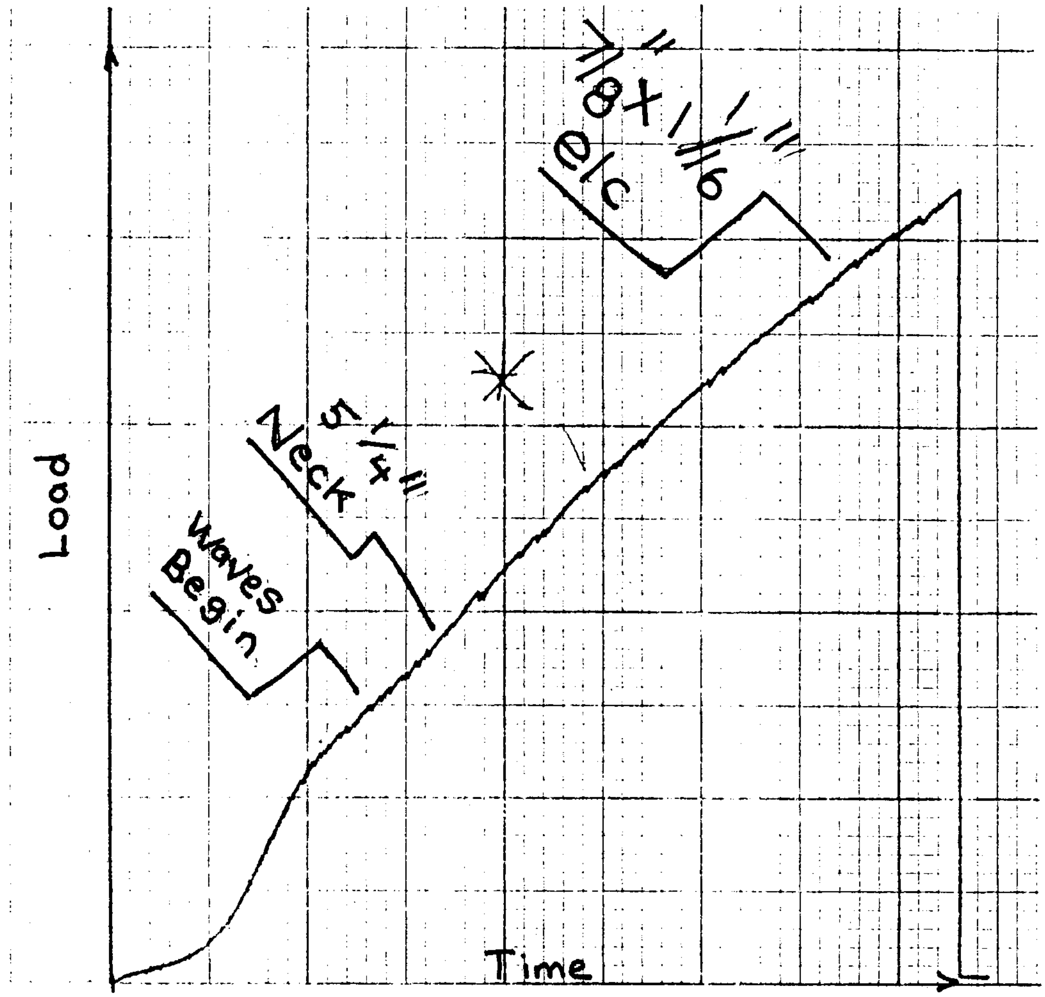


Figure 4.8 Typical CD test plot of time vs load.

failure, final neck and ellipse dimensions were recorded. Using this data and the last neck or ellipse information, the program would yield elastic recovery. See Appendix C for the program's output from the above points.

Normalized moduli versus distance in feet from the center (figure 4.9) were plotted in bar chart form to show a profile of changes across the final product of polypropylene. The moduli were normalized with respect to thickness to aid comparison. Figure 4.10 is a plot of Emd/Ecd versus distance in feet from center. This plot of anistropy aids in the relationships between the MD and CD moduli. Plotting yield point, also normalized with respect to thickness, versus distance from the center in feet demostrates another anistropic aspect of the final product, figure 4.11. To understand how the final product came to be as it is, normalized moduli, MD and CD, were plotted down the length of the TDO. Emd/Ecd down the length of the TDO was also charted to help show how the biaxial process progressed (figures 4.12 and 4.13).

Dr. Good entered some of the information from one of the 45 degree tests into a finite element code and plotted stress distribution [27]. Figure 4.14 illustrates sigma x stresses in the 45 degree test while figure 4.15 shows the sigma y stresses. At the bottom grip, grid deformation was plotted in close up figure 4.16. An overall grid deformation was plotted in figure 4.17. All of the previous figures from the finite element model were

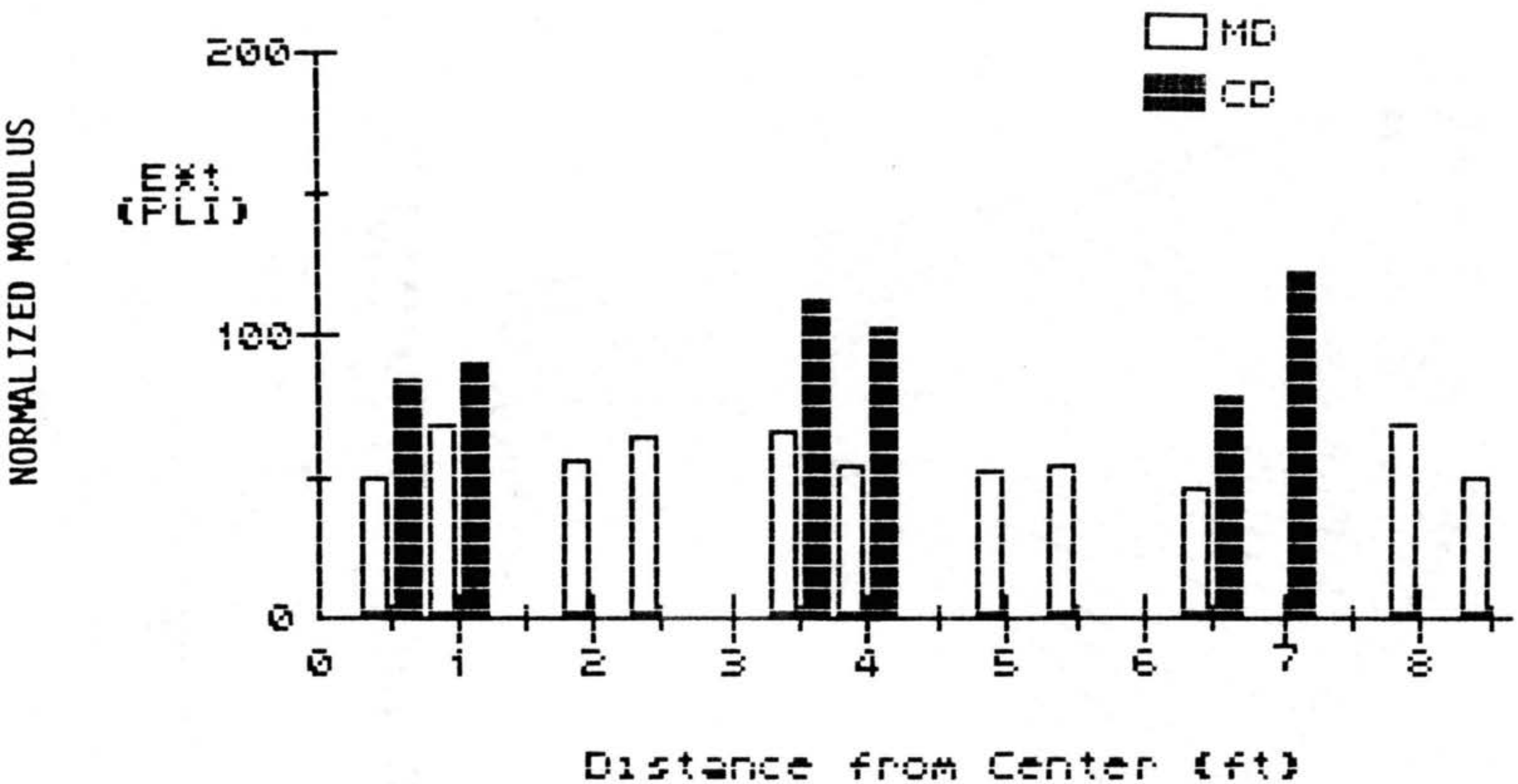


Figure 4.9 (E x t) vs distance from centerline of web. (Constant thickness of 0.79 mils)

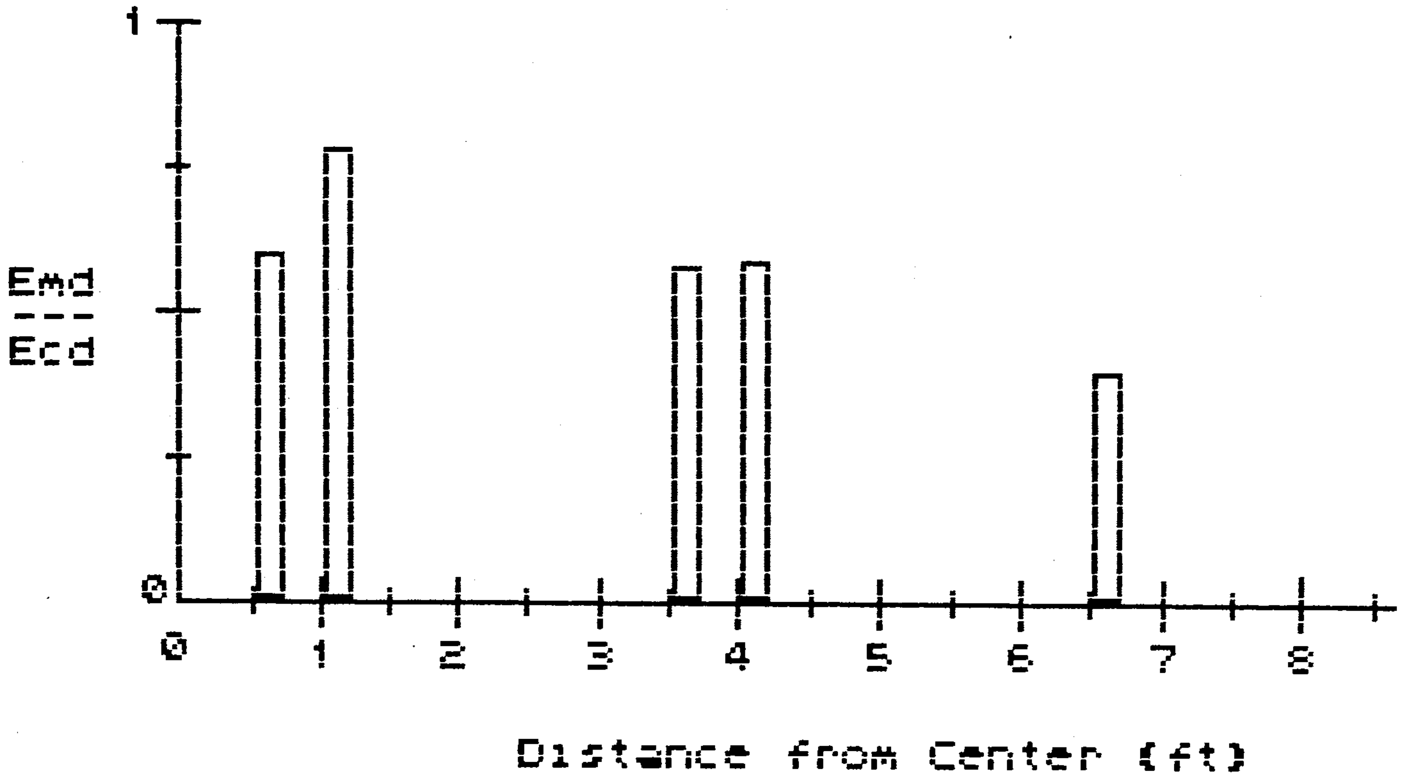


Figure 4.10 Anisotropy determined by Emd/Ecd as a function of position across the web.

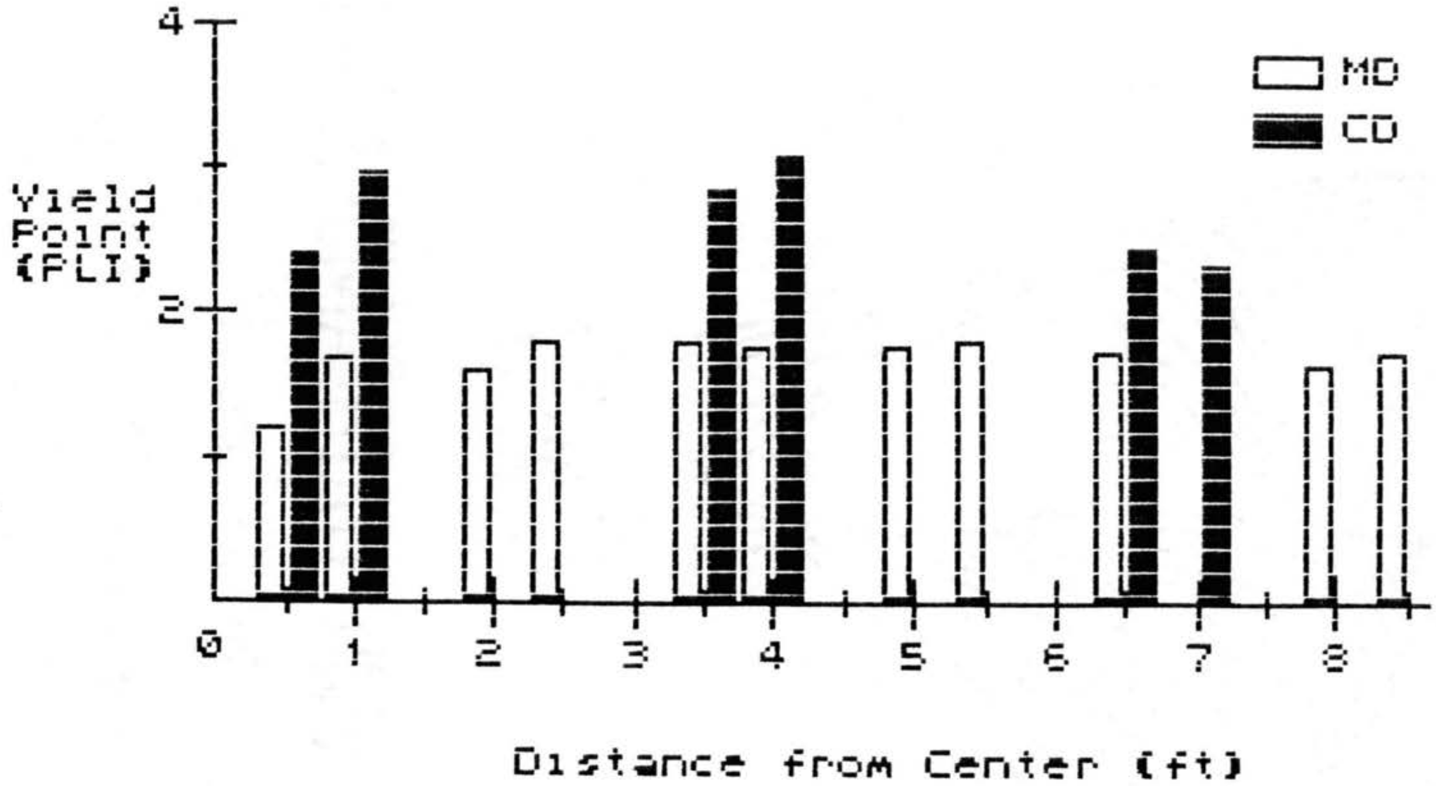


Figure 4.11 Yield point vs distance from centerline of web. (Constant thickness of 0.79 mils)

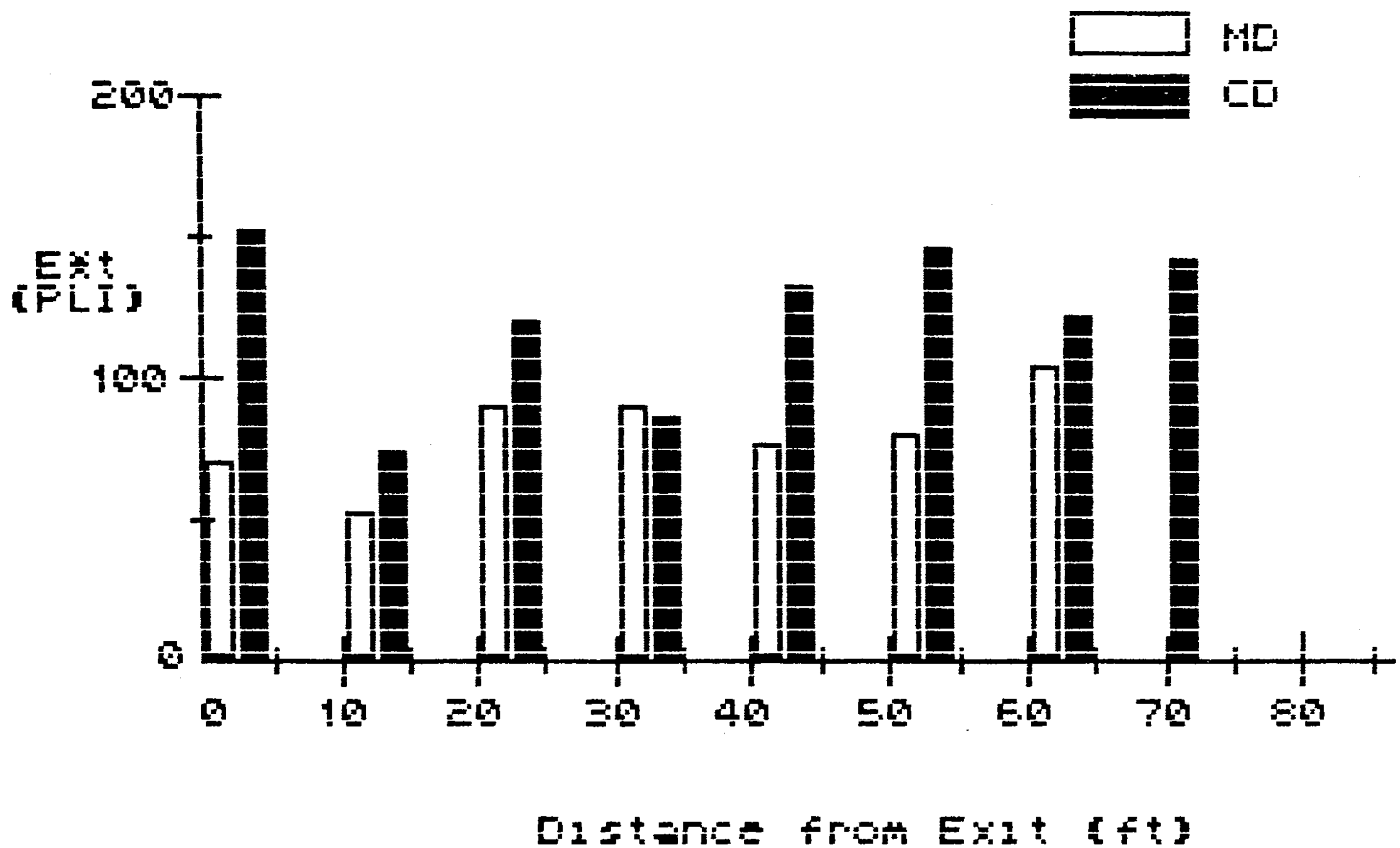


Figure 4.12 Normalized modulus (E x t) vs position from exit of TDO (varying thickness).

Figure 4.13 Anisotropy (Emd/Ecd) as a function of position in TDO.

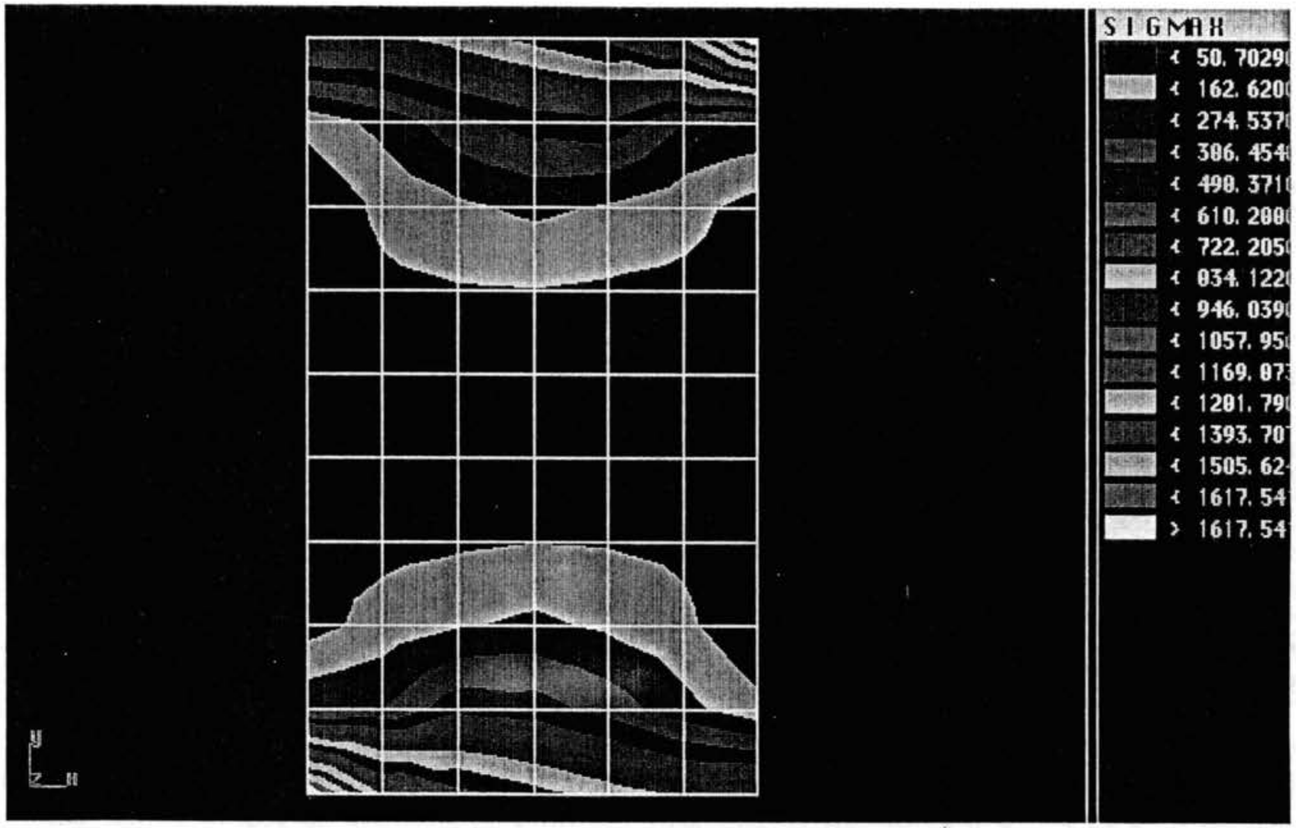


Figure 4.14 Finite element model of 45 degree orientation of polypropylene featuring sigma x.

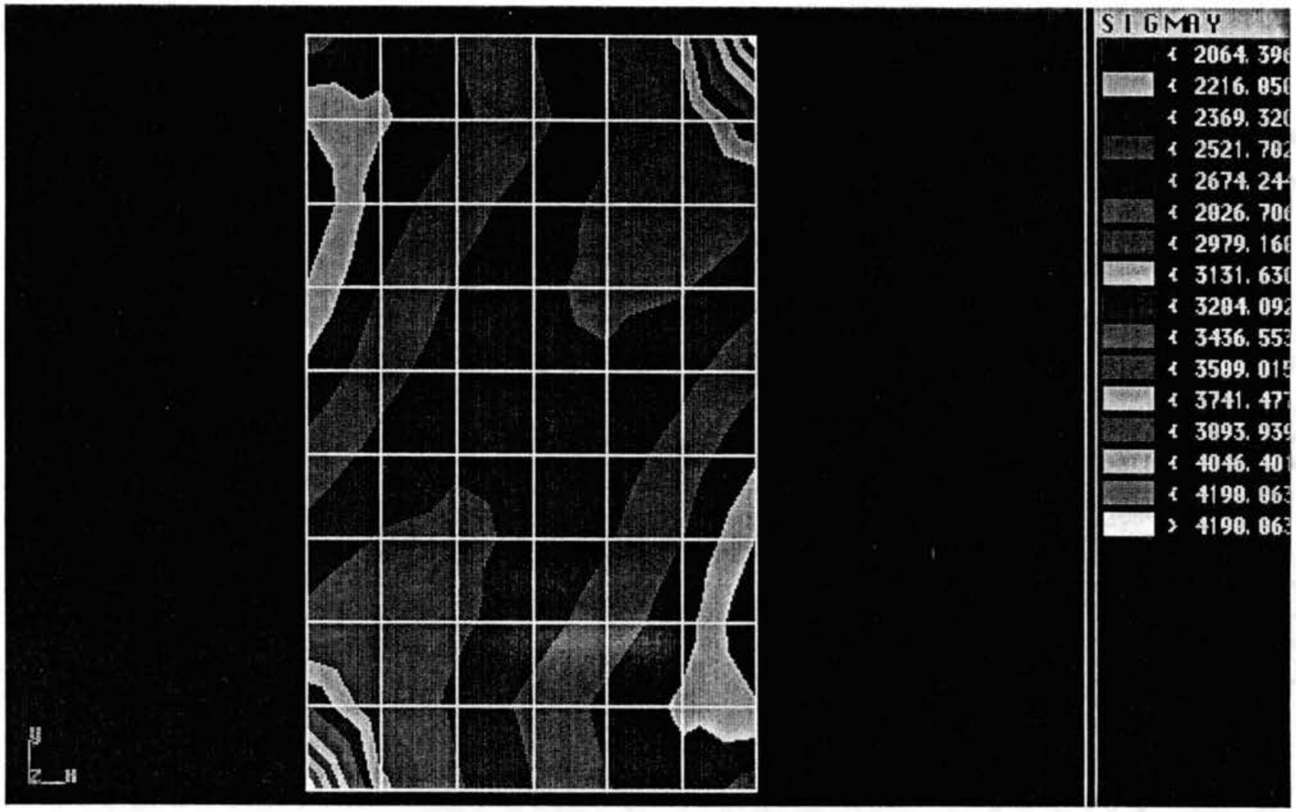


Figure 4.15 Finite element model of polypropylene oriented 45 degrees to MD. Featuring sigma y.

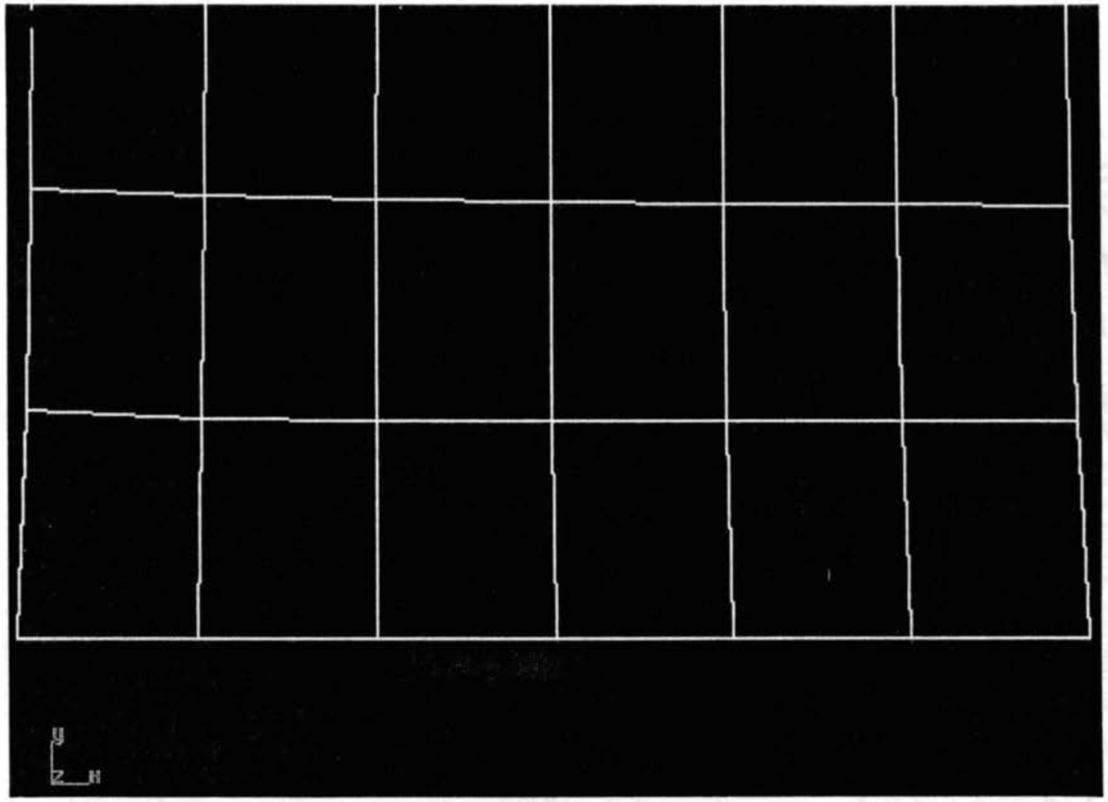


Figure 4.16 Grid deformation near grip for 45 degree orientation polypropylene sample modeled by finite element method.

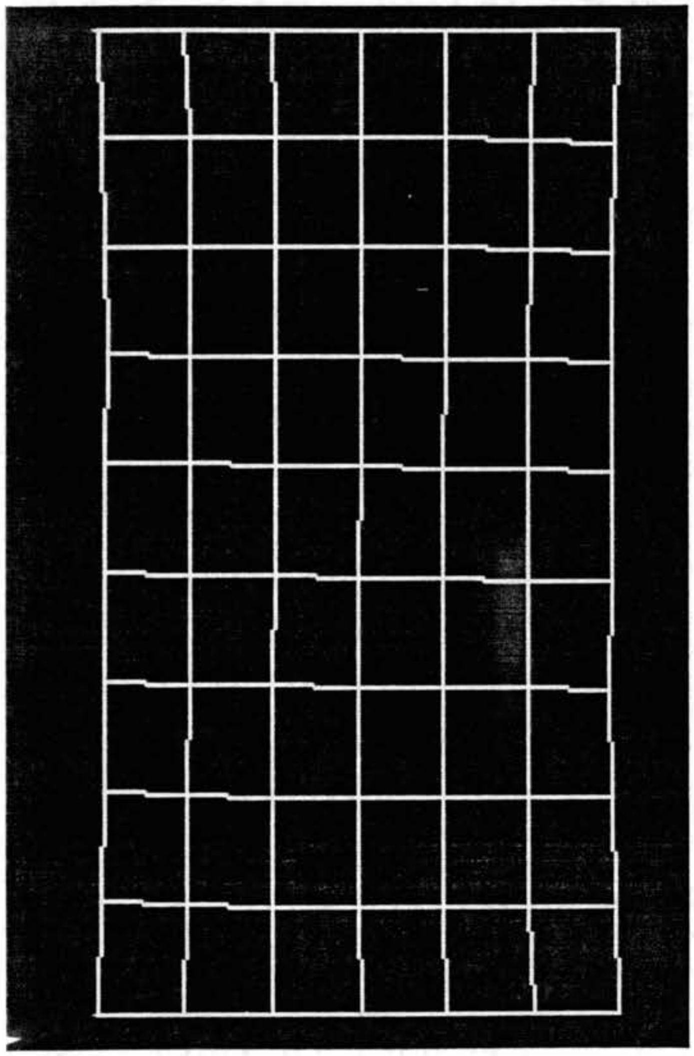


Figure 4.17 Overall grid deformation for 45 degree orientation polypropylene sample modeled by finite element method.

generated in the elastic range.

CHAPTER V

DISCUSSION

Static stress-strain tests on the final product of polypropylene were carried out on samples taken from different locations across the width of the web, starting from what was originally the center. From these tests, Young's moduli, normalized with respect to thickness, and plotted versus position from the center edge. In figure 4.9, the variations between normalized MD and CD moduli across the web, can be seen. The important point to note not only is that the MD and CD are not equal, but also that ratio of the modulus in the CD to that in the MD varies from 1.25 to 1.4. As can be seen in figure 4.10, the 1.25 ratio occurs near the center of the material while the 1.4 ratio of CD to MD appears at four feet from the center. The range of ratios may be caused by the distribution of stress as the polypropylene is oriented. Stress is applied in the desired direction of orientation in an attempt to align the molecular chains, but the stress distribution varies across the width of the web. This can be seen in the results of the finite element model, figure 4.14 [27]. If the stress varies across the web then the molecular alignment would also vary. Variations in molecular alignment will result in variations in yield point and stiffness. Forty-five degree to MD tests corroborate the inequality of the MD and CD moduli, figure 5.1. Figure 5.1 shows a deviation of the major axis from the direction of applied tension. Because the stiffnesses in the MD and CD are unequal, tests run in the 45 degree orientation have principal stresses that are rotated away from the MD and CD directions of loading. This is indicated by the change in the ellipse's major and minor axis directions. This rotation of principal stress directions induce shear stresses in both the MD and CD directions that warp the printed grid and ellipse's major axis directions. This can be seen in figure 5.1 and the finite element model simulation, figure 4.15 [27]. The simulation uses the same defined conditions as the 45 degree test while still in the elastic region. Figure 4.15 [27] provides an indication of the local stresses involved. Figure 4.3, a test run in the MD orientation, shows the principal stresses remain in the same directions as MD and CD of loading according to the axes' directions. Equal stiffnesses in both MD and CD do not yield a deviation of principal stress directions like that in figure 5.1. The purpose of biaxial stretching includes achieving equal stiffness in MD and CD. Figure 4.10 illustrates the amount of anisotropy of stiffness versus distance from center. Notice the inclination of higher anisotropy as distance increases away from the center. Kimura and Shimizu [17] point out that within

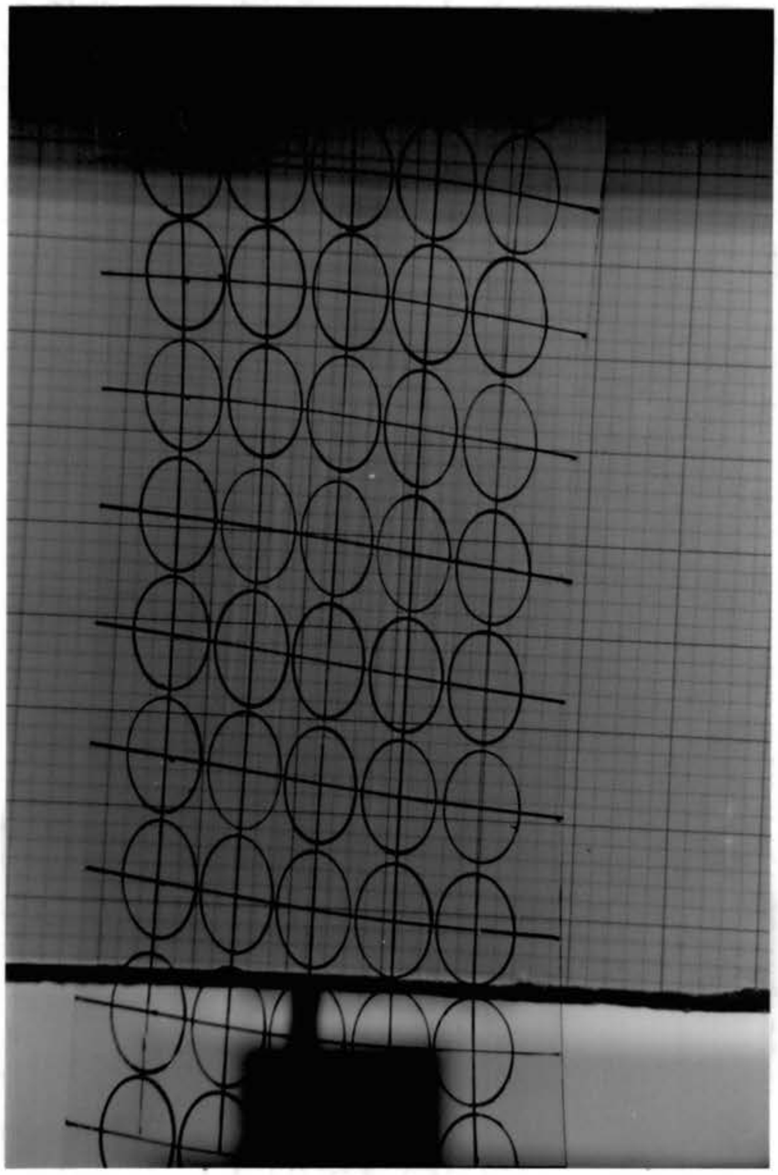


Figure 5.1 Polypropylene sample with 45 degree orientation under tension

rectangular specimens "the maxima of stress and strain could be found at the center of the sample." This is due to boundary conditions and geometry. The boundary conditions are: negligible CD displacement at the grips and applied displacement in the MD. This and the results shown in figure 4.9 suggest the biaxial process works to a varying degree with respect to the width of the web in the tenter. The non-uniformity of the stress distribution is partially hampering the process.

Figures 4.14 - 4.17 [27] were plotted while still in the elastic region of deformation. As the web enters the plastic region, the maxima stress would approach the center. The chart in figure 4.11 shows the trend for yield point versus distance from the center edge is similar to the trend for stiffness. CD yield points are also 1.25 to 1.4 times higher than their MD counterparts. Because yield point and stiffness are similarly affected by the biaxial stretching, it is also affected by the uneven stress distribution instilled by the process in a likewise manner.

Tests were also run on samples taken from the treater down to almost half the length of the TDO. As across the final product, MD and CD normalized moduli varied. The CD moduli were almost always consistently higher than the MD. The TDO is theoretically where the CD stiffness is increased to match that of the MD in figure 4.12. It is possible that as the web was stretched and annealed in the MDO that the material's molecular alignment did not occur to the degree desired. The MDO is supposed to achieve an MD preferred orientation, but the degree of orientation may not have been reached. It is possible the MDO stretching that occurs before the annealing takes place causes crazing that raises the internal energy of the material "due to new surface created inside the crazes" similar to results reported by Yefimov, Bulayev, Ozerin, Rebrov, Godovskii and Bakeyev [14]. This increase in internal energy could promote molecular chain randomness instead of alignment. As stated by Jenkins and Jenkins [10], there is an optimum temperature for achieve maximum preferred orientation. If that temperature is exceeded then the preferred orientation is decreased. Crazing could supply the additional energy needed to decrease the preferred orientation while in the MDO. Thicker samples, near the middle of the TDO, were visually observed to craze easily when loaded. The sample turned opaque in spots at a relative elongation of about 50 percent. As the test progressed, the opacity diminished.

Another possiblity that involves molecular alignment is a complex mixture of changing stress distribution, geometry and thermal energy. Because there was a relatively short time between the MDO operation and the start of the TDO stretching, little thermal energy has had time to be released. The geometry was changed between 70 and 40 feet and then held constant after 30 from the exit. If the molecular alignment was not given time to "set" after the stress from the TDO stretching was released, the web could have "snapped back" into its higher anisotropy configuration. Remember, the web is still at an elevated temperature and the TDO stress has been removed, but the inline tension that keeps the web on the rollers remains. This inline tension combined with stress relaxtion could cause the molecular chains to re-align in an unwanted manner. This might be prevented by allowing more "setting time" after the tenter.

Wave formation was also studied in both the polyester and the polypropylene. Wave formation is that point when the sample visibly displayed out of plane deformation. The onset of wave formation began within the elastic-plastic region described by Nilkanth [8] of the stress-strain curve usually before the yield point is reached. Typically, waves occurred at 80 percent of the yield point for the MD samples, but their formation in the CD direction behaved in a different manner. The onset of waves (CD direction tests) occurred at 125 percent of the yield values. Both MD and CD onsets were within the elastic-plastic region. This can be partially explained by looking at the elastic column buckling shown by Stevens [25] which is derived from Euler's formula for critical load. Only E and geometry play a part in that calculation for critical load. Therefore changes in E where the geometry is the same would proportionally affect the critical strain. The reverse is also true. Changing geometry, e.g. thickness, and keeping E constant would also change the point at which waves form.

Because CD is stiffer, it is presumed the critical strain would increase and therefore cause a higher strain for the onset of waves. However, the relationship between onset to wave formation and yield point is interesting. Euler's equation predicts "elastic" column buckling yet waves were observed to form in the elastic-plastic region. There seems to be some possible dependence on yield point. Euler's equation might be modified to include yield point for polymers to obtain a critical strain value for wave formation.

Mechanical tensile testing was chosen over optical and acoustical methods of determining E. They compare with the mechanical tensile testing in the following ways: Optical can measure displacements and Poisson's ratios but requires additional stress infomation to be useful (refer [15]); ultrasonics will return E values quickly from various points on the web, but those values are consistently higher than the mechanical E's observed. Mann, Baum, and Habeger [12] believe this is because ultrasonic testing gives much less time for viscoelastic relaxation than does mechanical tensile testing. Because there is not an established correlation between mechanically measured Young's moduli and acoustically measured values and the cost of the acoustical equipment is expensive, the mechanical tensile testing method was chosen.

Recommendations for future work include the following. It is necessary to find more accurate ways to detect the onset of waves, such as through laser interferometry. More material based testing on paper and other polymers to derive a unitless number based on material properties and geometry for the onset of waves needs to be done. Very useful information can be collected by either scanning with a digitizing camera for use on a computer or taking numerous photographs with a scale in the picture. Thinning information will prove useful in wave formation considerations. Image analysis techniques, either with video frame grabbing or high resolution still photography could prove to be useful. Joint work between finite element modeling and material testing is required. Dymanmic testing that could be used on-line to measure characteristics of wave formation, such as the start of out of plane deformation, amplitude of deformation, stress state at formation, vibrational effects on viscoelasticity and their effect on permanent setting of waves. Temperature effects on wave formation and setting should also be studied. Direction and values of principle moduli need to be determined. Poisson's ratios and shear moduli are also needed.

CHAPTER VI

CONCLUSIONS

The biaxial orientation process used in production of this web works with a varying degree of success relative to the location of sampling. This can be seen in variations in yield point and stiffness throughout the web. These variations may be caused by unequal stress distribution that affects molecular alignment. It is also possible while the web was stretched and annealed in the MDO that alignment did not occur to the desired degree. Crazing may have played an important part here, raising the web's internal energy to a point where it adversely affected the molecular alignment. Along with this, insufficient "setting time" could have prevented the desired alignment. Further study of how the stress is distributed and how this distribution affects molecular alignment could prove invaluable in improving the properties of the web through production technique changes.

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APPENDIXES

APPENDIX A

ANALYSIS OF UNCERTIANITY FOR NORMALIZED YOUNG'S MODULUS

$$E*t=(F2-F1)*Lo/[(L2-L1)*W]$$

Where: F1 and F2 are the loads selected on the linear portion of the stress-strain curve; L1 and L2 are the lenghts of the elastically deformed specimen correponding with F1 and F2; Lo is the original length of the undeformed specimen; W is the width of the undeformed specimen.

Estimation of uncertainity intervals:

$F=10 \pm 0.1$ lb
$L=12 \pm 0.032$ in
$W=6 \pm 0.032$ in

Relative Uncertainities:

$$Uf= \pm(.1)/(10) = \pm 0.0100$$
$$Ul= \pm(0.032/12)= \pm 0.0027$$
$$Uw= \pm(0.032/6) = \pm 0.0053$$

$$U_{\Delta}f= \pm \left|(0.0100)^2 + (0.0100)^2\right|^{\frac{1}{2}}= \pm 0.0141$$
$$U_{\Delta}l= \pm \left|(0.0027)^2 + (0.0027)^2\right|^{\frac{1}{2}}= \pm 0.0038$$

$$Ue = \pm \left|(U_{\Delta}f)^2 + (U_{\Delta}l)^2 + (Uw)^2\right|^{\frac{1}{2}}$$
$$Ue = \pm \left|(0.0141)^2 + (0.0038)^2 + (0.0053)^2\right|^{\frac{1}{2}} = \pm 0.0155$$

or

$Ue = \pm 1.6$ percent.

APPENDIX B

ANALYSIS OF UNCERTAININITY FOR YIELD POINT

$$Yp(pli)=F/W$$

Where: F is load at the yielding point and W is width of undeformed specimen.

from APPENDIX A:

$Uf= \pm 0.0100$
$Uw= \pm 0.0027$

The relative uncertainity for Y is:

$$Uy= \pm \left|(Uf)^2 + (Uw)^2\right|$$
$$Uy= \pm \left|(0.0100)^2 + (0.0027)^2\right|^{\frac{1}{2}}= \pm 0.0100$$

or $Uy= \pm 1.00$ percent.

APPENDIX C

COMPUTER PROGRAM FOR FINDING

ALL VALUES AND OUTPUT

```
'
'
'                                   Mr. Thesis
'
'
Dim Neck$(50,3),Elc$(50,4),D$(100,25),E$(100,20,3),
    F$(100,20,4),Parm1$(2),Parm2$(8)
Parm1$(1)="Thickness (mm)"
Parm1$(2)="Thickness (mils)"
Parm2$(1)="  Neck Reduction"
Parm2$(2)=" Ellipse A- circle A"
Parm2$(3)="      E (PSI)"
Parm2$(4)="Relaxation time (Sec)"
Parm2$(5)="Wave formation (PSI)"
Parm2$(6)="Wave formation (PLI)"
Parm2$(7)="Elastic Recovery"
Parm2$(8)=" Ell. Strains (True)"
5:
Cls
Print "Mr. Thesis"
Print "by Scott Robertson"
Print
Print "(D)ata entry"
Print "(C)alculation"
Print "(A)lter entry (correct)"
Print "(E)nd"
10:
A$=Upper$(Inkey$)
If A$="" Then
  Goto 10
Endif
A=Instr("DCAE",A$)
If A<>0 Then
  On A Gosub Zdata_entry,Calc,Edit,Endit
Endif
Goto 5
End
'
```

```
Procedure Endit
  Cls
  Print "Are you sure you want to END (Y/N)?"
  15:
  A$=Upper$(Inkey$)
  If A$="" Then
    Goto 15
  Endif
  If A$="Y" Then
    End
  Endif
Return
'
Procedure Zdata_entry
  If Exist("TEST.DAT") Then
    Open "A",#8,"TEST.DAT"
  Else
    Open "O",#8,"TEST.DAT"
  Endif
  20:
  Cls
  Print "(R)eturn to MAIN MENU"
  Print "(E)nter another test"
  25:
  A$=Upper$(Inkey$)
  If A$="" Then
    Goto 25
  Endif
  A=Instr("RE",A$)
  If A<>0 Then
    If A=1 Then
      Goto 30
    Endif
    If A=2 Then
      @Edata
      Goto 20
    Endif
  Endif
  Goto 25
  30:
  Close #8
Return
'
Procedure Edata
  40:
  @Input("Date",*Dated$)
  @Input("Test #",*Test$)
  @Input("Material note",*Material$)
  @Input("Thickness (mm)",*Thickness$)
  @Input("Specimen length (in.)",*Length$)
  @Input("Specimen width (in.)",*Width$)
  @Input("Material Orientation",*Material_orientation$)
  @Input("Test temp. (F)",*Test_temp$)
```

```
@Input("X scale (sec/cm)",*X_scale$)
@Input("Y scale (v/cm)",*Y_scale$)
@Input("E-X1 Coord. (in.)",*Ex1$)
@Input("E-Y1 Coord. (in.)",*Ey1$)
@Input("E-X2 Coord. (in.)",*Ex2$)
@Input("E-Y2 Coord. (in.)",*Ey2$)
@Input("Wave formation x (in.)",*Wave_x$)
@Input("Wave formation y (in.)",*Wave_y$)
@Input("# of NECK data points",*Neck$)
W=Val(Neck$)
If W<>0 Then
  For X=1 To W
    @Input("Enter "+Str$(X)+" of "+Str$(W)+" NECK dim.
    (in.)",*B$)
    Neck$(X,1)=B$
     @Input("Enter "+Str$(X)+" of "+Str$(W)+" NECK X-
     coord. (in.)",*C$)
    Neck$(X,2)=C$
    @Input("Enter "+Str$(X)+" of "+Str$(W)+" NECK Y-
    coord. (in.)",*D$)
    Neck$(X,3)=D$
  Next X
Endif
@Input("# of ELC data points",*Elc$)
U=Val(Elc$)
If U<>0 Then
  For X=1 To U
    @Input("Enter "+Str$(X)+" of "+Str$(U)+" ELC Major
    dim. (in.)",*E$)
    Elc$(X,1)=E$
    @Input("Enter "+Str$(X)+" of "+Str$(U)+" ELC Minor
    dim. (in.)",*F$)
    Elc$(X,2)=F$
    @Input("Enter "+Str$(X)+" of "+Str$(U)+" ELC X-coord.
    (in.)",*G$)
    Elc$(X,3)=G$
    @Input("Enter "+Str$(X)+" of "+Str$(U)+" ELC Y-coord.
    (in.)",*H$)
    Elc$(X,4)=H$
  Next X
Endif
@Input("Start Stress Relax x-coord. (in.)",*Stressrx$)
@Input("Start Stress Relax y-coord. (in.)",*Stressry$)
@Input("2nd Stress Relax x-coord. (in.)",*Stressr2x$)
@Input("2nd Stress Relax y-coord. (in.)",*Stressr2y$)
@Input("Elastic Recovery Neck dim. (in.)",*Ernd$)
@Input("Elastic Recovery ELC Major dim. (in.)",
*Eremajord$)
@Input("Elastic Recovery ELC Minor dim. (in.)",
*Ereminord$)
Print
Print "Everything correct (Y/N)?"
50:
```

```
  A$=Upper$(Inkey$)
  If A$="" Then
    Goto 50
  Endif
  If A$="N" Then
    Goto 40
  Endif
  If A$="Y" Then
    @Savedata
  Else
    Goto 50
  Endif
Return
'
Procedure Savedata
  @Output(Dated$)                                             !1
  @Output(Test$)                                              !2
  @Output(Material$)                                          !3
  @Output(Thickness$)                                         !4
  @Output(Length$)                                            !5
  @Output(Width$)                                             !6
  @Output(Material_orientation$)                              !7
  @Output(Test_temp$)                                         !8
  @Output(X_scale$)                                           !9
  @Output(Y_scale$)                                           !10
  @Output(Ex1$)                                               !11
  @Output(Ey1$)                                               !12
  @Output(Ex2$)                                               !13
  @Output(Ey2$)                                               !14
  @Output(Wave_x$)                                            !15
  @Output(Wave_y$)                                            !16
  @Output(Neck$)                                              !17
  W=Val(Neck$)
  If W<>0 Then
    For X=1 To W
      @Output(Neck$(X,1))
      @Output(Neck$(X,2))
      @Output(Neck$(X,3))
    Next X
  Endif
  @Output(Elc$)                                               !18
  U=Val(Elc$)
  If U<>0 Then
    For X=1 To U
       @Output(Elc$(X,1))
      @Output(Elc$(X,2))
      @Output(Elc$(X,3))
      @Output(Elc$(X,4))
    Next X
  Endif
  @Output(Stressrx$)                                          !19
  @Output(Stressry$)                                          !20
  @Output(Stressr2x$)                                         !21
```

```
  @Output(Stressr2y$)                                       !22
  @Output(Ernd$)                                            !23
  @Output(Eremajord$)                                       !24
  @Output(Ereminord$)                                       !25
Return
'
Procedure Input(W$,X%)
  Print W$;
  Input Temp$
  If Temp$<>"" Then
    *X%=Temp$
  Endif
Return
'
Procedure Output(S$)
  If S$<>"" Then
    Print #8,S$
  Else
    Print #8,"None"
  Endif
Return
'
Procedure Calc
  Cls
  Print "Loading...."
  Open "I",#8,"test.dat"
  Test=0
  Repeat
    Test=Test+1
    @Load(Test)
  Until Eof(#8)
  Close #8
  Print "Done."
  @Select
Return
'
Procedure Load(T)
  For Zz=1 To 17
    Input #8,D$(T,Zz)
  Next Zz
  If Val(D$(T,17))<>0 Then
    For Zz=1 To Val(D$(T,17))
      For W=1 To 3
        Input #8,E$(T,Zz,W)
      Next W
    Next Zz
  Endif
  Input #8,D$(T,18)
  If Val(D$(T,18))<>0 Then
    For Zz=1 To Val(D$(T,18))
      For W=1 To 4
        Input #8,F$(T,Zz,W)
      Next W
```

```
    Next Zz
  Endif
  For Zz=19 To 25
    Input #8,D$(T,Zz)
  Next Zz
Return
'
Procedure Decimal(A$,X%)
  Let Decimal=0
  If Instr(A$,".")=0 And Instr(A$,"/")<>0 Then
    A=Instr(A$," ")
    If A<>0 Then
      Let Decimal=Val(Left$(A$,A))
      A$=Mid$(A$,A+1)
    Endif
    C=Instr(A$,"/")
    If C<>0 Then
      Let Decimal=Decimal+Val(Left$(A$,C))/Val(Mid$(A$,C+1)
      )
    Endif
  Else
    Let Decimal=Val(A$)
  Endif
  *X%=Decimal
Return
'
Procedure E
  @Cdo(D$(T,4)+D$(T,5)+D$(T,6)+D$(T,11)+D$(T,12)+D$(T,13)
  +D$(T,14))
  If Cdo! Then
    @Decimal(D$(T,5),*Lo)
    @Decimal(D$(T,6),*W)
    L1=@Xcon(Val(D$(T,11)),T)
    L2=@Xcon(Val(D$(T,13)),T)
    @Force(D$(T,12),*Force1)
    @Force(D$(T,14),*Force2)
    Thickness=Val(D$(T,4))/25.4
    Delta1=L2-L1
    E=(Force2-Force1)*Lo/(Delta1*W*Thickness)
    Round=Int(Log10(E+1))+1
    Mid$(Work$,67,Round)=Str$(E)
  Else
    Mid$(Work$,67,4)="NCDO"
  Endif
Return
'
Deffn Tcon(T)=T/25.4
Deffn Xcon(X,T)=Val(D$(T,9))*0.0212*X
'
Procedure E_area
  On Which Gosub Screen,Prnter
  Work$=K$
  Mid$(Work$,40,19)="Strain  Stress(psi)"
```

```
  On Which Gosub Screen,Prnter
  Kr=Val(D$(T,18))
  If Kr<>0 Then
    For D=1 To Kr
      Work$=K$
      @Cdo(D$(T,11)+F$(T,D,1)+F$(T,D,2)+F$(T,D,3)+F$(T,D,4
      ))
  If Cdo! Then
        @Decimal(D$(T,5),*Lo)
        @Decimal(F$(T,D,1),*Major)
        @Decimal(F$(T,D,2),*Minor)
        @Decimal(D$(T,6),*W)
        E_area=Pi*Major*Minor/4-Pi/4
        Xj=@Xcon(Val(F$(T,D,3)),T)-@Xcon(Val(D$(T,11)),T)
        Xj=Xj/Lo
        @Stress(W,F$(T,D,4),*Yj)
        Mid$(Work$,40,5)=Left$(Str$(Xj),5)
        Mid$(Work$,50,Int(Log10(Yj+1)+1))=Str$(Yj)
        Mid$(Work$,67,5)=Left$(Str$(E_area),5)
      Else
        Mid$(Work$,40,4)="NCDO"
      Endif
      On Which Gosub Screen,Prnter
    Next D
  Endif
  Work$=K$
Return
'
Procedure Cdo(Check$)
  Cdo!=True
  If Instr(Upper$(Check$),"NONE")<>0 Then
    Cdo!=False
  Endif
Return
'
Procedure Select
  Select2:
  Cls
  Print "(1): Select print parms"
  Print "(2): Test order"
  Print "(3): Print"
  Print "(4): Quit"
  Print
  @One_key(4)
  If Key=4 Then
    Goto Select1
  Endif
  On Key Gosub Parms,Order,Prnt
  Goto Select2
  Select1:
Return
'
```

```
Procedure One_key(O)
  Key:
  A$=""
  A$=Inkey$
  If A$="" Then
    Goto Key
  Endif
  If Val(A$)>=1 And Val(A$)<=O Then
    Key=Val(A$)
  Else
    Goto Key
  Endif
Return
'
Procedure Order
  Order$=""
  Order:
  Cls
  Print "Current Order: ";Order$
  Input "Enter test# (Return/returns, All/All)";J$
  If J$="" Then
    Goto Order2
  Endif
  If Upper$(J$)="ALL" Then
    For Dd=1 To Test
       @Order_sum(D$(Dd,2))
    Next Dd
    Goto Order2
  Endif
  @Order_sum(J$)
  Goto Order
  Order2:
Return
'
Procedure Order_sum(H$)
  If Order$="" Then
    Order$=H$
  Else
    Order$=Order$+","+H$
  Endif
Return
'
Procedure Parms
  Cls
  Print "Select Parm 1"
  Print "(1): Thickness (mm)"
  Print "(2): Thickness (mils)"
  @One_key(2)
  P1=Key
  Print
  Print "Select Parm 2"
  Print "(1): Neck Reduction"
  Print "(2): Ellipse area- 1 inch. circle area"
```

```
    Print "(3): E (PSI)"
    Print "(4): Relaxation time (Sec)"
    Print "(5): Wave formation (PSI)"
    Print "(6): Wave formation (PLI)"
    Print "(7): Elastic Recovery"
    Print "(8): Ell. Strains (Engr)"
    @One_key(8)
    P2=Key
    Print
    Print "Select Parm 3"
    Print "(1): Pre 4/14/88 correction factor"
    Print "(2): Exit"
    @One_key(2)
    P3=-(Key=1)*0.35-(Key=2)
  Return
  '
  Procedure Prnt
    Cls
    K$=String$(79," ")
    Print "(1): Screen"
    Print "(2): Printer"
    @One_key(2)
    Which=Key
    Print "Want a header? (Y/N)"
    Prnt:
    A$=""
     A$=Inkey$
    If A$="" Then
      Goto Prnt
    Endif
    A$=Upper$(A$)
    If A$<>"Y" And A$<>"N" Then
      Goto Prnt
    Endif
    If Which=2 Then
      Open "",#7,"PRN:"
    Endif
    If A$="Y" Then
      Header$=K$
      First=Len(Parm1$(P1))
      Last=Len(Parm2$(P2))
      Mid$(Header$,42,First)=Parm1$(P1)
      Mid$(Header$,59,Last)=Parm2$(P2)
      Mid$(Header$,1,6)="Test #"
      Mid$(Header$,6,14)="Mat. Orient."
      Mid$(Header$,22,9)="Mat. Note"
      Work$=Header$
      On Which Gosub Screen,Prnter
      Work$=String$(79,"-")
      On Which Gosub Screen,Prnter
    Endif
    Repeat
      Work$=K$
```

```
    Xcv=Val(Order$)
    T=0
    Repeat
      T=T+1
    Until (Xcv=Val(D$(T,2)) Or T=>Test)
    Ww=Instr(Order$,",")
    Mid$(Work$,1,Len(D$(T,2)))=D$(T,2)
    Mid$(Work$,6,Len(D$(T,7)))=D$(T,7)
    Mid$(Work$,11,Len(D$(T,3)))=D$(T,3)
    On P1 Gosub Thickmm,Thickmils
    On P2 Gosub Necking,E_area,E,Relax,Wavepsi,Wavepli,
    Elastic,Ed
    On Key Gosub Screen,Prnter
    If Ww<>0 Then
      Order$=Mid$(Order$,Ww+1)
    Endif
  Until Ww=0
  If Which=2 Then
    Close #7
  Endif
  Input "Hit return";Ab$
Return
'
Procedure Screen
  Print Work$
Return
'
Procedure Prnter
  Print #7,Work$
Return
'
Procedure Thickmm
  Mid$(Work$,48,Len(D$(T,4)))=D$(T,4)
Return
'
Procedure Thickmils
  Mils=1000*Val(D$(T,4))/25.4
  Mid$(Work$,48,5)=Left$(Str$(Mils),5)
Return
'
Procedure Relax
  @Cdo(D$(T,19)+D$(T,20)+D$(T,21)+D$(T,22))
  If Cdo! Then
    Zzz=2.54*Val(D$(T,9))
    Tim1=Zzz*Val(D$(T,19))
    Tim2=Zzz*Val(D$(T,21))
    @Decimal(D$(T,6),*W)
    Relax=-(Tim2-Tim1)/(Log(Val(D$(T,22))/Val(D$(T,20))))
    Mid$(Work$,67,5)=Left$(Str$(Relax),5)
  Else
    Mid$(Work$,67,4)="NCDO"
  Endif
Return
```

```
'
Procedure Wavepsi
  @Cdo(D$(T,11)+D$(T,15)+D$(T,16))
  If Cdo! Then
    @Decimal(D$(T,6),*W)
    @Stress(W,D$(T,16),*Stress)
    Mid$(Work$,67,Int(Log10(Stress+1)+1))=Str$(Stress)
  Else
    Mid$(Work$,67,4)="NCDO"
  Endif
Return
'
Procedure Wavepli
  @Cdo(D$(T,11)+D$(T,15)+D$(T,16))
  If Cdo! Then
    @Decimal(D$(T,6),*W)
    @Force(D$(T,16),*Pli)
    Pli=Pli/W
    Mid$(Work$,67,5)=Left$(Str$(Pli),5)
  Else
    Mid$(Work$,67,4)="NCDO"
  Endif
Return
'
Procedure Necking
  On Which Gosub Screen,Prnter
  Work$=K$
  Mid$(Work$,10,21)="TStrain  TStress(psi)"
  Mid$(Work$,40,21)="EStrain  EStress(psi)"
  On Which Gosub Screen,Prnter
  Kr=Val(D$(T,17))
  If Kr<>0 Then
    For D=1 To Kr
      Work$=K$
      @Cdo(D$(T,11)+E$(T,D,1)+E$(T,D,2)+E$(T,D,3))
      If Cdo! Then
        @Decimal(D$(T,5),*Lo)
        @Decimal(D$(T,6),*W)
        @Decimal(E$(T,D,1),*Necko)
        Neck=(W-Necko)/W
        Xj=@Xcon(Val(E$(T,D,2)),T)-@Xcon(Val(D$(T,11)),T)
        Xtrue=Log((Xj+Lo)/Lo)
        Xj=Xj/Lo
        @Force(E$(T,D,3),*Ytrue)
        Ytrue=25.4*Ytrue/(Necko*Val(D$(T,4)))
        @Stress(W,E$(T,D,3),*Yj)
        Mid$(Work$,10,5)=Left$(Str$(Xtrue),5)
        Mid$(Work$,20,Int(Log10(Ytrue+1)+1))=Str$(Ytrue)
        Mid$(Work$,40,5)=Left$(Str$(Xj),5)
        Mid$(Work$,50,Int(Log10(Yj+1)+1))=Str$(Yj)
        Mid$(Work$,67,5)=Left$(Str$(Neck),5)
      Else
        Mid$(Work$,40,4)="NCDO"
```

```
      Endif
      On Which Gosub Screen,Prnter
    Next D
  Endif
  Work$=K$
Return
'
Procedure Stress(W,H$,X%)
  @Force(H$,*F)
  *X%=25.4*F/(W*Val(D$(T,4)))
Return
'
 Procedure Force(G$,F%)
  Volts=Val(G$)*Val(D$(T,10))
  If Val(D$(T,2))>44 Then
    *F%=P3*Volts*356
  Else
    *F%=P3*Volts*45.9
  Endif
Return
'
Procedure Edit
  Cls
  Print "Loading...."
  Open "I",#8,"test.dat"
  Test=0
  Repeat
    Test=Test+1
    @Load(Test)
  Until Eof(#8)
  Close #8
  Print "Done."
  Ditl:
  Input "Test# to edit (return to quit)";T$
  If T$<>"" Then
    Gt=0
    Repeat
      Gt=Gt+1
    Until (Val(T$)=Val(D$(Gt,2)) Or Gt>=Test)
    @Display(Gt)
     Goto Ditl
  Endif
  Open "O",#8,"Edited.dat"
  For T=1 To Test
    For Zz=1 To 17
      Print #8,D$(T,Zz)
    Next Zz
    If Val(D$(T,17))<>0 Then
      For Zz=1 To Val(D$(T,17))
        For W=1 To 3
          Print #8,E$(T,Zz,W)
        Next W
      Next Zz
```

```
    Endif
    Print #8,D$(T,18)
    If Val(D$(T,18))<>0 Then
      For Zz=1 To Val(D$(T,18))
        For W=1 To 4
          Print #8,F$(T,Zz,W)
        Next W
      Next Zz
    Endif
    For Zz=19 To 25
      Print #8,D$(T,Zz)
    Next Zz
  Next T
  Close #8
  Kill "test.dat"
  Name "edited.dat" As "test.dat"
Return
'
Procedure Display(T)
  Dis:
  Cls
  For Zz=1 To 17
    Print Zz;":";D$(T,Zz),
  Next Zz
  If Val(D$(T,17))<>0 Then
    For Zz=1 To Val(D$(T,17))
      For W=1 To 3
        Print "N ";Zz;",";W;":";E$(T,Zz,W),
      Next W
    Next Zz
  Endif
  Print 18;":";D$(T,18),
  If Val(D$(T,18))<>0 Then
    For Zz=1 To Val(D$(T,18))
      For W=1 To 4
        Print "E ";Zz;",";W;":";F$(T,Zz,W),
      Next W
    Next Zz
  Endif
  For Zz=19 To 25
    Print Zz;":";D$(T,Zz),
  Next Zz
  Print
  Input "Enter character";A$
  A$=Upper$(A$)
  Input "# 1";Dx$
  Dx=Val(Dx$)
  Input "# 2 ";Dy$
  Dy=Val(Dy$)
  If Val(A$)>=1 And Val(A$)<=25 Then
    Input "Enter new value";D$(T,Val(A$))
    Goto Dis
  Endif
```

```
  If A$="N" Then
    Input "Enter new neck";E$(T,Dx,Dy)
    Goto Dis
  Endif
  If A$="" Then
    Goto Dis3
  Endif
  If A$="E" Then
    Input "Enter new neck";F$(T,Dx,Dy)
    Goto Dis
  Endif
  Dis3:
Return
'
Procedure Elastic
  On Which Gosub Screen,Prnter
  Work$=K$
  Mid$(Work$,10,33)="Elastic Neck Recover% (Nu-Nl/Nl)="
  @Cdo(D$(T,23))
  If Cdo! Then
    Rt=Val(D$(T,17))
    If Rt<>0 Then
      @Decimal(E$(T,Rt,1),*Nl)
      @Decimal(D$(T,23),*Nu)
      Hk=(Nu-Nl)/Nl
      Mid$(Work$,51,5)=Left$(Str$(Hk),5)
    Else
      Mid$(Work$,51,4)="NCDO"
    Endif
  Else
    Mid$(Work$,51,4)="NCDO"
  Endif
  On Which Gosub Screen,Prnter
  Work$=K$
  Mid$(Work$,10,39)="Elastic Major Axis Recover% (Mu-
  Ml/Ml)="
  @Cdo(D$(T,24))
  If Cdo! Then
    Rt=Val(D$(T,18))
    If Rt<>0 Then
      @Decimal(F$(T,Rt,1),*Nl)
      @Decimal(D$(T,24),*Nu)
      Hk=(Nu-Nl)/Nl
      Mid$(Work$,51,5)=Left$(Str$(Hk),5)
    Else
      Mid$(Work$,51,4)="NCDO"
    Endif
  Else
    Mid$(Work$,51,4)="NCDO"
  Endif
      On Which Gosub Screen,Prnter
  Work$=K$
  Mid$(Work$,10,39)="Elastic Minor Axis Recover% (Mu-
```

```
  Ml/Ml)="
      @Cdo(D$(T,25))
      If Cdo! Then
        Rt=Val(D$(T,18))
    If Rt<>0 Then
      @Decimal(F$(T,Rt,2),*Nl)
      @Decimal(D$(T,25),*Nu)
      Hk=(Nu-Nl)/Nl
      Mid$(Work$,51,5)=Left$(Str$(Hk),5)
    Else
      Mid$(Work$,51,4)="NCDO"
    Endif
  Else
    Mid$(Work$,51,4)="NCDO"
  Endif
  On Which Gosub Screen,Prnter
  Work$=K$
Return
'
Procedure Ed
  On Which Gosub Screen,Prnter
  Work$=K$
  Mid$(Work$,40,37)="Strain  Stress(psi)    Major    Minor"
  On Which Gosub Screen,Prnter
  Kr=Val(D$(T,18))
  If Kr<>0 Then
    For D=1 To Kr
      Work$=K$
      @Cdo(D$(T,11)+F$(T,D,1)+F$(T,D,2)+F$(T,D,3)+F$(T,D,4
      ))
      If Cdo! Then
        @Decimal(F$(T,D,1),*Major)
        @Decimal(F$(T,D,2),*Minor)
        @Decimal(D$(T,5),*Lo)
        @Decimal(D$(T,6),*W)
        Xj=@Xcon(Val(F$(T,D,3)),T)-@Xcon(Val(D$(T,11)),T)
        Xj=Xj/Lo
        @Stress(W,F$(T,D,4),*Yj)
        Mid$(Work$,40,5)=Left$(Str$(Xj),5)
        Mid$(Work$,50,Int(Log10(Yj+1)+1))=Str$(Yj)
        Ma=Int(Log(Major)*10000)/10000
        Mi=Int(Log(Minor)*10000)/10000
        Mid$(Work$,63,5)=Left$(Str$(Ma),5)
        Mid$(Work$,72,5)=Left$(Str$(Mi),5)
        If Abs(Abs(Ma)-Abs(Mi))>0.06 Then
          Mid$(Work$,78,1)="*"
        Endif
      Else
        Mid$(Work$,40,4)="NCDO"
      Endif
      On Which Gosub Screen,Prnter
    Next D
  Endif
  Work$=K$
Return
```

```
                         OUTPUT
Test   Mat. Orient.   Mat. Note  Thick. (mils)  Neck Reduc.
------------------------------------------------------------

31    MD    PP South Piece          0.787
  TStrain  TStress(psi)      EStrain  EStress(psi)
   0.264      2156            0.302    1797          0.166

35    MD    PP South Piece          0.787
   TStrain  TStress(psi)     EStrain  EStress(psi)
    0.227     1804            0.255    1578          0.125

40    CD    PP South Piece          0.787
   TStrain  TStress(psi)      EStrain  EStress(psi)
    0.087     8617            0.091     8433         0.021
    0.135     13248           0.144     12402        0.063
    0.200     19431           0.221     17363        0.106

42    CD    PP South Piece          0.787
   TStrain  TStress(psi)      EStrain  EStress(psi)
    0.127     11906            0.136     11420       0.040

30    CD    PP North Piece          0.787
   TStrain  TStress(psi)      EStrain  EStress(psi)
    0.091     3442             0.095     3285        0.045

57    MD    PP TDO 0' from Exit     0.866
   TStrain  TStress(psi)      EStrain  EStress(psi)
    0.107     3752             0.113     3596        0.041
    0.205     5161             0.227     4623        0.104

62    MD    PP TDO 0' from Exit     0.866
   TStrain  TStress(psi)      EStrain  EStress(psi)
     0.100     4288            0.106     4110        0.041
     0.194     5978            0.214     5480        0.083
     0.280     7618            0.323     6507        0.145

61    MD    PP TDO 0' from Exit     0.866
   TStrain  TStress(psi)      EStrain  EStress(psi)
     0.091     4697            0.095     4513        0.039

53    CD    PP TDO 0' from Exit     0.866
   TStrain  TStress(psi)      EStrain  EStress(psi)
    0.071     9932             0.074     9535        0.04

60    CD    PP TDO 0' from Exit     0.866
   TStrain  TStress(psi)      EStrain  EStress(psi)
    0.105     11437            0.111     10960       0.041

55    MD    PP TDO 20' from exit    1.259
   TStrain  TStress(psi)      EStrain  EStress(psi)
    0.093     3366             0.098     3229        0.040
    0.190     4623             0.209     4152        0.102

59    MD    PP TDO 20' from exit    1.259
```

TStrain	TStress(psi)	EStrain	EStress(psi)	
0.112	3516	0.119	3296	0.062
0.176	4205	0.193	3767	0.104

91 CD PP TDO 20' from exit 1.259

TStrain	TStress(psi)	EStrain	EStress(psi)	
0.077	4997	0.080	4945	0.010
0.118	7125	0.125	6828	0.041

90 MD PP TDO 30' from exit 1.377

TStrain	TStress(psi)	EStrain	EStress(psi)	
0.085	2319	0.089	2251	0.029
0.128	2583	0.136	2455	0.049
0.187	3032	0.206	2762	0.089
0.241	3523	0.273	3069	0.128
0.301	3936	0.351	3274	0.168
0.343	4410	0.410	3581	0.188
0.410	5861	0.507	3888	0.336

72 MD PP TDO 30' from exit 1.377

TStrain	TStress(psi)	EStrain	EStress(psi)	
0.105	2741	0.110	2583	0.057
0.170	3298	0.185	2981	0.096
0.235	3789	0.265	3279	0.134
0.336	4551	0.399	3676	0.192

85 MD PP TDO 40' from exit 1.456

TStrain	TStress(psi)	EStrain	EStress(psi)	
0.100	2172	0.106	2125	0.021

87 MD PP TDO 40' from exit 1.456

TStrain	TStress(psi)	EStrain	EStress(psi)	
0.100	2160	0.106	2094	0.030
0.152	2606	0.164	2394	0.081
0.192	2888	0.212	2593	0.102
0.213	3069	0.238	2693	0.122
0.259	3258	0.296	2793	0.142
0.292	3620	0.339	2992	0.173
0.345	4010	0.413	3192	0.204

83 CD PP TDO 40' from exit 1.456

TStrain	TStress(psi)	EStrain	EStress(psi)	
0.113	5430	0.119	5199	0.042

77 CD PP TDO 40' from exit 1.456

TStrain	TStress(psi)	EStrain	EStress(psi)	
0.085	5332	0.089	5100	0.043
0.115	7047	0.122	6587	0.065
0.159	8970	0.172	8287	0.076

80 MD PP TDO 50' from exit 1.574

TStrain	TStress(psi)	EStrain	EStress(psi)	
0.115	2511	0.122	2354	0.062

	0.168	2877	0.184	2637	0.083
	0.246	3639	0.278	3108	0.145
	0.301	4173	0.351	3390	0.187
	0.327	4462	0.387	3579	0.197
79	MD	PP TDO 50' from exit	1.574		
	TStrain	TStress(psi)	EStrain	EStress(psi)	
	0.115	2441	0.122	2347	0.038
33	MD	PP TDO 60' from exit	1.771		
	TStrain	TStress(psi)	EStrain	EStress(psi)	
	0.157	1118	0.171	1025	0.083
	0.231	1369	0.260	1198	0.125
	0.338	1833	0.402	1489	0.187
	0.306	2214	0.358	1684	0.239
43	MD	PP TDO 60' from exit	1.771		
	TStrain	TStress(psi)	EStrain	EStress(psi)	
	0.141	3051	0.151	2860	0.062
	0.244	4194	0.277	3670	0.125
	0.331	5314	0.393	4318	0.187
	0.377	6021	0.459	4641	0.229
	0.435	6764	0.545	5073	0.25
50	MD	PP TDO 60' from exit	1.771		
	TStrain	TStress(psi)	EStrain	EStress(psi)	
	0.071	2992	0.074	2930	0.020
	0.187	5297	0.206	4856	0.083
65	MD	PP TDO 60' from exit	1.771		
	TStrain	TStress(psi)	EStrain	EStress(psi)	
	0.211	54477	0.235	50030	0.081
	0.246	54207	0.279	47569	0.122
	0.324	65673	0.382	54951	0.163
	0.373	74194	0.453	59052	0.204
52	CD	PP TDO 60' from exit	1.771		
	TStrain	TStress(psi)	EStrain	EStress(psi)	
	0.059	3444	0.060	3364	0.023
78	CD	PP TDO 60' from exit	1.771		
	TStrain	TStress(psi)	EStrain	EStress(psi)	
	0.077	3253	0.080	3105	0.045
69	CD	PP TDO 70' from exit	1.968		
	TStrain	TStress(psi)	EStrain	EStress(psi)	
	0.113	4438	0.120	4245	0.043
	0.192	6200	0.212	5661	0.086
	0.260	7595	0.297	6604	0.130
	0.300	8346	0.350	7076	0.152
	0.351	9580	0.421	7705	0.195
	0.393	10166	0.482	8177	0.195

105 MD #1 (6" from center edge) 0.787

TStrain	TStress(psi)	EStrain	EStress(psi)	
0.166	3741	0.181	3426	0.084

103 MD #2 (12" from center edge) 0.787

TStrain	TStress(psi)	EStrain	EStress(psi)	
0.070	3078	0.072	3014	0.020
0.159	4420	0.172	4144	0.062
0.219	5046	0.245	4521	0.104

109 MD #5 (42" from center edge) 0.787

TStrain	TStress(psi)	EStrain	EStress(psi)	
0.077	3078	0.080	3014	0.020
0.130	3974	0.139	3767	0.052
0.178	4521	0.195	4144	0.083
0.219	5046	0.245	4521	0.104
0.276	5734	0.318	4897	0.145
0.317	6409	0.373	5274	0.177
0.359	7138	0.432	5651	0.208
0.410	7927	0.507	6028	0.239

108 MD #6 (48" from center edge) 0.787

TStrain	TStress(psi)	EStrain	EStress(psi)	
0.115	3889	0.122	3728	0.041

115 MD #10 (48" from center edge) 0.787

TStrain	TStress(psi)	EStrain	EStress(psi)	
0.035	2260	0.036	2214	0.020

114 MD #11 (96" from center edge) 0.787

TStrain	TStress(psi)	EStrain	EStress(psi)	
0.038	2474	0.039	2448	0.010
0.103	3538	0.108	3390	0.041
0.168	4521	0.184	4144	0.083
0.201	4893	0.223	4332	0.114
0.250	5513	0.284	4709	0.145

97 MD #12(102" fromm center edge) 0.787

TStrain	TStress(psi)	EStrain	EStress(psi)	
0.056	2637	0.058	2583	0.020
0.123	3734	0.131	3506	0.061

100 CD #13 (6" from center edge) 0.787

TStrain	TStress(psi)	EStrain	EStress(psi)	
0.054	5194	0.055	5086	0.020
0.100	9042	0.106	8665	0.041

104 CD #14 (6" from center edge) 0.787

TStrain	TStress(psi)	EStrain	EStress(psi)	
0.088	8850	0.092	8665	0.020

93 CD #16 (42" from center edge) 0.787

TStrain	TStress(psi)	EStrain	EStress(psi)

0.100	9435	0.106	9042	0.041
0.164	13563	0.178	12433	0.083

113 CD #17 (78" from center edge) 0.787

TStrain	TStress(psi)	EStrain	EStress(psi)	
0.027	3078	0.027	3045	0.010
0.090	7551	0.094	7233	0.042
0.120	10363	0.128	9708	0.063

101 CD #18 (78" from center edge) 0.787

TStrain	TStress(psi)	EStrain	EStress(psi)	
0.075	6059	0.078	5845	0.035
0.115	8465	0.122	8037	0.050
0.149	11008	0.161	10229	0.070

96 CD #19 (84" from center edge) 0.787

TStrain	TStress(psi)	EStrain	EStress(psi)	
0.056	5274	0.058	5167	0.020
0.100	8272	0.106	7935	0.040

66 CD #20 (84" from center edge) 0.787

TStrain	TStress(psi)	EStrain	EStress(psi)	
0.149	13664	0.161	12810	0.062
0.192	17664	0.212	15824	0.104

116 MD PP TDO 10' from exit 1.181

TStrain	TStress(psi)	EStrain	EStress(psi)	
0.125	1048	0.133	994	0.051
0.159	1205	0.172	1118	0.072
0.232	1435	0.262	1242	0.134
0.288	1617	0.334	1367	0.154
0.301	1786	0.351	1491	0.164
0.301	1786	0.351	1491	0.164

117 45 PP North Piece 0.787

TStrain	TStress(psi)	EStrain	EStress(psi)	
0.082	2358	0.085	2308	0.021
0.141	3269	0.151	3078	0.058
0.262	4973	0.300	4232	0.148

118 CD PP TDO 10' from exit 1.181

TStrain	TStress(psi)	EStrain	EStress(psi)	
0.106	2157	0.111	2049	0.05
0.162	2883	0.176	2652	0.08

119 45 PP North Piece 0.787

TStrain	TStress(psi)	EStrain	EStress(psi)	
0.107	1808	0.113	1695	0.062
0.171	2944	0.186	2637	0.104
0.233	4410	0.262	3767	0.145

121 MD PP TDO 10' from exit 1.181

TStrain	TStress(psi)	EStrain	EStress(psi)	

0.002	0	0.002	0	0.02
0.005	0	0.005	0	0.06

Mat.: Material, Orient.: Orientation, Thick.: Thickness, Reduc.: Reduction, PP: Polypropylene.
TStrain: True Strain with respect to neck.
TStress: True Stress with respect to neck.
EStrain: Engineering Strain with respect to neck.
EStress: Engineering Stress with respect to neck.
Neck Reduc.: (Original width of web-New width)/Original width.

Test	Mat.	Orient.	Mat. Note	Thick. (mils)	Ell. A-circle A
31	MD	PP South Piece		0.787	
			Strain	Stress(psi)	
			0.189	1530	-0.01
			0.277	1748	-0.08
			0.487	2137	-0.04
35	MD	PP South Piece		0.787	
			Strain	Stress(psi)	
			0.130	1263	-0.05
			0.226	1505	-0.02
40	CD	PP South Piece		0.787	
			Strain	Stress(psi)	
			0.110	9922	-0.05
42	CD	PP South Piece		0.787	
			Strain	Stress(psi)	
			0.103	8565	-0.05
26	MD	PP North Piece		0.787	
			Strain	Stress(psi)	
			0.111	5586	-0.00
			0.209	7043	-0.02
57	MD	PP TDO 0' from Exit		0.866	
			Strain	Stress(psi)	
			0.206	4452	-0.01
62	MD	PP TDO 0' from Exit		0.866	
			Strain	Stress(psi)	
			0.143	4795	-0.05
			0.275	6165	0.030
60	CD	PP TDO 0' from Exit		0.866	
			Strain	Stress(psi)	
			0.143	13700	-0.05
55	MD	PP TDO 20' from exit		1.259	

			Strain	Stress(psi)	
			0.151	3690	-0.05
59	MD	PP TDO 20' from exit 1.259			
			Strain	Stress(psi)	
			0.151	3532	-0.01
91	CD	PP TDO 20' from exit 1.259			
			Strain	Stress(psi)	
			0.064	4003	-0.02
			0.111	6357	-0.05
94	CD	PP TDO 20' from exit 1.259			
			Strain	Stress(psi)	
			0.084	4914	-0.05
90	MD	PP TDO 30' from exit 1.377			
			Strain	Stress(psi)	
			0.117	2353	-0.05
			0.184	2660	-0.03
			0.239	2967	0.052
			0.306	3171	0.058
			0.390	3478	0.024
			0.471	3785	-0.00
72	MD	PP TDO 30' from exit 1.377			
			Strain	Stress(psi)	
			0.096	2484	-0.09
			0.202	2981	-0.06
			0.334	3577	-0.04
85	MD	PP TDO 40' from exit 1.456			
			Strain	Stress(psi)	
			0.089	2018	-0.05
			0.167	2337	-0.03
			0.217	2762	-0.06
87	MD	PP TDO 40' from exit 1.456			
			Strain	Stress(psi)	
			0.090	1995	-0.07
			0.196	2493	-0.08
			0.304	2793	-0.08
			0.402	3192	-0.07
83	CD	PP TDO 40' from exit 1.456			
			Strain	Stress(psi)	
			0.103	4679	-0.02
77	CD	PP TDO 40' from exit 1.456			
			Strain	Stress(psi)	
			0.106	5950	-0.07
			0.156	7969	-0.05

80	MD	PP TDO 50' from exit 1.574			
			Strain	Stress(psi)	
			0.100	2166	-0.07
			0.248	3014	-0.04
			0.384	3579	-0.04
79	MD	PP TDO 50' from exit 1.574			
			Strain	Stress(psi)	
			0.114	2260	-0.07
25	CD	PP TDO 50' from exit 1.574			
			Strain	Stress(psi)	
			0.193	10201	-0.01
			0.251	11901	-0.02
33	MD	PP TDO 60' from exit 1.771			
			Strain	Stress(psi)	
			0.154	982	-0.01
			0.330	1360	-0.11
			0.450	1586	0.024
43	MD	PP TDO 60' from exit 1.771			
			Strain	Stress(psi)	
			0.111	2536	-0.15
			0.217	3346	-0.06
			0.353	4102	-0.04
			0.456	4318	-0.01
			0.512	4911	-0.01
			0.585	5289	-0.00
50	MD	PP TDO 60' from exit 1.771			
			Strain	Stress(psi)	
			0.132	3935	-0.05
			0.307	5525	0.012
65	MD	PP TDO 60' from exit 1.771			
			Strain	Stress(psi)	
			0.135	34447	-0.05
			0.235	44289	-0.06
			0.412	57412	-0.04
52	CD	PP TDO 60' from exit 1.771			
			Strain	Stress(psi)	
			0.166	7009	-0.05
69	CD	PP TDO 70' from exit 1.968			
			Strain	Stress(psi)	
			0.103	3774	-0.09
			0.191	5346	-0.01
			0.279	6447	-0.02
			0.359	7233	0.024
			0.432	7862	0.171

105 MD #1(6" from center edge) 0.787

Strain	Stress(psi)	
0.111	3045	-0.02

103 MD #2(12" from center edge) 0.787

Strain	Stress(psi)	
0.055	3014	-0.02
0.114	3579	-0.05
0.206	4144	-0.06

106 MD #4(30" from center edge) 0.787

Strain	Stress(psi)	
0.055	3045	-0.02
0.122	3807	-0.05

109 MD #5(42" from center edge) 0.787

Strain	Stress(psi)	
0.066	3014	-0.05
0.122	3579	-0.05
0.178	4144	-0.06
0.228	4521	-0.06
0.301	4897	-0.05
0.357	5274	-0.03
0.418	5651	-0.14
0.490	6028	-0.04

108 MD #6(48" from center edge) 0.787

Strain	Stress(psi)	
0.066	2983	-0.02
0.106	3355	-0.02
0.172	4101	-0.03

115 MD #10(48" from center edge) 0.787

Strain	Stress(psi)	
0.061	2583	-0.00

114 MD #11(96" from center edge) 0.787

Strain	Stress(psi)	
0.061	2825	-0.02
0.150	3767	-0.00
0.251	4521	0.009
0.256	4521	0.001

97 MD #12(102" form center edge) 0.787

Strain	Stress(psi)	
0.041	2399	-0.02
0.108	3321	-0.02

100 CD #13(6" from center edge) 0.787

Strain	Stress(psi)	
0.039	3767	-0.02
0.089	7535	-0.02

104 CD #14(6" from center edge) 0.787

Strain	Stress(psi)	
0.075	5651	-0.02

93 CD #16(42" from center edge) 0.787

Strain	Stress(psi)	
0.117	9419	-0.00
0.167	12056	-0.03
0.251	15070	-0.01

113 CD #17(78" from center edge) 0.787

Strain	Stress(psi)	
0.078	6091	-0.02
0.156	11421	-0.05

101 CD #18(78" from center edge) 0.787

Strain	Stress(psi)	
0.066	5114	-0.02
0.111	7672	-0.02
0.145	9499	-0.05

96 CD #19(84" from center edge) 0.787

Strain	Stress(psi)	
0.044	4059	-0.04
0.089	7012	-0.05

66 CD #20(84" from center edge) 0.787

Strain	Stress(psi)	
0.100	8854	-0.09
0.186	14317	-0.02

67 CD #22(48" from center edge) 0.787

Strain	Stress(psi)	
0.117	10518	-0.09

64 CD #24(12" from center edge) 0.787

Strain	Stress(psi)	
0.116	10549	-0.05

116 MD PP TDO 10' from exit 1.181

Strain	Stress(psi)	
0.106	994	-0.00
0.223	1242	0.059
0.295	1267	-0.00
0.351	1491	-0.01

117 45 PP North Piece 0.787

Strain	Stress(psi)	
0.116	2693	-0.02
0.171	3270	-0.01
0.232	3463	-0.02
0.302	4232	-0.04

118	cd	PP TDO 10' from exit	1.181		
			Strain	Stress(psi)	
			0.141	2411	0.019
			0.200	2893	0.015
119	45	PP North Piece	0.787		
			Strain	Stress(psi)	
			0.131	1883	-0.05
			0.206	2825	-0.02
121	MD	PP TDO 10' from exit	1.181		
			Strain	Stress(psi)	
			0.004	0	-0.05
			0.008	0	-0.02

Mat.: Material, Thick.: Thickness, Ell. A: Ellipse Area, circle A: 1" Circle's area.
Strain: Engineering Strain in MD of Instron.
Stress: Engineering Stress in MD of Instron.

Test	Mat.	Orient. Mat. Note	Thick. (mils)	E (PSI)
31	MD	PP South Piece	0.787	33683
35	MD	PP South Piece	0.787	26045
40	CD	PP South Piece	0.787	87521
42	CD	PP South Piece	0.787	82490
17	45	PP South Piece	0.787	159618
20	45	PP South Piece	0.787	137483
22	MD	PP North Piece	0.787	152377
26	MD	PP North Piece	0.787	119985
30	CD	PP North Piece	0.787	52493
32	CD	PP North Piece	0.787	50763
34	CD	PP North Piece	0.787	38495
23	45	PP North Piece	0.787	175739
57	MD	PP TDO 0' from Exit	0.866	57444
62	MD	PP TDO 0' from Exit	0.866	68026
58	MD	PP TDO 0' from Exit	0.866	124495
61	MD	PP TDO 0' from Exit	0.866	97318
56	CD	PP TDO 0' from Exit	0.866	198847
53	CD	PP TDO 0' from Exit	0.866	177258
60	CD	PP TDO 0' from Exit	0.866	116325
71	CD	PP TDO 10' from exit	1.181	38269
70	CD	PP TDO 10' from exit	1.181	47392
45	MD	PP TDO 10' from exit	1.181	64533
49	CD	PP TDO 10' from exit	1.181	56580
47	CD	PP TDO 10' from exit	1.181	66321
55	MD	PP TDO 20' from exit	1.259	73654
59	MD	PP TDO 20' from exit	1.259	67951
91	CD	PP TDO 20' from exit	1.259	84417
94	CD	PP TDO 20' from exit	1.259	106632
90	MD	PP TDO 30' from exit	1.377	61133
72	MD	PP TDO 30' from exit	1.377	72181
86	CD	PP TDO 30' from exit	1.377	66155

114	MD	#11(96" from center edge)	0.787	86828
97	MD	#12(102" from center edge)	0.787	72455
100	CD	#13(6" from center edge)	0.787	135067
104	CD	#14(6" from center edge)	0.787	81040
102	CD	#15(42" from center edge)	0.787	148527
93	CD	#16(42" from center edge)	0.787	135067
113	CD	#17(78" from center edge)	0.787	98575
101	CD	#18(78" from center edge)	0.787	98230
96	CD	#19(84" from center edge)	0.787	139274
66	CD	#20(84" from center edge)	0.787	168834
68	CD	#21	0.787	114807
67	CD	#22(48" from center edge)	0.787	122860
63	CD	#23(12" from center edge)	0.787	120849
64	CD	#24(12" from center edge)	0.787	106070
116	MD	PP TDO 10' from exit	1.181	22279
117	45	PP North Piece	0.787	41580
119	45	PP North Piece	0.787	31101
120.	CD	PP TDO 10' from exit	1.181	25591

Mat.: Material, Thick.: Thickness, E: Young's Modulus.

Test	Mat. Orient.	Mat. Note	Thick. (mils)	Relax. time (Sec)
31	MD	PP South Piece	0.787	780.3
29	MD	PP North Piece	0.787	739.8
34	CD	PP North Piece	0.787	1085
90	MD	PP TDO 30' from exit	1.377	1181
72	MD	PP TDO 30' from exit	1.377	629.9
87	MD	PP TDO 40' from exit	1.456	1158
77	CD	PP TDO 40' from exit	1.456	784.0
80	MD	PP TDO 50' from exit	1.574	603.0
43	MD	PP TDO 60' from exit	1.771	834.5
65	MD	PP TDO 60' from exit	1.771	907.6
36	MD	PP TDO 70' from exit	1.968	719.2
69	CD	PP TDO 70' from exit	1.968	991.3
109	MD	#5(42" from center edge)	0.787	977.0
116	MD	PP TDO 10' from exit	1.181	595.1
117	45	PP North Piece	0.787	980.9
118	CD	PP TDO 10' from exit	1.181	317.5
119	45	PP North Piece	0.787	739.8
121	MD	PP TDO 10' from exit	1.181	13.65

Relax. time: Relaxation time.

Test	Mat. Orient.	Mat. Note	Thick. (mils)	Wave form. (PSI)
31	MD	PP South Piece	0.787	859
35	MD	PP South Piece	0.787	1020
40	CD	PP South Piece	0.787	4464
42	CD	PP South Piece	0.787	5710
17	45	PP South Piece	0.787	2855
20	45	PP South Piece	0.787	971

22	MD	PP North Piece	0.787	2428
26	MD	PP North Piece	0.787	2671
30	CD	PP North Piece	0.787	1059
32	CD	PP North Piece	0.787	1076
34	CD	PP North Piece	0.787	1700
23	45	PP North Piece	0.787	1774
57	MD	PP TDO 0' from Exit	0.866	3082
62	MD	PP TDO 0' from Exit	0.866	3596
58	MD	PP TDO 0' from Exit	0.866	4646
61	MD	PP TDO 0' from Exit	0.866	3868
56	CD	PP TDO 0' from Exit	0.866	8220
53	CD	PP TDO 0' from Exit	0.866	6576
60	CD	PP TDO 0' from Exit	0.866	7535
45	MD	PP TDO 10' from exit	1.181	1539
47	CD	PP TDO 10' from exit	1.181	1107
55	MD	PP TDO 20' from exit	1.259	2537
59	MD	PP TDO 20' from exit	1.259	2590
94	CD	PP TDO 20' from exit	1.259	3194
24	CD	PP TDO 50' from exit	1.574	1700
25	CD	PP TDO 50' from exit	1.574	728
33	MD	PP TDO 60' from exit	1.771	431
43	MD	PP TDO 60' from exit	1.771	1889
50	MD	PP TDO 60' from exit	1.771	1674
65	MD	PP TDO 60' from exit	1.771	22144
52	CD	PP TDO 60' from exit	1.771	2616
54	CD	PP TDO 60' from exit	1.771	2846
69	CD	PP TDO 70' from exit	1.968	2673
93	CD	#16(42" from center edge)	0.787	4897
67	CD	#22(48" from center edge)	0.787	4798
64	CD	#24(12" from center edge)	0.787	6028
116	MD	PP TDO 10' from exit	1.181	372
117	45	PP North Piece	0.787	1539
118	CD	PP TDO 10' from exit	1.181	1929
119	45	PP North Piece	0.787	1130
120.	CD	PP TDO 10' from exit	1.181	1205

Wave form.: Wave formation or Onset of Waves.

Test	Mat. Orient.	Mat. Note	Thick. (mils)	Wave form. (PLI)
31	MD	PP South Piece	0.787	0.677
35	MD	PP South Piece	0.787	0.803
40	CD	PP South Piece	0.787	3.515
42	CD	PP South Piece	0.787	4.496
17	45	PP South Piece	0.787	2.248
20	45	PP South Piece	0.787	0.765
22	MD	PP North Piece	0.787	1.912
26	MD	PP North Piece	0.787	2.103
30	CD	PP North Piece	0.787	0.834
32	CD	PP North Piece	0.787	0.847
34	CD	PP North Piece	0.787	1.338
23	45	PP North Piece	0.787	1.396
57	MD	PP TDO 0' from Exit	0.866	2.67

62	MD	PP TDO 0' from Exit	0.866	3.115
58	MD	PP TDO 0' from Exit	0.866	4.024
61	MD	PP TDO 0' from Exit	0.866	3.350
56	CD	PP TDO 0' from Exit	0.866	7.12
53	CD	PP TDO 0' from Exit	0.866	5.696
60	CD	PP TDO 0' from Exit	0.866	6.526
45	MD	PP TDO 10' from exit	1.181	1.817
47	CD	PP TDO 10' from exit	1.181	1.307
55	MD	PP TDO 20' from exit	1.259	3.196
59	MD	PP TDO 20' from exit	1.259	3.263
94	CD	PP TDO 20' from exit	1.259	4.024
24	CD	PP TDO 50' from exit	1.574	2.677
25	CD	PP TDO 50' from exit	1.574	1.147
33	MD	PP TDO 60' from exit	1.771	0.765
43	MD	PP TDO 60' from exit	1.771	3.346
50	MD	PP TDO 60' from exit	1.771	2.966
65	MD	PP TDO 60' from exit	1.771	39.23
52	CD	PP TDO 60' from exit	1.771	4.636
54	CD	PP TDO 60' from exit	1.771	5.043
69	CD	PP TDO 70' from exit	1.968	5.262
93	CD	#16(42" from center edge)	0.787	3.856
67	CD	#22(48" from center edge)	0.787	3.777
64	CD	#24(12" from center edge)	0.787	4.746
116	MD	PP TDO 10' from exit	1.181	0.440
117	45	PP North Piece	0.787	1.211
118	CD	PP TDO 10' from exit	1.181	2.278
119	45	PP North Piece	0.787	0.89
120	CD	PP TDO 10' from exit	1.181	1.424

Test Mat. Orient. Mat. Note Thick. (mils) Elastic Rec.

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35 MD PP South Piece 0.787
Elastic Neck Recovery (Nu-Nl/Nl)= 0.047
Elastic Major Axis Recovery (Mu-Ml/Ml)= -0.13
Elastic Minor Axis Recovery (Mu-Ml/Ml)= 0.076

40 CD PP South Piece 0.787
Elastic Neck Recovery (Nu-Nl/Nl)= 0.059
Elastic Major Axis Recovery (Mu-Ml/Ml)= -0.05
Elastic Minor Axis Recovery (Mu-Ml/Ml)= 0.035

42 CD PP South Piece 0.787
Elastic Neck Recovery (Nu-Nl/Nl)= 0.042
Elastic Major Axis Recovery (Mu-Ml/Ml)= -0.05
Elastic Minor Axis Recovery (Mu-Ml/Ml) 0.071

21 45 PP South Piece 0.787
Elastic Neck Recovery (Nu-Nl/Nl)= ----
Elastic Major Axis Recovery (Mu-Ml/Ml)= -0.09
Elastic Minor Axis Recovery (Mu-Ml/Ml)= 0.2

26 MD PP North Piece 0.787
Elastic Neck Recovery (Nu-Nl/Nl)= ----

```
     Elastic Major Axis Recovery (Mu-Ml/Ml)=   0.212
     Elastic Minor Axis Recovery (Mu-Ml/Ml)=  -0.2

29   MD   PP North Piece           0.787
     Elastic Neck Recovery (Nu-Nl/Nl)=         0
     Elastic Major Axis Recovery (Mu-Ml/Ml)=  -0.09
     Elastic Minor Axis Recovery (Mu-Ml/Ml)=   0

34   CD   PP North Piece           0.787
     Elastic Neck Recovery (Nu-Nl/Nl)=         ----
     Elastic Major Axis Recovery (Mu-Ml/Ml)=  -0.05
     Elastic Minor Axis Recovery (Mu-Ml/Ml)=   0.037

57   MD   PP TDO 0' from Exit      0.866
     Elastic Neck Recovery (Nu-Nl/Nl)=         0.069
     Elastic Major Axis Recovery (Mu-Ml/Ml)=  -0.11
     Elastic Minor Axis Recovery (Mu-Ml/Ml)=   0.071

62   MD   PP TDO 0' from Exit      0.866
     Elastic Neck Recovery (Nu-Nl/Nl)=         0.073
     Elastic Major Axis Recovery (Mu-Ml/Ml)=  -0.13
     Elastic Minor Axis Recovery (Mu-Ml/Ml)=   0

61   MD   PP TDO 0' from Exit      0.866
     Elastic Neck Recovery (Nu-Nl/Nl)=         0.020
     Elastic Major Axis Recovery (Mu-Ml/Ml)=   ----
     Elastic Minor Axis Recovery (Mu-Ml/Ml)=   ----

53   CD   PP TDO 0' from Exit      0.866
     Elastic Neck Recovery (Nu-Nl/Nl)=         0.020
     Elastic Major Axis Recovery (Mu-Ml/Ml)=   ----
     Elastic Minor Axis Recovery (Mu-Ml/Ml)=   ----

60   CD   PP TDO 0' from Exit      0.866
     Elastic Neck Recovery (Nu-Nl/Nl)=         0.021
     Elastic Major Axis Recovery (Mu-Ml/Ml)=  -0.05
     Elastic Minor Axis Recovery (Mu-Ml/Ml)=   0.107

55   MD   PP TDO 20' from exit     1.259
     Elastic Neck Recovery (Nu-Nl/Nl)=         0.068
     Elastic Major Axis Recovery (Mu-Ml/Ml)=  -0.05
     Elastic Minor Axis Recovery (Mu-Ml/Ml)=   0.071

59   MD   PP TDO 20' from exit     1.259
     Elastic Neck Recovery (Nu-Nl/Nl)=         0.069
     Elastic Major Axis Recovery (Mu-Ml/Ml)=  -0.08
     Elastic Minor Axis Recovery (Mu-Ml/Ml)=   0.071

91   CD   PP TDO 20' from exit     1.259
     Elastic Neck Recovery (Nu-Nl/Nl)=         0.021
     Elastic Major Axis Recovery (Mu-Ml/Ml)=  -0.02
     Elastic Minor Axis Recovery (Mu-Ml/Ml)=   0.035
```

90	MD PP TDO 30' from exit	1.377	
	Elastic Neck Recovery (Nu-Nl/Nl)=		0.261
	Elastic Major Axis Recovery (Mu-Ml/Ml)=		-0.13
	Elastic Minor Axis Recovery (Mu-Ml/Ml)=		0.130
72	MD PP TDO 30' from exit	1.377	
	Elastic Neck Recovery (Nu-Nl/Nl)=		0.071
	Elastic Major Axis Recovery (Mu-Ml/Ml)=		----
	Elastic Minor Axis Recovery (Mu-Ml/Ml)=		----
87	MD PP TDO 40' from exit	1.456	
	Elastic Neck Recovery (Nu-Nl/Nl)=		-0.08
	Elastic Major Axis Recovery (Mu-Ml/Ml)=		-0.14
	Elastic Minor Axis Recovery (Mu-Ml/Ml)=		0.272
80	MD PP TDO 50' from exit	1.574	
	Elastic Neck Recovery (Nu-Nl/Nl)=		0.064
	Elastic Major Axis Recovery (Mu-Ml/Ml)=		-0.1
	Elastic Minor Axis Recovery (Mu-Ml/Ml)=		-0.41
25	CD PP TDO 50' from exit	1.574	
	Elastic Neck Recovery (Nu-Nl/Nl)=		----
	Elastic Major Axis Recovery (Mu-Ml/Ml)=		-0.13
	Elastic Minor Axis Recovery (Mu-Ml/Ml)=		0.076
33	MD PP TDO 60' from exit	1.771	
	Elastic Neck Recovery (Nu-Nl/Nl)=		0.095
	Elastic Major Axis Recovery (Mu-Ml/Ml)=		-0.13
	Elastic Minor Axis Recovery (Mu-Ml/Ml)=		0.083
43	MD PP TDO 60' from exit	1.771	
	Elastic Neck Recovery (Nu-Nl/Nl)=		0.069
	Elastic Major Axis Recovery (Mu-Ml/Ml)=		-0.13
	Elastic Minor Axis Recovery (Mu-Ml/Ml)=		0.090
50	MD PP TDO 60' from exit	1.771	
	Elastic Neck Recovery (Nu-Nl/Nl)=		0.022
	Elastic Major Axis Recovery (Mu-Ml/Ml)=		-0.17
	Elastic Minor Axis Recovery (Mu-Ml/Ml)=		0.076
52	CD PP TDO 60' from exit	1.771	
	Elastic Neck Recovery (Nu-Nl/Nl)=		0
	Elastic Major Axis Recovery (Mu-Ml/Ml)=		-0.05
	Elastic Minor Axis Recovery (Mu-Ml/Ml)=		0.071
36	MD PP TDO 70' from exit	1.968	
	Elastic Neck Recovery (Nu-Nl/Nl)=		0.025
	Elastic Major Axis Recovery (Mu-Ml/Ml)=		-0.09
	Elastic Minor Axis Recovery (Mu-Ml/Ml)=		0.083
51	CD PP TDO 70' from exit	1.968	
	Elastic Neck Recovery (Nu-Nl/Nl)=		-0.04
	Elastic Major Axis Recovery (Mu-Ml/Ml)=		-0.08

Elastic Minor Axis Recovery (Mu-Ml/Ml)= 0.071

69 CD PP TDO 70' from exit 1.968
Elastic Neck Recovery (Nu-Nl/Nl)= 0
Elastic Major Axis Recovery (Mu-Ml/Ml)= -0.23
Elastic Minor Axis Recovery (Mu-Ml/Ml)= 0

109 MD #5(42" from center edge) 0.787
Elastic Neck Recovery (Nu-Nl/Nl)= 0.082
Elastic Major Axis Recovery (Mu-Ml/Ml)= -0.13
Elastic Minor Axis Recovery (Mu-Ml/Ml)= 0.090

93 CD #16(42" from center edge) 0.787
Elastic Neck Recovery (Nu-Nl/Nl)= 0.045
Elastic Major Axis Recovery (Mu-Ml/Ml)= -0.08
Elastic Minor Axis Recovery (Mu-Ml/Ml)= 0.071

116 MD PP TDO 10' from exit 1.181
Elastic Neck Recovery (Nu-Nl/Nl)= 0.061
Elastic Major Axis Recovery (Mu-Ml/Ml)= -0.14
Elastic Minor Axis Recovery (Mu-Ml/Ml)= 0.166

117 45 PP North Piece 0.787
Elastic Neck Recovery (Nu-Nl/Nl)= 0.1
Elastic Major Axis Recovery (Mu-Ml/Ml)= -0.1
Elastic Minor Axis Recovery (Mu-Ml/Ml)= 0.166

118 CD PP TDO 10' from exit 1.181
Elastic Neck Recovery (Nu-Nl/Nl)= 0.043
Elastic Major Axis Recovery (Mu-Ml/Ml)= -0.08
Elastic Minor Axis Recovery (Mu-Ml/Ml)= 0.034

119 45 PP North Piece 0.787
Elastic Neck Recovery (Nu-Nl/Nl)= 0.073
Elastic Major Axis Recovery (Mu-Ml/Ml)= -0.05
Elastic Minor Axis Recovery (Mu-Ml/Ml)= 0.076

121 MD PP TDO 10' from exit 1.181
Elastic Neck Recovery (Nu-Nl/Nl)= -0.03
Elastic Major Axis Recovery (Mu-Ml/Ml)= -0.07
Elastic Minor Axis Recovery (Mu-Ml/Ml)= 0.076

Elastic Rec.: Elastic Recovery.
(Nu-Nl/Nl): (Unload Neck dimension-last measured Loaded Neck dimension)/last measured Loaded Neck dimension.
(Mu-Ml/Ml): (Unload Axis dimension-last measured Loaded Axis dimension)/last measured Loaded Axis dimension.

Test	Mat. Orient.	Mat. Note		Thick. (mils)	Ell. Strains	
31	MD	PP South Piece		0.787		
			Strain	Stress(psi)	Major	Minor
			0.189	1530	0.117	-0.13
			0.277	1748	0.171	-0.28
			0.487	2137	0.318	-0.37
35	MD	PP South Piece		0.787		
			Strain	Stress(psi)	Major	Minor
			0.130	1263	0.060	-0.13
			0.226	1505	0.171	-0.20
40	CD	PP South Piece		0.787		
			Strain	Stress(psi)	Major	Minor
			0.110	9922	0.060	-0.13
42	CD	PP South Piece		0.787		
			Strain	Stress(psi)	Major	Minor
			0.103	8565	0.060	-0.13
26	MD	PP North Piece		0.787		
			Strain	Stress(psi)	Major	Minor
			0.111	5586	0.060	-0.06
			0.209	7043	0.030	-0.06
34	CD	PP North Piece		0.787		
			Strain	Stress(psi)	Major	Minor
			0.127	3400	0.060	-0.13
			0.217	4906	0.117	-0.16
62	MD	PP TDO 0' from Exit		0.866		
			Strain	Stress(psi)	Major	Minor
			0.143	4795	0.060	-0.13
			0.275	6165	0.171	-0.13
60	CD	PP TDO 0' from Exit		0.866		
			Strain	Stress(psi)	Major	Minor
			0.143	13700	0.060	-0.13
59	MD	PP TDO 20' from exit		1.259		
			Strain	Stress(psi)	Major	Minor
			0.151	3532	0.117	-0.13
91	CD	PP TDO 20' from exit		1.259		
			Strain	Stress(psi)	Major	Minor
			0.064	4003	0.030	-0.06
			0.111	6357	0.060	-0.13
94	CD	PP TDO 20' from exit		1.259		
			Strain	Stress(psi)	Major	Minor
			0.084	4914	0.060	-0.13

90 MD PP TDO 30' from exit 1.377

Strain	Stress(psi)	Major	Minor
0.117	2353	0.060	-0.13
0.184	2660	0.117	-0.16
0.239	2967	0.271	-0.20
0.306	3171	0.318	-0.24
0.390	3478	0.318	-0.28
0.471	3785	0.318	-0.33

72 MD PP TDO 30' from exit 1.377

Strain	Stress(psi)	Major	Minor
0.096	2484	0	-0.13
0.202	2981	0.117	-0.20
0.334	3577	0.223	-0.28

85 MD PP TDO 40' from exit 1.456

Strain	Stress(psi)	Major	Minor
0.089	2018	0.030	-0.09
0.167	2337	0.089	-0.13
0.217	2762	0.117	-0.20

87 MD PP TDO 40' from exit 1.456

Strain	Stress(psi)	Major	Minor
0.090	1995	0.030	-0.13
0.196	2493	0.089	-0.20
0.304	2793	0.171	-0.28
0.402	3192	0.271	-0.37

83 CD PP TDO 40' from exit 1.456

Strain	Stress(psi)	Major	Minor
0.103	4679	0.030	-0.06

77 CD PP TDO 40' from exit 1.456

Strain	Stress(psi)	Major	Minor
0.106	5950	0.030	-0.13
0.156	7969	0.060	-0.13

80 MD PP TDO 50' from exit 1.574

Strain	Stress(psi)	Major	Minor
0.100	2166	0.030	-0.13
0.248	3014	0.223	-0.28
0.384	3579	0.223	-0.28

79 MD PP TDO 50' from exit 1.574

Strain	Stress(psi)	Major	Minor
0.114	2260	0.030	-0.13

25 CD PP TDO 50' from exit 1.574

Strain	Stress(psi)	Major	Minor
0.193	10201	0.117	-0.13
0.251	11901	0.171	-0.20

33 MD PP TDO 60' from exit 1.771

			Strain	Stress(psi)	Major	Minor
			0.154	982	0.117	-0.13
			0.330	1360	0.223	-0.37
			0.450	1586	0.318	-0.28
43	MD	PP TDO 60' from exit	1.771			
			Strain	Stress(psi)	Major	Minor
			0.111	2536	0.060	-0.28
			0.217	3346	0.117	-0.20
			0.353	4102	0.223	-0.28
			0.456	4318	0.271	-0.28
			0.512	4911	0.271	-0.28
			0.585	5289	0.362	-0.37
50	MD	PP TDO 60' from exit	1.771			
			Strain	Stress(psi)	Major	Minor
			0.132	3935	0.060	-0.13
			0.307	5525	0.223	-0.20
65	MD	PP TDO 60' from exit	1.771			
			Strain	Stress(psi)	Major	Minor
			0.135	34447	0.060	-0.13
			0.235	44289	0.117	-0.20
			0.412	57412	0.223	-0.28
52	CD	PP TDO 60' from exit	1.771			
			Strain	Stress(psi)	Major	Minor
			0.166	7009	0.060	-0.13
69	CD	PP TDO 70' from exit	1.968			
			Strain	Stress(psi)	Major	Minor
			0.103	3774	0	-0.13
			0.191	5346	0.117	-0.13
			0.279	6447	0.171	-0.20
			0.359	7233	0.318	-0.28
			0.432	7862	0.485	-0.28
105	MD	#1(6" from center edge)	0.787			
			Strain	Stress(psi)	Major	Minor
			0.111	3045	0.060	-0.09
103	MD	#2(12" from center edge)	0.787			
			Strain	Stress(psi)	Major	Minor
			0.055	3014	0.030	-0.06
			0.114	3579	0.060	-0.13
			0.206	4144	0.117	-0.20
106	MD	#4(30" from center edge)	0.787			
			Strain	Stress(psi)	Major	Minor
			0.055	3045	0.030	-0.06
			0.122	3807	0.060	-0.13
109	MD	#5(42" from center edge)	0.787			

Strain	Stress(psi)	Major	Minor
0.066	3014	0.030	-0.09
0.122	3579	0.060	-0.13
0.178	4144	0.089	-0.16
0.228	4521	0.117	-0.20
0.301	4897	0.171	-0.24
0.357	5274	0.247	-0.28
0.418	5651	0.271	-0.47
0.490	6028	0.318	-0.37

108 MD #6(48" from center edge) 0.787

Strain	Stress(psi)	Major	Minor
0.066	2983	0	-0.03
0.106	3355	0.030	-0.06
0.172	4101	0.089	-0.13

115 MD #10(48" from center edge) 0.787

Strain	Stress(psi)	Major	Minor
0.061	2583	0.030	-0.03

114 MD #11(96" from center edge) 0.787

Strain	Stress(psi)	Major	Minor
0.061	2825	0.030	-0.06
0.150	3767	0.089	-0.09
0.251	4521	0.145	-0.13
0.256	4521	0.171	-0.16

97 MD #12(102" form center edge) 0.787

Strain	Stress(psi)	Major	Minor
0.041	2399	0	-0.03
0.108	3321	0.030	-0.06

100 CD #13(6" from center edge) 0.787

Strain	Stress(psi)	Major	Minor
0.039	3767	0	-0.03
0.089	7535	0.030	-0.06

104 CD #14(6" from center edge) 0.787

Strain	Stress(psi)	Major	Minor
0.075	5651	0.030	-0.06

93 CD #16(42" from center edge) 0.787

Strain	Stress(psi)	Major	Minor
0.117	9419	0.060	-0.06
0.167	12056	0.089	-0.13
0.251	15070	0.117	-0.13

113 CD #17(78" from center edge) 0.787

Strain	Stress(psi)	Major	Minor
0.078	6091	0.030	-0.06
0.156	11421	0.060	-0.13

101 CD #18(78" from center edge) 0.787

			Strain	Stress(psi)	Major	Minor
			0.066	5114	0.030	-0.06
			0.111	7672	0.060	-0.09
			0.145	9499	0.060	-0.13
96	CD	#19(84" from center edge) 0.787				
			Strain	Stress(psi)	Major	Minor
			0.044	4059	0	-0.06
			0.089	7012	0.030	-0.09
66	CD	#20(84" from center edge) 0.787				
			Strain	Stress(psi)	Major	Minor
			0.100	8854	0	-0.13
			0.186	14317	0.171	-0.20
68	CD	#21 0.787				
			Strain	Stress(psi)	Major	Minor
			0.064	6405	0	-0.06
67	CD	#22(48" from center edge) 0.787				
			Strain	Stress(psi)	Major	Minor
			0.117	10518	0	-0.13
64	CD	#24(12" from center edge) 0.787				
			Strain	Stress(psi)	Major	Minor
			0.116	10549	0.060	-0.13
116	MD	PP TDO 10' from exit 1.181				
			Strain	Stress(psi)	Major	Minor
			0.106	994	0.060	-0.06
			0.223	1242	0.171	-0.09
			0.295	1267	0.197	-0.20
			0.351	1491	0.271	-0.28
117	45	PP North Piece 0.787				
			Strain	Stress(psi)	Major	Minor
			0.116	2693	0.060	-0.09
			0.171	3270	0.117	-0.13
			0.232	3463	0.171	-0.20
			0.302	4232	0.223	-0.28
118	CD	PP TDO 10' from exit 1.181				
			Strain	Stress(psi)	Major	Minor
			0.141	2411	0.089	-0.06
			0.200	2893	0.117	-0.09
119	45	PP North Piece 0.787				
			Strain	Stress(psi)	Major	Minor
			0.131	1883	0.060	-0.13
			0.206	2825	0.171	-0.20
121	MD	PP TDO 10' from exit 1.181				
			Strain	Stress(psi)	Major	Minor

	0.004	0	0.060	-0.13
	0.008	0	0.171	-0.20

Ell. strains: True Strains of Major and Minor axes of the Ellipses.

APPENDIX D

CALIBRATION FOR INSTRON SYSTEM

5 pound standard weight caused the following displacements:

at 25 millivolts per centimeter:	5/8 inches;
at 0.05 Volts per centimeter:	9/32 inches;
at 0.25 Volts per centimeter:	1/16 inches;
at 0.5 Volts per centimeter:	1/32 inches.

10 pound standard weight caused the following displacements:

at 25 millivolts per centimeter:	1 1/8 inches;
at 0.05 Volts per centimeter:	9/16 inches;
at 0.25 Volts per centimeter:	1/8 inches;

Time ellapsed on the plotter was so close to that of the standard that the difference was negligible. The standard is 10 second = 10 second and 120 seconds = 120 seconds.

APPENDIX E

TEST BLANK

WEB HANDLING MATERIAL TESTING.

DATE/TEST NUMBER ______ ______

Adhesive:
Material:
Thickness: _____ in. (_____mm)
Test Specimen Size:
Test Specimen Grip: Roll ___ Clamp ___
Material Orientation: MD ___ CD ___ Other ___
# of times wrapped around bar:
Test temperature: ___ F (____ C)
Crosshead Speed: ____ (in/min)

Superimposed Grid ___ Circles dia. ____ in.
___ Squares side ____ in.
___ Other description:

Observations:

Necking:

Center buckling:

Cross web waves:

End Failure:

Edge Failure:

Other:

VITA

Scott E. Robertson

Candidate for the Degree of

Master of Science

Thesis: DETERMINATION OF VARIATIONS IN CERTAIN MECHANICAL PROPERTIES ACROSS THE WIDTH OF A FINISHED PRODUCT OF POLYPROPYLENE WEB

Major Field: Mechanical Engineering

Biographical:

Personal Data: Born in Tulsa, Oklahoma, November 22, 1963, the son of Dick Ross and Vida Marie Robertson.

Education: Graduated from Broken Arrow High School, Broken Arrow, Oklahoma, in May 1982; recieved Bachelor of Science Degree in Mechanical Engineering from Oklahoma State University at Stillwater in May, 1986; completed requirements for Masters of Science degree at Oklahoma State University in May, 1989.

Professional Experience: Teaching Assistant, Department of Mechanical Engineering, Oklahoma State University, August, 1986, to May, 1987. Web Handling Researcher, Department of Mechanical Engineering, Oklahoma State University, June, 1988, to January,1989.