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TENSILE COMPARISON OF THE VARIABLES USING THE STATASYS 3-D MODELER

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TENSILE COMPARISON OF THE
VARIABLES USING THE STRATASYS
3-D MODELER

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by

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An Abstract of the Thesis by

William Oscar Birt

The objective of this study was to investigate some of the different variables that were used in building a prototype model on the Stratasys 3-D Modeler.

Variables tested were: 1) speed of the head (.2 in. per second, .4 in. per second, .6 in. per second). 2) z slice (.010 in., .020 in., .030 in. [maximum possible z slice]). 3) road width (.025 in., .050 in., .075 in.). 4) orientation angle of the path (0 degrees, 45 degrees, 90 degrees in the x-y plane). 5) tip and liquefier temperatures ([lowest possible temperature] 119 degrees Celsius, 124 degrees Celsius, 128 degrees Celsius [highest possible temperature]). 6) envelope temperature (15 degrees Celsius, 23 degrees Celsius, 30 degrees Celsius).

There were 34 tests and each test had 10 specimens in it for a total of 340 tensile specimens. Each test consisted of the six variables, stated previously.

Tests indicated that the "orientation angle" variable had the greatest effect on tensile strength. As the angle

approached 90 degrees in the x-y plane, the tensile strength increased. The variable having the second greatest effect on tensile strength was "road width" with .050 in. road width providing the strongest specimens of the three road widths. The third greatest effect was found to be the "z slice", .030 in., which was the maximum recommended z slice. As the z slice increased, the tensile strength increased. Results of tests showed that two variables-- "speed of the head" and "liquefier and tip" tied showing they had the same effect upon the tensile strength of the specimens. The tensile strength of test specimens were higher at the .2 in. per second. As with the temperature of the tip and liquefier, the tensile strength was higher at the 119 degrees Celsius temperature. The variable that had the least amount of significance was the envelope temperature of 104 degrees Celsius.

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Chapter I

Introduction

Since the beginning of time, people have been making prototypes out of clay and wax. This process has always been a very long drawn out process taking months and sometimes years to complete just one model.

The Egyptians were the first to develop the process called "lost wax process" which involves forming wax into a model and then putting clay around the wax model. The next step was to put the model into a furnace to bake the clay and melt the wax out. Their method had one draw back, the person making the wax model had to be a skilled craftsmen. Years of training were required to become a skilled craftsmen. The Egyptians kept their model making procedure a secret for almost 100 years. This method is still being used today.

In the early 1900's, polymer materials were discovered and allowed man to produce models faster, but the person still had to be a skilled craftsmen. In 1989, a company called Stratasys produced a machine that could take a computer aided drafting design (CADD) file and generate a three-dimensional (3-D) model from it. The time required to produce a prototype using the Stratasys equipment reduced model making time to days instead of months or years.

There are several variables that are associated with the use of the Stratasys equipment. In order to understand these variables, one must study them in detail. This research study

provides modelers information about the effects of these variables on making a model. By understanding and controlling these variables, the best possible models can be produced.

Problem Statement

What effect do the variables-- orientation of the road path, road width, speed, envelope temperature, liquefier temperature, tip temperature, and z slice have on the tensile strength of polyamide (P300) test specimens that were produced by the Stratasys 3-D modeler, compared to a standard ASTM tensile specimen that was produced by an injection molding machine?

Subproblems

The following subproblems were addressed:

1. To determine the effect of the orientation of the road path upon test specimen strength. The three orientations were: 0 degrees, 45 degrees, and 90 degrees in the x-y plane.

2. To determine the effect of the road width upon the test specimen strength. The three road widths were: .025 in., .050 in., and .075 in.

3. To determine the effect of the z slice upon the test specimen strength. The three z slices were: .010 in., .020 in., and .030 in..

4. To determine the effect of the envelope temperature upon the test specimen strength. The three temperatures were: 15 degrees Celsius, 23 degrees Celsius, and 30 degrees Celsius.

5. To determine the effect of the liquefier and tip temperatures upon the test specimen strength. The three temperatures were: 119 degrees Celsius, 124 degrees Celsius,

and 128 degrees Celsius.

6. To determine the effect of the speed of the head upon the test specimen strength. The three speeds were: .2 in. per second, .4 in. per second, .6 in. per second.

Null-Hypotheses

The following null-hypotheses were tested:

1. There will be no significant difference between the tensile strength of the test specimens using different temperatures of the polymer melt or tip, and the control sample.

2. There will be no significant difference between the tensile strength of the test specimens using different orientations angle and the control sample

3. There will be no significant difference between the tensile strength of the test specimens using different road widths and the control sample.

4. There will be no significant difference between the tensile strength of the test specimens using different z slices and the control sample.

5. There will be no significant difference between the tensile strength of the test specimens using different envelope temperatures and the control sample.

6. There will be no significant difference between the tensile strength of the test specimens using different speeds of the head and the control sample.

Assumptions

The assumptions for this research study were:

1. Polyamide (P300) material used in making both test specimens and control specimens is identical in composition. The only difference is the type of machine used to produce the specimens.

2. The Stratasys 3-D Modeler was fully operational and functioned normally within the processing parameters during this sequence of sample part production and that the Stratasys equipment was calibrated correctly.

Significance of the Study

The research study was significant in that it:

1. Determined effects of orientation of the road path, speed, road width, z slice, and temperatures of the liquefier, tip, and envelope had upon the test specimens while specimens were being manufactured by the Stratasys 3-D modeler.

2. Determined which variables had the greatest effect upon tensile strength of the specimen, enabling one to apply the knowledge gained to optimize the model making process.

3. Determined variable settings for making test specimens in terms of tensile strength, including the best speed, temperatures of the tip, liquefier, and envelope, z slice, orientation of the road path, and road width.

Delimitations

The delimitations of this research study included the following:

1. The study did not evaluate any material other than polyamide (P300), supplied by Stratasys Inc. The specimens made were representative of the same type of material tested.
2. The study was limited to testing the tensile strength of polyamide (P300) specimens. No other mechanical properties were checked.
3. The study did not evaluate the preparation and training needed to operate the Stratasys equipment.
4. The study was limited to the equipment at Pittsburg State University, for testing and preparing the test specimens.
5. The study was limited to the tensile test bar mold at Pittsburg State University and the injection mold machine-- Van Dorn 75, serial number 75-RS-3F-1898.

Define Terms

ASTM — ASTM stands for American Standard for Testing and Material.

CNC — Computer numerical control (CNC) is a way of controlling equipment with a computer using numerical control.

Envelope — Envelope is an area were the model or test piece is made.

Injection - molding - machine — Injection molding machine is a device that forms plastic pellet into a usable form by

	injecting the material into a mold under pressure.
Liquefier	Liquefier is a device that melts the filament.
Orientation	Orientation is the angle of the road path for the reference line.
Polyamide	Polyamide is a polymer that is based on nitrogen branch polymer.
P(300)	P(300) is the trade name that Stratasys uses for Polyamide, which is the type of material compounded to their specifications.
Rapid-prototyping	Rapid prototyping is a method of production that produces the first test model.
Road width	Road width is the distance from one edge to the other edge, 90 degrees from the direction of the road.
"Set" group	Set group is a group of 10 specimens that have all of the same testing variables.
Speed	Speed is the rate of travel over a given distance.
Stratasys - 3-D Modeler	Stratasys 3-D Modeler is a rapid prototyping device that is used in making prototypes or models from a computer aided drafting program.
Tensile - strength	Tensile Strength is the relation between the stress vs strain resulting from pulling forces exerting stress on a specimen.
Test specimen	Test specimen is a piece of material that is designed in testing the strength of a certain kind of material, and is made in accordance to ASTM guide lines.
Tip	Tip is a device that is placed on the end of the liquefier to obtain the certain range road widths.
Z slice	Z slice is the thickness of the material in the vertical direction.

Chapter II

Review of the Related Literature

Historical Overview

Since the beginning of time, people have configured materials to meet their needs. Examples included making a weapon out of flint, or molding clay into containers to hold water. As people continued to progress through time, they assimilated new materials and developed new techniques of constructing materials from their environment to suit their demands. People soon discovered that they could heat up copper and tin to manufacture an alloy called bronze. People discovered that molten metal poured into containers and allowed to solidify would take the from of the mold cavity.

In the present day, people still melt metals and pour it into molds to produce parts. The techniques used to process the materials are different and the methods of manufacturing molds have changed over time. Presently, people no longer have to hammer away at stone to make mold patterns. Today people may use a machine called the Stratasys 3-D Modeler and high speed computers to design parts in the casting industry. To appreciate the new technology, one must have some knowledge of the evolution of technology of the casting industry.

History of the Casting Industry

The first documented casting was found in the Middle East. The Babylonians are acknowledged for discovering how to cast copper into religious artifacts. "The oldest known

casting in existence, a cast copper frog found in Mesopotamia, probably cast about 3200 BC " (Simpson, 1969,13). In 3200 BC, the only mold fabricating materials were stone, or clay. A person would have to unearth suitable size stones and carve out the cavities. The stones would then be fastened together and the molten metal poured into the cavity. The mold manufacturing process took around four to five months to make the first mold.

Later people realized that they could construct parts from wax by forming clay around the wax patterns, and then baking the clay so the wax would melt away creating a cavity in the desired shape. Then, molten metal (gold, silver, copper) was poured into the cavity and allowed to solidify. The hard clay was removed from around the part, so the craftsman could obtain their casting. This technique was called the "lost wax method". This allowed people to develop weapons and tools so that they could satisfy their needs in adapting to their environment. The modern day form of this process, called "investment casting", involves a wax pattern that is immersed into a ceramic slurry to construct a shell. The ceramic mold assembly is then heated up so the wax pattern melts out, producing a mold cavity.

In the late 1800s and early 1900s, other techniques of mold manufacturing transformed the casting industry. Workers soon discovered how to use cores and special formulation of sands to manufacture larger and better parts. The mold

patterns still had to be fabricated by hand using power tools, which helped accelerate the mold manufacturing procedure.

After World War II, many advances took place in the casting industry. As plastics were invented, mold patterns were being fabricated from epoxy and polyurthane resins which increased the production of mold patterns. The biggest advancement came in the 1960s when "H. F. Shroyer was granted a patent for the use of the polystyrene for mold patterns" (Simpson, 1969,245). Capabilities to make mold patterns increased because now they could replicate a mold pattern in a matter of weeks instead of months. This new technique allowed the manufacture of substantially larger and more intricate parts, but it was still time consuming to manufacture the final merchandise.

Industry had to wait 28 years for more favorable rapid prototyping technologies to emerge. One of these new technologies was Fused Deposition Modeling (FDM). The evolution of the computer was critical to this technology. Fused Deposition Modeling (FDM) technology required a computer that could perform millions of operations per second and could handle complex 3-D solid modeling.

History and Description of Stratasys, Inc.

"In 1988 Stratasys, Inc. was founded and in 1990 the first Stratasys product, the 3-D Modeler was announced" (The Company, 1992,1). The Stratasys 3-D modeler employs Fused Deposition Modeling (FDM) technology. This technique involves

starting out on a UNIX based workstation with a central processing unit that is based on reduce instruction-set computing (RISC). Application software used by the system is called Camax, a very powerful computer-aided drafting and computer aided manufacturing software package that produces computer numerical code (CNC). The part can be designed using the Camax software or it can be imported via diskettes as IGES or STL format files (Crump, 1992,36).

Once the part is in the workstation memory, the part can be sliced into mathematical layers. Layers can vary in thickness from .002 of an in. to .030 in. thick. The road width can vary from to .009 in. to .250 in. in width (Fused Deposition Modeling, 1992,1). Once the part has been sliced, the next step is to generate a (CNC) code. The code (CNC) is then downloaded into the Stratasys 3-D Modeler via a serial RS-232 port (Concept Modeling, 1992,1). Once the file is in the 3-D Modeler memory, the construction procedure begins.

The material, plastic filament wrapped on a spool in the machine, is used to construct the part. The filament is .050 in. in diameter and arrives in segments on half mile spools. It is located in the back of the machine and is fed up into the machine via a plastic tube. The filament is drawn into the head by the feed wheels. From here, the filament proceeds into a heating assembly where it liquefies and extrudes out the tip. As the material extrudes out of the tip, the material quickly solidifies. The 3-D Modeler processes the

CNC code and deposits the layers in a consecutive format. The 3-D Modeler continues to deposit material until all of the slice layers are completed. See Figure 4. It can achieve a tolerance of +/- .005 in. over the entire part. The 3-D Modeler has a repeatability of to +/- .001 in. (Fused Deposition Modeling, 1992,1). Using the Stratasys 3-D Modeler, an engineer can produce a part in a matter of minutes or hours, compared to weeks or months. An engineer can transform a design idea into a physical part so that non-technical personnel can visualize the part. The principle application for the Stratasys 3-D Modeler is to design and replicate prototype parts in order to save time and money.

Rapid Prototyping Methods

Currently there are two groups of rapid prototyping methods. The first group is based upon using a laser to solidify the material or crosslink it. The second group is based upon a non-laser design, where a UV lamp is used or a three-dimensional (3-D) plotting or printing method of laying down material or binder is utilized. One thing all of the rapid prototyping systems have in common is the requirement of a CAD system to slice up the a 3-D model into 2-D curves so the rapid prototyping machines can produce models in layers.

There are currently three companies that use a laser-base system. They are the (three dimensional) 3-D System , (Desk Top Manufacturing) DTM Sinter , and Helisys. The 3-D System is called stereolithography, which uses a laser to crosslink

a photopolymer resin bath. See Figure 7. The 3-D System makes three different models that can be bought by a company. DTM Sinter employees a laser to sinter a very fine powder into a solid layer. See Figure 8. DTM material selection is far greater than the 3-D System, since it can use either polycarbonate, nylon, and waxes. The last system that employs a laser is the laminated object manufacturing (LOM) Helisys. This process uses paper that has an adhesive backing that is pulled up into the modeling envelope where a hot roller passes over it. Next a laser cuts out the outline of the CAD image on the paper and the process starts over again until the part is completed. See Figure 9.

There are two other rapid prototyping methods that are non-laser based systems. These are Cubital and Stratasys 3D Modelers. The Cubital system uses photocopier technology to produce a mask. See Figure 5. The next step is to expose the mask to a strong UV light, which shines through the unmasked areas and onto a photopolymer resin. The third step involves wiping off all of the uncured resin. The fourth step is laying down a layer of wax material. The fifth step is cooling the wax and milling it to the correct height. See Figure 6. The process starts over again, until the part is finished. The last system is the Stratasys 3D Modeler, which was described in the previous section.

Rapid Prototyping Research

By using a rapid prototyping process, one can save time

and money. A study was done by Newel Corporation to compare how much time and money could be saved by utilizing a rapid prototyping method compared to conventional methods. The study proved that the rapid prototyping method saved them 14 days and 250 dollars which allowed Newel Corporation to market the part sooner. See Figures 1 and 2. The Newel Corporation was not the only corporation using rapid prototyping methods. General Motors, Pittsburg State University, John Deere, Allison, Ford and Biomet are just a few of the companies currently using rapid prototyping technologies.

<u>Summary</u>

Although the idea of rapid prototyping has been around for years, it has only been recently that the time required for producing a prototype part has been cut down to days instead of weeks or months. The technology of rapid prototyping seems to be moving in the direction of getting better as time goes by. This study represented the first time that someone <u>could</u> test the orientation of the path, road width, z slice, speed, temperature of tip, liquefier, envelope examine of the effect upon the tensile strength of a specimen. Prior to this time, these variables could not be tested because the technology had not developed to a point where it was possible.

Chapter III

Research Design Procedures

This study compared the effects of orientation of path, road width, z slice, speed, temperatures of the tip, liquefier, and envelope upon tensile strength of specimens. The effect each variable had upon the tensile strength of the specimens produced on the Stratasys 3-D Modeler were tested independently and compared against a set of control specimens.

The data was derived from 34 specimen sets, which were comprised of ten identical polyamide (P300) tensile test specimens. Each of the 10 test specimens were produced according to the machine settings associated with the "set". Each set had six variables which were tested on polyamide (P300). The six variables had three possible sub-variables in every variable for a total of 18 test variables. The variables with sub-variables were: Orientation of Path (0 degrees, 45 degrees, 90 degrees in the x-y plane), road width (.025 in., .050 in., .075 in.), z slice (.010 in., .020 in., .030 in.), speed (.2 in. per second, .4 in. per second, .6 in. per second), temperature of tip and liquefier (119 degrees Celsius, 124 degrees Celsius, 128 degrees Celsius), temperature of the envelope (15 degrees Celsius, 23 degrees Celsius, 30 degrees Celsius). The test variables were placed in a computer program called "Experimental on a Chip" which produced 34 "sets of specimens", each with six variables. Since there were 10 specimens per set, there were a total of

340 specimens tested. The control specimens were molded under ASTM 638 D processing procedure for polyamide (P300). Tensile testing was done in accordance of ASTM 638 testing polyamide (P300) material. Drying of the test specimens prior to testing was done in accordance to ASTM standards.

Designing and Testing Tensile Specimens

The specimens that were made on the Stratasys 3-D Modeler were in accordance of ASTM 638. The tensile specimens were Type I. See Figure 2. The study addressed the ASTM 638 tensile testing guidelines for:

1. Drying material prior to modeling test specimens.
2. Tensile testing polyamide (P300) material.

Statistical Analysis Procedure

The statistical analysis that was used on the tensile specimens was a two-way "analysis of variance" (ANOVA) method. See Appendix B for the table and equations that were used. Each specimen set was compared to the control for a check to the 95 percent confidence level. Afterward each sub-variable was checked for a 95 percent confidence level.

Data Needed for each Subproblem

The first subproblem was to determine what effect the orientation of the road path had upon test specimen tensile strength, compared to the control. The three orientations that were tested were: 0 degrees, 45 degrees and 90 degrees in the x-y plane. The data needed was derived from tensile test results, which were analyzed by using a statistical two-way

ANOVA method to determine significance between the control specimens and the three orientations of the tests specimens being tested. These results can be found in Appendix D. The charts of results can be found in the Appendix C.

The second subproblem was to determine what effect the road width had upon test specimen tensile strength, compared to the control. The three road widths were: .025 in., .050 in., and .075 in.. The data needed was derived from the tensile test results, which were analyzed by using a statistical two-way ANOVA method on the results to determine significance between the control specimens and the three road widths of specimens being tested. These results can be found in Appendix D. The charts of results can be found in the Appendix C.

The third subproblem was to determine what effect the z slice thickness had upon test specimen tensile strength, compared to the control. The three z slices were: .010 in., .020 in., and .030 in.. The data needed was derived from the tensile tests results, which were analyzed by using a statistical two-way ANOVA method to determine significance between the control specimens and the three z slice specimens being tested. These results can be found in Appendix D. The charts of results can be found in the Appendix C.

The fourth subproblem was to determine what effect the envelope temperature had upon test specimen tensile strength, compared to the control. The three temperature were: 15

degrees Celsius, 23 degrees Celsius, and 30 degrees Celsius. The data needed was derived from the tensile tests results, which were analyzed by using a statistical two-way ANOVA method to determine significance between the control specimens and the three envelope temperatures specimens being tested. These results can be found in Appendix D. The charts of results can be found in the Appendix C.

The fifth subproblem was to determine what effect the liquefier and tip temperature had upon test specimen tensile strength, compared to the control. The temperatures were: 119 degrees Celsius, 124 degrees Celsius, and 128 degrees Celsius. The data needed was derived from the tensile tests results, which were analyzed by using a statistical two-way ANOVA method to determine significance between the control specimens and the three tip and liquefier temperatures specimens being tested. These results can be found in Appendix D. The charts of results can be found in the Appendix C.

The sixth subproblem was to determine what effect the speed had upon the test specimen tensile strength, compared to the control. The three speeds were: .2 in. per second, .4 in. per second, and .6 in. per second. The data needed was derived from the tensile tests results, which were analyzed by using a statistical two-way ANOVA method to determine significance between the control specimens and the three speeds specimens being tested. These results can be found in Appendix D. The charts of the results can be found in the

Appendix C.

Procedure for making test specimens

1. Open an UNIX window on the Silicon Graphic Workstation.
2. Change to the working directory.
3. Type in CMX to start the CAD program.
4. Draw the outline of the tensile specimen according to ASTM D-638.
5. Copy the outline in the z axis at the desired z thickness until a total thickness of .130 in. has been reached.
6. Copy all of the outlines over one in. and do this until ten specimens have been made.
7. Next step is to generate a tool path.
8. Set the desired speed, road width, and angle of orientation of the path for the given set of tests specimens.
9. Select the specimens and click on the "OK" icon.
10. Click on the "EXEC" icon to generate the tool paths.
11. Select the "sml out" menu bar to produce a CNC code file and send it to the Stratasys 3-D Modeler.
12. Select the "roughing box" icon to position the models in the middle of the working envelope.
13. Select the "EXEC" icon to start the sml generation process.

Procedure Setting up the Stratasys 3-D Modeler

1. Turn on the 3-D modeler.

2. Download the buttons for the 3-D modeler. This loads important information from the Silicon Graphic Workstation to the 3-D modeler.

3. Place a spool of P300 in the back of the modeler.

4. Push the load button to load the filament into the liquefier.

5. Push the filament up the filament tube.

6. Wait for the filament to begin extruding.

7. Push the load button to stop the loading process.

8. Screw the .025 in. tip onto the liquefier.

9. Set the liquefier and tip temperatures to the desired set points.

10. Set the envelope temperature. If the desired temperature is below 20 degrees C, then use the foam door and turn on the air conditioner.

11. Place a foam block into the 3-D modeler. The foam block is the material that test specimens will be made on.

12. At the Silicon Graphics workstation, open up a unix window.

13. Change to the working directory.

14. Send the "SML" file to the 3-D modeler.

15. Go to the 3-D modeler to start the modeling process. Position the tip in the front left corner of the foam block by using the arrow keys on the 3-D

modeler.

16. Used a feeler gage to make sure the tip was .001 in. off the foam block.

17. Push the pause button to start the modeling process.

18. When the 3-D modeler is finished remove the foam block. Then remove the test specimens from the foam block and record the testing variables on the tests specimen.

<u>Testing Procedure that were used on the Instron</u>

1. Turn on the "Instron", "MacLab", "Ehman hard drive", and the "Mac Plus".

2. Click on the "New MacLab" to start the testing program.

3. Set air pressure to 90 psi for the pneumatic grippers.

4. Set the grain to 10 mv per division.

5. Click on the positive and negative boxes for the correct input signal.

6. On the "Instron" check to make sure the D load cell is in the Instron, make sure that the switch is in the correct position, and set the gripper speed to 2 in. per minute.

7. Click on the "off set adjustment" icon to calibrate the "MacLab".

8. Zero the scale by using the course or fine adjustments.

9. Hang a one-pound weight on the top griper.

10. Record the millivolt reading.

11. Click on the unit conversion.

12. Select the "pounds" unit

13. Input the negative slope values.

14. Input the positive slope values.

15. Close window for the unit conversion on the Mac Plus.

16. Close the "off-set adjustment" window on the Mac Plus.

17. Set the gage length to 2 in..

18. Place specimen in the pneumatic grippers.

19. Close the pneumatic grippers.

20. Click on "start" in the "New MacLab".

21. Wait for the New "MacLab" to say "recording" and push the down button on the "Instron".

22. When the specimen breaks push the stop button on the "Instron" and remove the test specimen and push the return button.

23. Click on "halt" in the "New MacLab" to stop recording.

24. Highlight "area of interest" on the curve.

25. Click on "display" and select "zoom display".

26. Move the cross-hair to the desired location of interest.

27. Record the pounds and time readings.

28. Repeat steps 18 - 27 until all of the test specimens have been completed.

29. When finished, turn off equipment.

CHAPTER IV

Results and Discussion

The P300 test specimens consisted of 34 sets with ten tensile specimens in each set. A total of 340 specimens had to be made. Once made, the specimens were labeled using a 12-digit numbering system which provided information about the variables used to produce it. For example, for a specimen number "905010211930", the first and second digits indicated that the orientation angle of the path was 90 degrees (Note: a 0 degree orientation angle results in an eleven digit number). The third and fourth digits described the road width .050 in., the fifth and sixth digits noted the z slice as .010 in.. The seventh digit explained that the speed of the head was .2 in. per second. The eighth thru the tenth digit noted the temperature of the tip and liquefier as being 119 degrees C. The last two digits indicated that the temperature of the envelope was 30 degrees C. All of the specimens had a number that represented test variables' setting during the building process. The Stratasys 3-D Modeler generated ten specimens per set. Some of the sets required a large number of hours to produce. The specimen sets requiring the longest time to produce took 24 hours. Sets 02510212815, 452510212430, 902510211930 required a lengthy production time because these specimens had the slowest speed, the smallest road width, and the thinnest z slice. The quickest sets to produce took one hour. Specimens sets 07530612815, and 907530612830 had the

fastest speeds, widest road width, and the largest z slice, and therefore could be produced quickly.

The control specimens were manufactured using the Van Dorn injection molder. The control specimens were identical in size and all were produced under the same conditions.

Tensile Data

The control specimens had a tensile mean of 3512 psi and a standard deviation of 13. The control specimens were difficult to make, because the material tended to freeze off in the runners.

Specimens with 0 degree of orientation angle, .025 in. wide for the road width, .010 in. thick for the z slice, .2 in. per second for speed, 128 degrees Celsius for tip and liquefier temperatures, and 15 degrees Celsius for the envelope temperature (02510212815) had a tensile mean of 1842 psi, a standard deviation of 73 and a two-way ANOVA with an F ratio of 4549. This makes this set of variables significant at the 95 percent confidence level when compared to the control specimens. The failures of this group of tensile bars were not as expected. The failures occurred across the bond instead of with the bond, indicating bond strength was stronger than the material. See Tables 1-2, and Figure 10 for values and illustrations of tensile strength.

Specimens with 0 degree of orientation angle, .025 in. wide for the road width, .010 in. thick for the z slice, .6 in. per second for speed, 119 degrees Celsius for tip and

liquefier temperatures, and 15 degrees Celsius for the envelope temperature (02510611915) had a tensile mean of 1724 psi, a standard deviation of 29 and a two-way ANOVA with an F ratio of 28329. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. The failures of this group of tensile bars were not as expected. The failures occurred across the bond instead of with the bond, indicating bond strength was stronger than the material. This group also had one of the highest F ratio which was stated above and one of the lowest standard deviations. See Tables 3-4, and Figure 11 for values and illustrations of tensile strength.

Specimens with 0 degree of orientation angle, .025 in. wide for the road width, .020 in. thick for the z slice, .4 in. per second for speed, 128 degrees Celsius for the tip and liquefier temperatures, and 15 degrees Celsius for the envelope temperature (02520412815) had a tensile mean of 1667 psi, a standard deviation of 51 and a two-way ANOVA with an F ratio of 10949. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. The failures of this group of tensile bars were not as expected. The failures occurred across the bond instead of with the bond, indicating bond strength was stronger than the material. See Tables 5-6, and Figure 12 for values and illustrations of tensile strength.

Specimens with 0 degree of orientation angle, .025 in.

wide for the road width, .020 in. thick for the z slice, .6 in. per second for speed, 124 degrees Celsius for the tip and liquefier temperatures, and 30 degrees Celsius for the envelope temperature (02520612430) had a tensile mean of 1831 psi, a standard deviation of 66 and a two-way ANOVA with an F ratio of 5475. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. The failures of this group of tensile bars were not as expected. The failures occurred across the bond instead of with the bond, indicating bond strength was stronger than the material. See Tables 7-8, and Figure 13 for values and illustrations of tensile strength.

Specimens with 0 degree of orientation angle, .025 in. wide for the road width, .030 in. thick for the z slice, .2 in. per second for speed, 124 degrees Celsius for the tip and liquefier temperatures, and 15 degrees Celsius for the envelope temperature (02530212415) had a tensile mean of 1740 psi, a standard deviation of 55 and a two-way ANOVA with an F ratio of 8680. This made this set of variables significant 95 percent confidence level when compared to the control specimens. The failures of this group of tensile bars were not as expected The failures occurred across the bond instead of with the bond, indicating bond strength was stronger than the material. See Tables 9-10, and Figure 14 for values and illustrations of tensile strength.

Specimens with 0 degree of orientation angle, .025 in.

wide for the road width, .030 in. thick for the z slice, .6 in. per second for speed, 119 degrees Celsius for the tip and liquefier temperatures, and 30 degrees Celsius for the envelope temperature (02530611930) had a tensile mean of 1770 psi, a standard deviation of 60 and a two-way ANOVA with an F ratio of 7221. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. The failures of this group of tensile bars were not as expected. The failures occurred across the bond instead of with the bond, indicating the bond strength was stronger than the material. See Tables 11-12, and Figure 15 for values and illustrations of tensile strength.

Specimens with 0 degree orientation angle, .075 in. wide for the road width, .010 in. thick for the z slice, .6 in. per second for speed, 119 degrees Celsius for the tip and liquefier temperatures, and 30 degrees Celsius for the envelope temperature (07510611930) had a tensile mean of 1626 psi, a standard deviation of 29 and a two-way ANOVA with an F ratio of 30745. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. The failures of this group of tensile bars were as expected. The failures occurred with the bond instead of across the bond, indicating the bond strength was weaker than the material. This group had the highest F ratio and the lowest standard deviation of all the test specimens, which was stated above. See Tables 13-14, and Figure 16 for values and

illustrations of tensile strength.

Specimens with 0 degree orientation angle, .075 in. wide for the road width, .010 in. thick for the z slice, .6 in. per second for speed, 128 degrees Celsius for the tip and liquefier temperatures, and 23 degrees Celsius for the envelope temperature (07510612823) had a tensile mean of 1479, a standard deviation of 51 and a two-way ANOVA with an F ratio of 13048. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. The failures of this group of tensile bars were as expected. The failures occurred with the bond instead of across the bond, indicating the bond strength was weaker than the material. This group had the lowest tensile mean out of all of the tensile specimens. See Tables 15-16, and Figure 17 for values and illustrations of tensile strength.

Specimens with 0 degree orientation angle, .075 in. wide for the road width, .010 in. thick for the z slice, .6 in. per second for speed, 128 degrees Celsius for the tip and liquefier temperatures, and 30 degrees Celsius for the envelope temperature (07510612830) had a tensile mean of 2184 psi, a standard deviation of 127 and a two ANOVA with an F ratio of 962. This made this set of variables significant a the 95 percent confidence level when compared to the control specimens. The failures of this group of tensile bars were not as expected. The failures occurred across the bond instead of with the bond, indicating the bond strength was

stronger than the material. This group had the lowest F ratio out of all of the tensile specimens, which was stated above. See Tables 17-18, and Figure 18 for values and illustrations of tensile strength.

Specimens with 0 degree orientation angle, .075 in. wide for the road width, .030 in. thick for the z slice, .2 in. per second for speed, 128 degrees Celsius for the tip and liquefier temperatures, and 30 degrees Celsius for the envelope temperature (07530212830) had a tensile mean of 2388 psi, a standard deviation of 88 and a two ANOVA with an F ratio of 1425. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. The failures of this group of tensile bars were not as expected. The failures occurred across the bond instead of with the bond, indicating the bond strength was stronger than the material. See Tables 19-20, and Figure 19 for values and illustrations of tensile strength.

Specimens with 0 degree orientation angle, .075 in. wide for the road width, .030 in. thick for the z slice, .6 in. per second for speed, 119 degrees Celsius for the tip and liquefier temperatures, and 15 degrees Celsius for the envelope temperature (07530611915) had a tensile mean of 2576 psi, a standard deviation of 43 and a two ANOVA with an F ratio of 3900. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. The failures of this group of tensile bars

were not as expected. The failures occurred across the bond instead of with the bond, indicating the bond strength was stronger than the material. This group had the highest tensile mean out of all of the 0 degree orientation angle specimens, which was stated above. See Tables 21-22, and Figure 20 for values and illustrations of tensile strength.

Specimens with 0 degree orientation angle, .075 in. wide for the road width, .030 in. thick for the z slice, .6 in. per second for speed, 128 degrees Celsius for the tip and liquefier temperatures, and 15 degrees Celsius for the envelope temperature (07530612815) had a tensile mean of 2048 psi, a standard deviation of 139 and a two-way ANOVA with an F ratio of 976. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. The failures of this group of tensile bars were not as expected. The failures occurred across the bond instead of with the bond, indicating the bond strength was stronger than the material. This group had the highest standard deviation out of all of the tensile specimens, which was stated above. See Tables 23-24, and Figure 21 for values and illustrations of tensile strength.

Specimens with 45 degrees orientation angle, .025 in. wide for the road width, .010 in. thick for the z slice, .2 in. per second for speed, 124 degrees Celsius for the tip and liquefier temperatures, and 30 degrees Celsius for the envelope temperature (452510212430) had a tensile mean of 2776

psi, a standard deviation of 65 and a two-way ANOVA with an F ratio of 1082. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. The failures of this group of tensile bars were not as expected. The failures occurred across the bond at a 45 degrees angle instead of with the bond. Showing that the bond strength was stronger than the material. This group had the highest tensile mean out of all of the 45 degrees orientation specimens, which was stated above. See Tables 25-26, and Figure 22 for values and illustrations of tensile strength.

Specimens with 45 degrees orientation angle, .025 in. wide for the road width, .020 in. thick for the z slice, .6 in. per second, 119 degrees Celsius for the tip and liquefier temperatures, and 15 degrees Celsius for the envelope temperature (452520611915) had a tensile mean of 2400 psi, a standard deviation of 65 and a two-way ANOVA with an F ratio of 2470. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. The failures of this group of tensile bars were not as expected. The failures occurred across the bond at a 45 degrees angle instead of with the bond. Showing that the bond strength was stronger than the material. See Tables 27-28, and Figure 23 for values and illustrations of tensile strength.

Specimens with 45 degrees orientation angle, .025 in.

wide for the road width, .020 in. thick for the z slice, .6 in. per second, 128 degrees Celsius for the tip and liquefier temperatures, and 30 degrees Celsius for the envelope temperature (452520612830) had a tensile mean of 2392 psi, a standard deviation of 58 and a two-way ANOVA with an F ratio of 3121. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. The failures of this group of tensile bars were not as expected. The failures occurred across the bond at a 45 degrees angle instead of with the bond, indicating bond strength was stronger than the material. See Tables 29-30, and Figure 24 for values and illustrations of tensile strength.

Specimens with 45 degrees orientation angle, .075 in. wide for the road width, .010 in. thick for the z slice, .2 in. per second, 124 degrees Celsius for the tip and liquefier temperatures, and 15 degrees Celsius for the envelope temperature (457510212415) had a tensile mean of 2026 psi, a standard deviation of 60 and a two-way ANOVA with an F ratio of 5159. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. The failures of this group of tensile bars were as expected, the failures occurred with the bond angle. Showing that the bond strength was weaker than the material. This group had the lowest tensile mean out of all of the 45 degrees orientation specimens, which was stated above. See Tables 31-32, and Figure 25 for values and illustrations of tensile

strength.

Specimens with 45 degrees orientation angle, .075 in. wide for the road width, .030 in. thick for the z slice, .4 in. per second, 119 degrees Celsius for the tip and liquefier temperatures, and 30 degrees Celsius for the envelope temperature (457530411930) had a tensile mean of 2332 psi, a standard deviation of 51 and a two-way ANOVA with an F ratio of 4514. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. The failures of this group of tensile bars were not as expected. The failures occurred across the bond at a 45 degrees angle. Showing that the bond strength was stronger than the material. See Tables 33-34, and Figure 26 for values and illustrations of tensile strength.

Specimens with 90 degrees orientation angle, .025 in. wide for the road width, .010 in. thick for the z slice, .2 in. per second, 119 degrees Celsius for the tip and liquefier temperatures, and 30 degrees Celsius for the envelope temperature (902510211930) had a tensile mean of 2664 psi, a standard deviation of 50 and a two-way ANOVA with an F ratio of 2374. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. The failures of this group of tensile bars were as expected. The tensile bars behaved just like the control specimens which were injection molded. The tensile specimen necked down and then failed at the thinnest sections. See

Tables 35-36, and Figure 27 for values and illustrations of tensile strength.

Specimens with 90 degrees orientation angle, .025 in. wide for the road width, .010 in. thick for the z slice, .6 in. per second, 119 degrees Celsius for the tip and liquefier temperatures, and 30 degrees Celsius for the envelope temperature (902510611930) had a tensile mean of 2623 psi, a standard deviation of 60 and a two-way ANOVA with an F ratio of 1850. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. The failures of this group of tensile bars were as expected. The tensile bars behaved just like the control specimens which were injection molded. The tensile specimen necked down and then failed at the thinnest sections. See Tables 37-38, and Figure 28 for values and illustrations of tensile strength.

Specimens with 90 degrees orientation angle, .025 in. wide for the road width, .010 in. thick for the z slice, .6 in. per second, 124 degrees Celsius for the tip and liquefier temperatures, and 15 degrees Celsius for the envelope temperature (902510612415) had a tensile mean of 2550 psi, a standard deviation of 37 and a two-way ANOVA with an F ratio of 5263. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. The failures of this group of tensile bars were as expected. The tensile bars behaved just like the control

specimens which were injection molded. The tensile specimen necked down and then failed at the thinnest sections. See Tables 39-40, and Figure 29 for values and illustrations of tensile strength.

Specimens with 90 degrees orientation angle, .025 in. wide for the road width, .010 in. thick for the z slice, .6 in. per second, 128 degrees Celsius for the tip and liquefier temperatures, and 15 degrees Celsius for the envelope temperature (902510612815) had a tensile mean of 2483 psi, a standard deviation of 59 and a two-way ANOVA with an F ratio of 2539. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. The failures of this group of tensile bars were as expected. The tensile bars behaved just like the control specimens which were injection molded. The tensile specimen necked down and then failed at the thinnest sections. See Tables 41-42, and Figure 30 for values and illustrations of tensile strength.

Specimens with 90 degrees orientation angle, .025 in. wide for the road width, .020 in. thick for the z slice, .4 in. per second, 119 degrees Celsius for the tip and liquefier temperatures, and 15 degrees Celsius for the envelope temperature (902520411915) had a tensile mean of 2442 psi, a standard deviation of 62 and a two-way ANOVA with an F ratio of 2523. This made this set of variables significant at the 95 percent confidence level when compared to the control

specimens. The failures of this group of tensile bars were as expected. The tensile bars behaved just like the control specimens which were injection molded. The tensile specimen necked down and then failed at the thinnest sections. See Tables 43-44, and Figure 31 for values and illustrations of tensile strength.

Specimens with 90 degrees orientation angle, .025 in. wide for the road width, .030 in. thick for the z slice, .4 in. per second, 128 degrees Celsius for the tip and liquefier temperatures, and 23 degrees Celsius for the envelope temperature (902530412823) had a tensile mean of 2309 psi, a standard deviation of 79 and a two-way ANOVA with an F ratio of 2026. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. The failures of this group of tensile bars were as expected. The tensile bars behaved just like the control specimens which were injection molded. The tensile specimen necked down and then failed at the thinnest sections. See Tables 45-46, and Figure 32 for values and illustrations of tensile strength.

Specimens with 90 degrees orientation angle, .025 in. wide for the road width, .030 in. thick for the z slice, .6 in. per second, 124 degrees Celsius for the tip and liquefier temperatures, and 15 degrees Celsius for the envelope temperature (902530612415) had a tensile mean of 2464 psi, a standard deviation of 41 and a two-way ANOVA with an F ratio

of 5194. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. The failures of this group of tensile bars were as expected. The tensile bars behaved just like the control specimens which were injection molded. The tensile specimen necked down and then failed at the thinnest sections. See Tables 47-48, and Figure 33 for values and illustrations of tensile strength.

Specimens with 90 degrees orientation angle, .050 in. wide for the road width, .020 in. thick for the z slice, .6 in. per second, 119 degrees Celsius for the tip and liquefier temperatures, and 23 degrees Celsius for the envelope temperature (905020611923) had a tensile mean of 2516 psi, a standard deviation of 85 and a two-way ANOVA with an F ratio of 1200. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. The failures of this group of tensile bars were as expected, the tensile bars behaved just like the control specimens which were injection molded. The tensile specimen necked down and then failed at the thinnest sections. See Tables 49-50, and Figure 34 for values and illustrations of tensile strength.

Specimens with 90 degrees orientation angle, .050 in. wide for the road width, .030 in. thick for the z slice, .4 in. per second, 124 degrees Celsius for the tip and liquefier temperatures, and 30 degrees Celsius for the envelope

temperature (905030412430) had a tensile mean of 2750 psi, a standard deviation of 92 and a two-way ANOVA with an F ratio of 592. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. The failures of this group of tensile bars were as expected. The tensile bars behaved just like the control specimens which were injection molded. The tensile specimen necked down and then failed at the thinnest sections. This group had the highest tensile mean out of all of the tensile specimens, which was stated above. See Tables 51-52, and Figure 35 for values and illustrations of tensile strength.

Specimens with 90 degrees orientation angle, .075 in. wide for the road width, .010 in. thick for the z slice, .2 in. per second, 119 degrees Celsius for the tip and liquefier temperatures, and 30 degrees Celsius for the envelope temperature (907510211930) had a tensile mean of 2589 psi, a standard deviation of 79 and a two-way ANOVA with an F ratio of 1178. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. The failures of this group of tensile bars were as expected. The tensile bars behaved just like the control specimens which were injection molded. The tensile specimen necked down and then failed at the thinnest sections. See Tables 53-54, and Figure 36 for values and illustrations of tensile strength.

Specimens with 90 degrees orientation angle, .075 in.

wide for the road width, .010 in. thick for the z slice, .2 in. per second, 128 degrees Celsius for the tip and liquefier temperatures, and 30 degrees Celsius for the envelope temperature (907510212830) had a tensile mean of 2486 psi, a standard deviation of 77 and a two-way ANOVA with an F ratio of 1530. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. The failures of this group of tensile bars were as expected. The tensile bars behaved just like the control specimens which were injection molded. The tensile specimen necked down and then failed at the thinnest sections. See Tables 55-56, and Figure 37 for values and illustrations of tensile strength.

Specimens with 90 degrees orientation angle, .075 in. wide for the road width, .010 in. thick for the z slice, .6 in. per second, 119 degrees Celsius for the tip and liquefier temperatures, and 15 degrees Celsius for the envelope temperature (907510611915) had a tensile mean of 2707 psi, a standard deviation of 57 and a two-way ANOVA with an F ratio of 1688. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. The failures of this group of tensile bars were as expected, the tensile bars behaved just like the control specimens which were injection molded. The tensile specimen necked down and then failed at the thinnest sections. See Tables 57-58, and Figure 38 for values and illustrations of

tensile strength.

Specimens with 90 degrees orientation angle, .075 in. wide for the road width, .020 in. thick for the z slice, .4 in. per second, 128 degrees Celsius for the tip and liquefier temperatures, and 15 degrees Celsius for the envelope temperature (907520412815) had a tensile mean of 2726 psi, a standard deviation of 46 and a two-way ANOVA with an F ratio of 2381. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. The failures of this group of tensile bars were as expected. The tensile bars behaved just like the control specimens which were injection molded. The tensile specimen necked down and then failed at the thinnest sections. See Tables 59-60, and Figure 39 for values and illustrations of tensile strength.

Specimens with 90 degrees orientation angle, .075 in. wide for the road width, .030 in. thick for the z slice, .2 in. per second, 119 degrees Celsius for the tip and liquefier temperatures, and 15 degrees Celsius for the envelope temperature (907530211915) had a tensile mean of 2551 psi, a standard deviation of 43 and a two-way ANOVA with an F ratio of 4090. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. The failures of this group of tensile bars were as expected, the tensile bars behaved just like the control specimens which were injection molded. The tensile specimen

necked down and then failed at the thinnest sections. See Tables 61-62, and Figure 40 for values and illustrations of tensile strength.

Specimens with 90 degrees orientation angle, .075 in. wide for the road width, .030 in. thick for the z slice, .2 in. per second, 128 degrees Celsius for the tip and liquefier temperatures, and 15 degrees Celsius for the envelope temperature (907530212815) had a tensile mean of 2562 psi, a standard deviation of 40 and a two-way ANOVA with an F ratio of 4423. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. The failures of this group of tensile bars were as expected. The tensile bars behaved just like the control specimens which were injection molded. The tensile specimen necked down and then failed at the thinnest sections. See Tables 63-64, and Figure 41 for values and illustrations of tensile strength.

Specimens with 90 degrees orientation angle, .075 in. wide for the road width, .030 in. thick for the z slice, .6 in. per second, 128 degrees Celsius for the tip and liquefier temperatures, and 30 degrees Celsius for the envelope temperature (907530612830) had a tensile mean of 2688 psi, a standard deviation of 54 and a two-way ANOVA with an F ratio of 1955. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. The failures of this group of tensile bars were as

expected. The tensile bars behaved just like the control specimens which were injection molded. The tensile specimen necked down and then failed at the thinnest sections. See Tables 65-66, and Figure 42 for values and illustrations of tensile strength.

Specimens with 90 degrees orientation angle, .050 in. wide for the road width, .010 in. thick for the z slice, .2 in. per second, 119 degrees Celsius for the tip and liquefier temperatures, and 30 degrees Celsius for the envelope temperature (905010211930) had a tensile mean of 2449 psi, a standard deviation of 30 and a two-way ANOVA with an F ratio of 9355. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. The failures of this group of tensile bars were as expected. The tensile bars behaved just like the control specimens which were injection molded. The tensile specimen necked down and then failed at the thinnest sections. See Tables 67-68, and Figure 43 for values and illustrations of tensile strength.

Two-Way Analysis of Variance Between the Control and Different Groups

A two-way ANOVA between the control group and each of the different specimens "set" groups was preformed. It was found that all "sets" were significant at the 95 percent confidence level when compared to the control group. Descriptions of the comparison between each of the specimens "set" groups and

the control group are discussed in the following paragraphs

All of the tensile specimens that had a road width of .025 in. were compared to the control specimens in a two-way ANOVA with an F ratio of 110. This made road width of .025 in. significant at the 95 percent confidence level when compared to the control specimens. See Table 69 for values and Tables 1-68 for tensile strength.

All of the tensile specimens that had a road width of .050 in. were compared to the control specimens in a two-way ANOVA with an F ratio of 376. This made road width of .050 in. significant at the 95 percent confidence level when compared to the control specimens. See Table 70 for values and Tables 1-68 for tensile strength.

All of the tensile specimens that had a road width of .075 in. were compared to the control specimens in a two-way ANOVA with an F ratio of 95. This made road width of .075 significant at the 95 percent confidence level when compared to the control specimens. See Table 71 for values and Tables 1-68 for tensile strength.

All of the tensile specimens that had a 0 degree orientation angle were compared to the control specimens in a two-way ANOVA with an F ratio of 7. This made 0 degree orientation angle significant at the 95 percent confidence level when compared to the control specimens. See Table 72 for values and Tables 1-68 for tensile strength.

All of the tensile specimens that had a 45 degrees

orientation angle were compared to the control specimens in a two-way ANOVA with an F ratio of 202. This made 45 degrees orientation angle significant at the 95 percent confidence level when compared to the control specimens. See Table 73 for values and Tables 1-68 for tensile strength.

All of the tensile specimens that had a 90 degrees orientation angle were compared to the control specimens in a two-way ANOVA with an F ratio of 517. This made 90 degrees orientation angle significant at the 95 percent confidence level when compared to the control specimens. See Table 74 for values and Tables 1-68 for tensile strength.

All of the tensile specimens that had a .010 in. in z slice were compared to the control specimens in a two-way ANOVA with an F ratio of 84. This made z slice of .010 in. significant at the 95 percent confidence level when compared to the control specimens. See Table 75 for values and Tables 1-68 for tensile strength.

All of the tensile specimens that had a .020 in. in z slice were compared to the control specimens in a two-way ANOVA with an F ratio of 113. This made z slice of .020 in. significant at the 95 percent confidence level when compared to the control specimens. See Table 76 for values and Tables 1-68 for tensile strength.

All of the tensile specimens that had a .030 in. in z slice were compared to the control specimens in a two-way ANOVA with an F ratio of 124. This made z slice of .030 in.

significant at the 95 percent confidence level when compared to the control specimens. See Table 77 for values and Tables 1-68 for tensile strength.

All of the tensile specimens that had a speed of .2 in. per second were compared to the control specimens in a two-way ANOVA with an F ratio of 115. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. See Table 78 for values and Tables 1-68 for tensile strength.

All of the tensile specimens that had a speed of .4 in. per second were compared to the control specimens in a two-way ANOVA with an F ratio of 95. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. See Table 79 for values and Tables 1-68 for tensile strength.

All of the tensile specimens that had a speed of .6 in. per second were compared to the control specimens in a two-way ANOVA with an F ratio of 99. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. See Table 80 for values and Tables 1-68 for tensile strength.

All of the tensile specimens that had a tip and liquefier temperatures of 119 degrees Celsius were compared to the control specimens in a two-way ANOVA with an F ratio of 115. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. See

Table 81 for values and Tables 1-68 for tensile strength.

All of the tensile specimens that had a tip and liquefier temperatures of 124 degrees Celsius were compared to the control specimens in a two-way ANOVA with an F ratio of 84. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. See Table 82 for values and Tables 1-68 for tensile strength.

All of the tensile specimens that had a tip and liquefier temperatures of 128 degrees Celsius were compared to the control specimens in a two-way ANOVA with an F ratio of 95. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. See Table 83 for values and Tables 1-68 for tensile strength.

All of the tensile specimens that had a envelope temperature of 15 degrees Celsius were compared to the control specimens in a two-way ANOVA with an F ratio of 40. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. See Table 84 for values and Tables 1-68 for tensile strength.

All of the tensile specimens that had a envelope temperature of 23 degrees Celsius were compared to the control specimens in a two-way ANOVA with an F ratio of 92. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. See Table 85 for values and Tables 1-68 for tensile strength.

All of the tensile specimens that had a envelope

temperature of 30 degrees Celsius were compared to the control specimens in a two-way ANOVA with an F ratio of 104. This made this set of variables significant at the 95 percent confidence level when compared to the control specimens. See Table 86 for values and Tables 1-68 for tensile strength.

CHAPTER V

Conclusion and Recommendations

From the tensile data Tables 1-68 and Figures 10-43 and two-way ANOVA, the six subproblems were analyzed. The following provides a detailed look into each subproblem.

Conclusion for the First Subproblem

The first subproblem was to determine what effect the orientation of the road path had upon the test specimen. The three orientations were: 0 degrees, 45 degrees, and 90 degrees in the x-y plane.

By analyzing the tensile data in Tables 1-68, and Figures 10-43, and the two-way ANOVA Tables 72-74, the data indicates that as the orientation angle approaches 90 degrees the tensile specimens becomes stronger. The two-way ANOVA Tables 72-74 indicates that the 90 degrees specimens has the highest significant difference between the orientation angle and the control specimens. The F ratio of the 90 degrees orientation angle was 51,7 compared to the F ratio of the 45 degrees orientation angle which was 202, and the 0 degree orientation angle displayed an F ratio of 7. This seems to indicate there is a significant difference between the orientation angle and the control samples, which cancels the second null-hypothesis which states: "there was no significant difference in the tensile strength between the orientation angle and the control sample".

Conclusion to the Second Subproblem

The second subproblem was to determine what effect the road width had upon the test specimen. The three road widths were: .025 in., .050 in., and .075 in..

From the tensile data Tables 1-68 and Figures 10-43 the data indicates that the .050 in. road width was the most significant of the three road widths. But the final conclusion is based on the results of the two-way ANOVA Tables 69-71. These Tables indicate there is a significant difference between the control specimens and the three road widths. The .025 in. road width had a F ratio of 110 while the .050 in. road width had a F ratio of 376, and the .075 in. road width had a F ratio of 95. This seems to indicate there is a significant difference between the road widths and the control samples, which cancels the third null-hypothesis which states: "there was no significant difference in the tensile strength between the road width and the control samples".

Conclusion for the Third Subproblem

The third subproblem was to determine what effect the z slice had upon the test specimen. The three z slices were: .010 in., .020 in., and .030 in..

By analyzing the tensile Tables 1-68, and Figures 10-43 the data indicates a difference between the z slice tensile strength and the control specimens' tensile strength. As the z slice increased the tensile strength of the specimen increased. This is indicated by the two-way ANOVA Tables 75-77. The .010 in. z slice had a F ratio of 84, while the .020

in. z slice had a F ratio of 113, and the .030 in. z slice had a F ratio of 124. This seems to indicate there is a significant difference between the z slice and the control specimens, which cancels fourth null-hypothesis which states: "there was no significant difference in the tensile strength between the z slice and the control samples".

<u>Conclusion to the Fourth Subproblem</u>

The fourth subproblem was to determine what effect the envelope temperature had upon the test specimen. The three temperatures were: 15 degrees Celsius, 23 degrees Celsius, and 30 degrees Celsius.

From viewing the tensile data Tables 1-68 and Figures 10-43, the data indicates that the tensile strength of the specimens increased as the temperature increased. There was a substantial difference between the lower temperature of 15 degrees Celsius and the middle temperature 23 degrees Celsius, but there was almost no difference between the middle temperature 23 degrees Celsius and the highest temperature of 30 degrees Celsius. This was indicated in the two-way ANOVA Tables 84-86 showing the difference between the control specimens and the envelope temperature specimens. The 15 degrees Celsius specimens had a F ratio of 40, while the 23 degrees Celsius specimens had a F ratio of 92, and the 30 degrees Celsius specimens had a F ratio of 104. This seems to indicate there is a significant difference between the envelope temperature and the control samples, which cancels

fourth null-hypothesis which states: "there was no significant difference in the tensile strength between the envelope temperature and the control samples".

Conclusion to the Fifth Subproblem

The fifth subproblem was to determine what effect the liquefier and tip temperatures had upon the test specimen. The three temperatures were: 119 degrees Celsius, 124 degrees Celsius, and 128 degrees Celsius.

By analyzing the tensile data in Tables 1-68 and Figures 10-43 the data indicates that the tensile strength of the specimens decreased as the temperature increased to 124 degrees Celsius. However, the tensile strengths increased as the temperature increased from 124 to 128 degrees Celsius. This can be observed in the two-way ANOVA Tables 81-83, which were the control compared to the different temperatures of the tip and liquefier. The 119 degrees Celsius specimens had a F ratio of 115, while the 124 degrees Celsius specimens had a F ratio of 84, and the 128 degrees Celsius specimens had a F ratio of 95. This seems to indicate there is a significant difference between the tip and liquefier temperatures and the control samples, which cancels first null-hypothesis which states: "there was no significant difference in the tensile strength between the temperatures of the polymer melt or tip and the control samples".

Conclusion of the Sixth Subproblem

The sixth subproblem was to determine what effect the

speed of the head had upon the test specimen. Three speeds were: .2 in. per second, .4 in. per second, and .6 in. per second.

Upon viewing the tensile data from Tables 1-68 and Figures 10-43, the data indicates that as the speed increased from .2 in. per second to .4 in. per second the tensile strength of the test specimens decreased, but as the speed increased from .4 in. per second to .6 in. per second the tensile strength increased. This is indicated by the two-way ANOVA Tables 78-80. The .2 in. per second specimens had a F ratio of 115, while the .4 in. per second specimens had a F ratio of 95, and the .6 in. per second specimens had a F ratio of 99. From this, one can conclude that strongest specimens had a speed of .2 in. per second. This seems to indicate there is a significant difference between the speed of the head and the control samples which disproves sixth null-hypothesis which states: "that there was no significant difference in the tensile strength between the speed of the head and the control samples".

<u>Over all Conclusion</u>

The six variables that were used in this research were: speed, z slice, orientation angle of the road path, road width, tip and liquefier temperatures, and the envelope temperature, The most significant variables in this test can be found by analyzing the two-way ANOVA Tables 69-86. The variable that had the greatest significance was the 90 degrees

orientation angle, which had a F ratio of 517. The second variable of greatest significance was the .050 in. road width that had significant difference of 376. The third variable of greatest significance was the .030 in. of z slice that had a significant difference of 124. The fourth variable was the 119 degrees Celsius of the tip and liquefier that had a significant difference of 115. The fifth variable was the speed of the head which had F ratio of 115. The sixth variable was the envelope temperature of 30 degrees Celsius, which had a F ratio of 104. The fourth and fifth variables can be placed in any order since both were 115.

Recommendations

On the basis of the findings and conclusion of this study, it is recommended that more research should be done on the impact strength, and flexural strength of a model produced on the Stratasys 3-D Modeler.

Since the Stratasys Company is upgrading the equipment, this research should be done on the new upgraded equipment to determine if the new upgrades effect the tensile strength of the specimens differently.

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APPENDIX A

Materials and Equipment

Materials

1. Foam blocks provided by Stratasys Inc.
2. Polyamide (P300) in filament form at .05 in. in diameter provided by Stratasys Inc.

Equipment

1. Silicon Graphic Workstation (SGI) Personal Iris T25, 16 megabytes of random access memory, 380 megabytes of hard drive. (Serial # E0100304).
2. Silicon Graphic Monitor, 23 in. (Serial # 74271).
3. Camax software (Version 5.0a).
4. UNIX operating system (Version 4.0.5.f).
5. Proto Slice (Version 2.2).
6. Stratasys 3-D Modeler (Serial # 3009).
7. Ermen air conditioner (Serial # 321J124).
8. Macintosh Plus (Serial # 07226).
9. Ehman 80 megabyte hard drive (Serial # 72297).
10. Mac operation system (Version 3).
11. MacLab, Analog Digital Instrument (Serial # 8603).
12. Instron tensile tester (Serial # 374).
13. Load Cell D (Serial # a161).
14. Caliper (Serial # 120).
15. Van Dorn 75 ton injection molding machine (Serial # 75-RS-3F-1898).

APPENDIX B

Formulas

$$Area = Thickness \times width$$

$$Tensile = \frac{Load}{Area}$$

$$Equation\ 1 = \sum \sum x^2$$

METHOD FOR EQUATION 1
A. Square each score.
B. Sum all the squared scores in each group.
C. Sum all the squared group scores.

$$Equation\ 2 = \frac{\left(\sum x\right)^2}{N}$$

METHOD FOR EQUATION 2
A. Sum all the scores.
B. Square the sum.
C. Divide by N.

$$Equation\ 3 = \sum \left[\frac{\left(\sum x\right)^2}{N} \right]$$

METHOD FOR EQUATION 3
A. Sum the scores in each group.
B. Square the sum for each group.
C. Divide the Square by the number in each group.
D. Sum for all the groups.

Two-way Analysis of Variance Tables

Source of Variation	df	Sums of Squares	Mean Squares	F Ratio
Between	K-1	Equation 3 - Equation 2	SS_b/df	MS_b/MS_w
Within	N-K	Equation 1 - Equation 3	SS_w/df	
Total	N-1	Equation 1 - Equation 2		

K-1 = Number of groups - 1
N-K = Number of observations - Number of groups
N-1 = Number of observations - 1

APPENDIX C

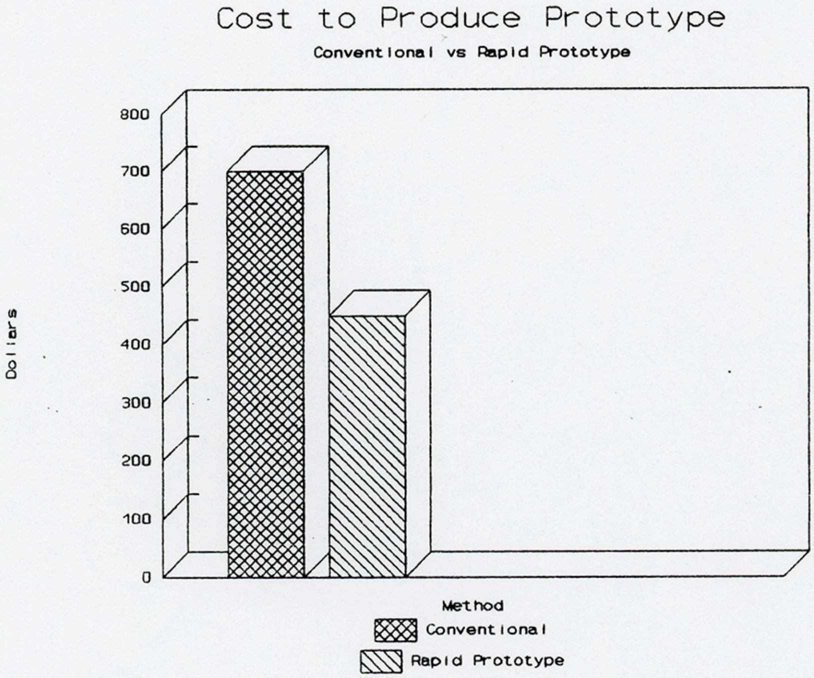


Figure 1 Newel Cost "Conventional vs Rapid Prototype"

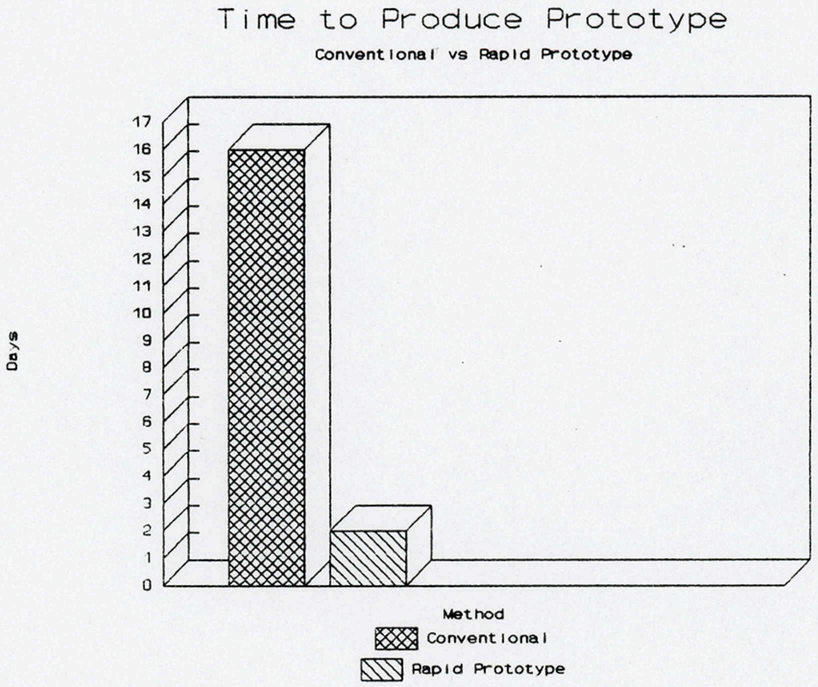


Figure 2 Newel Time "Conventional vs Rapid Prototype"

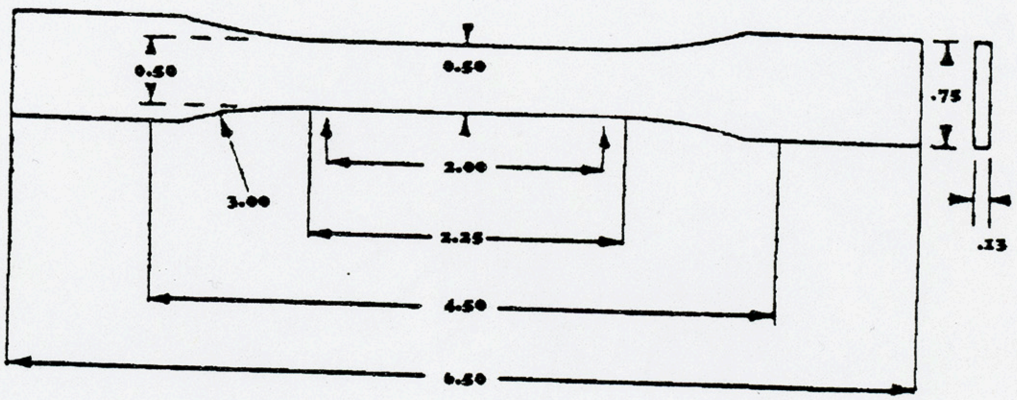


Figure 3 ASTM 638 tensile test bar

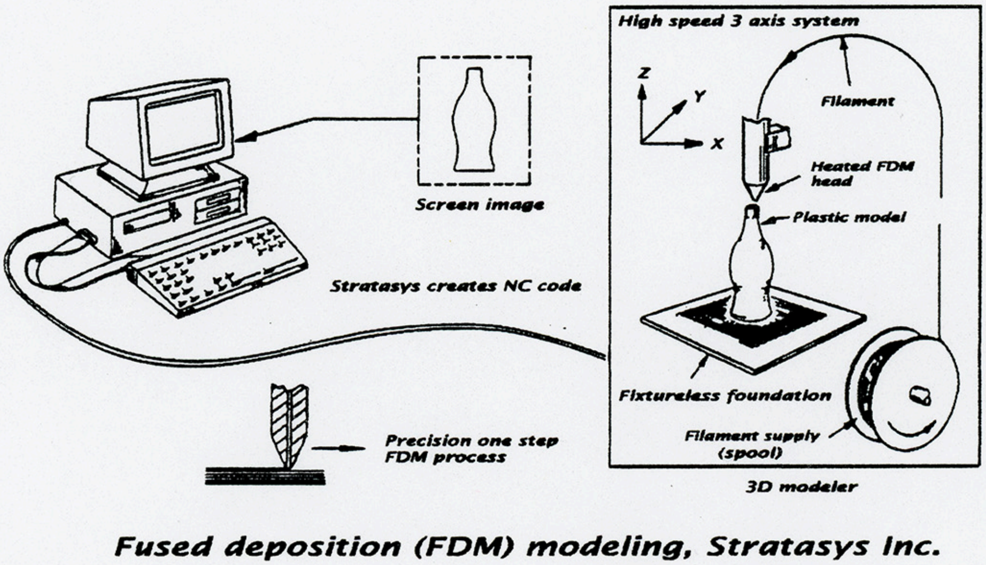
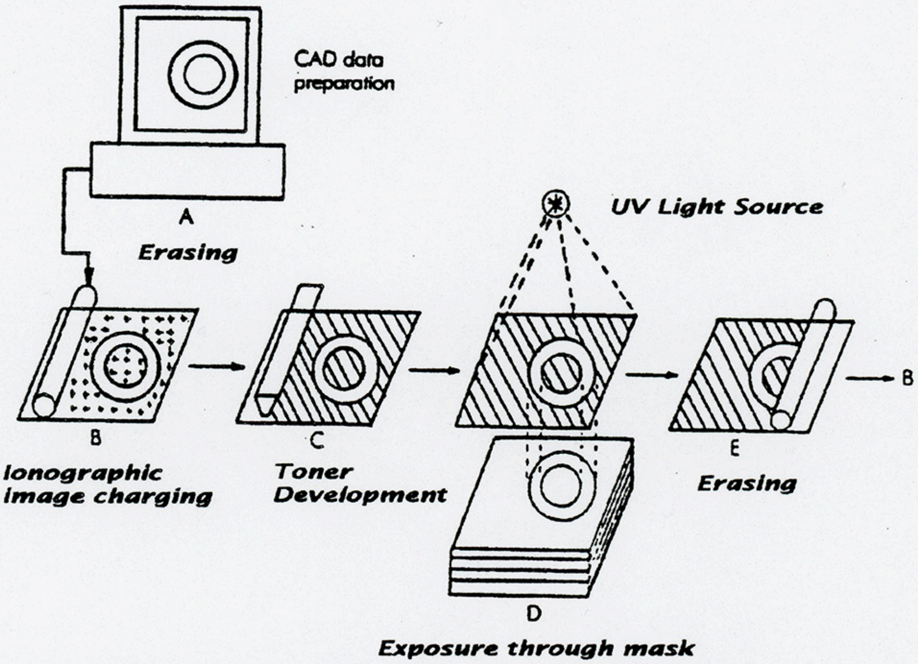


Figure 4 Stratasys building method (Jacobs 1992, 408)



Creation of exposure mask for Solider system.

Figure 5 Cubital mask building method (Jacobs 1992, 417)

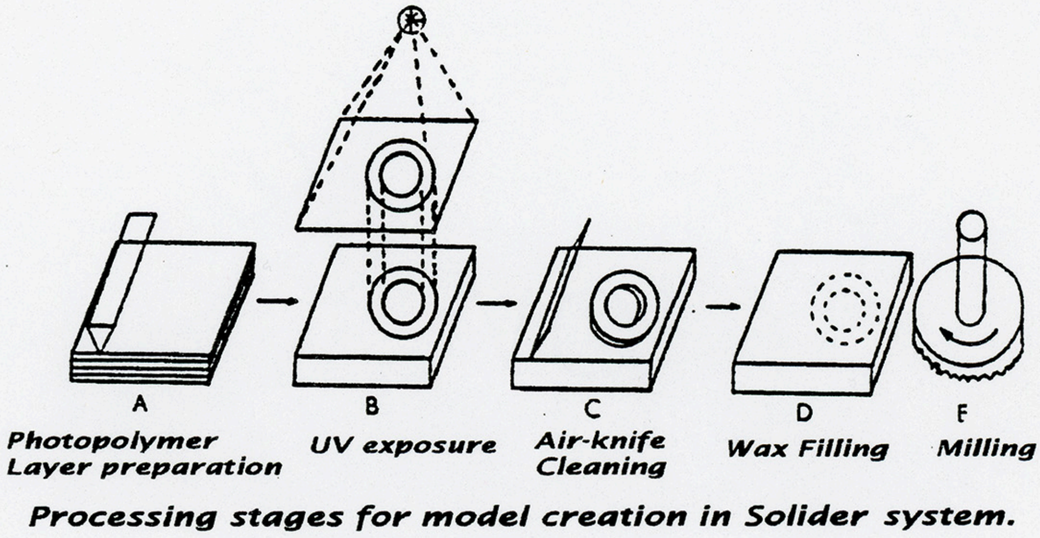


Figure 6 Cubital building method (Jacobs 1992, 417)

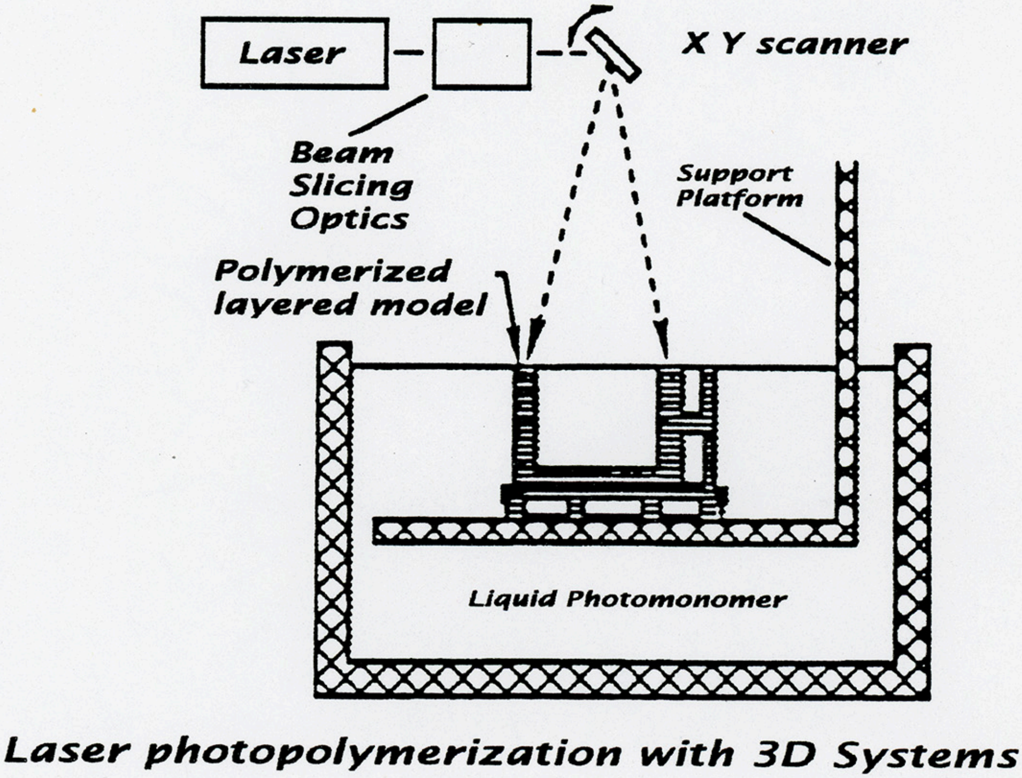
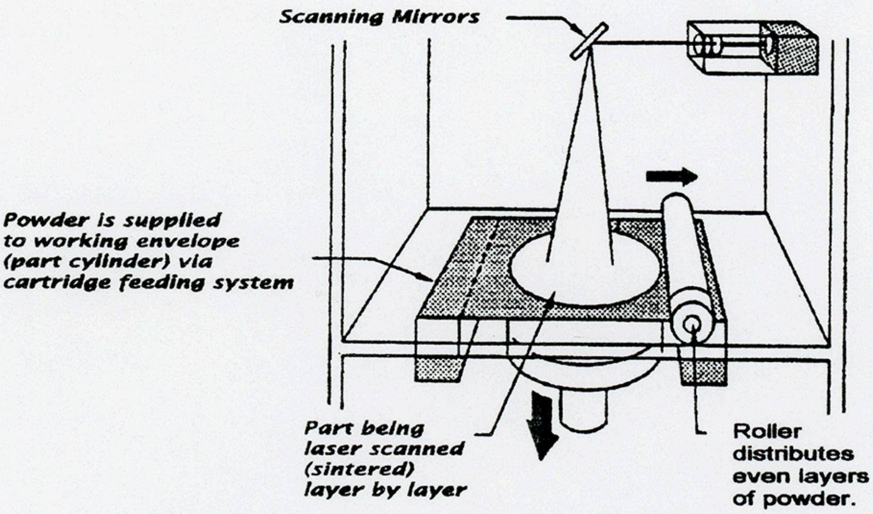
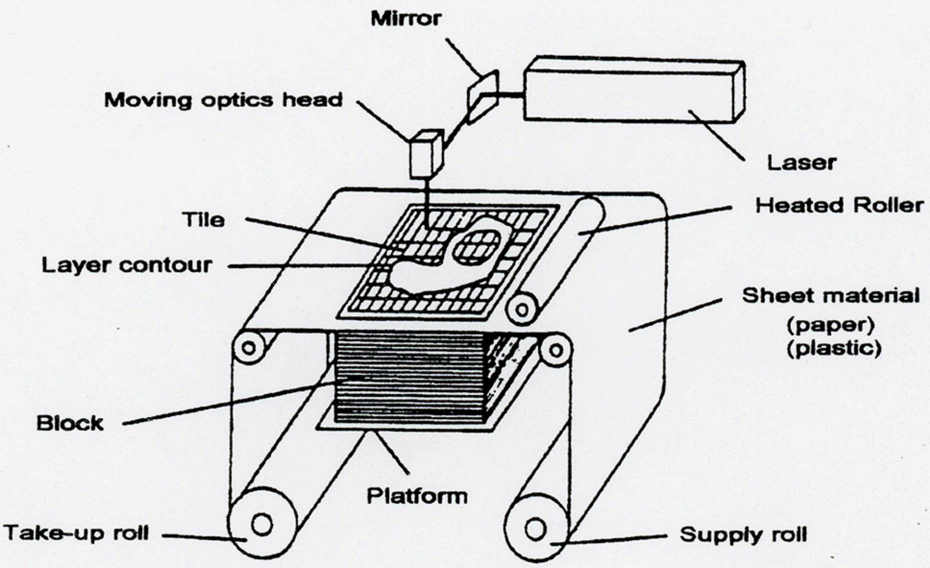


Figure 7 3-D building method (Jacobs 1992, 398)



Selective Laser Sintering (SLS) process, DTM Corp.

Figure 8 DTM building method (Jacobs 1992,401)



Laminated object manufacturing, Helisis Corp.

Figure 9 Helisis building method (Jacobs 1992, 412)

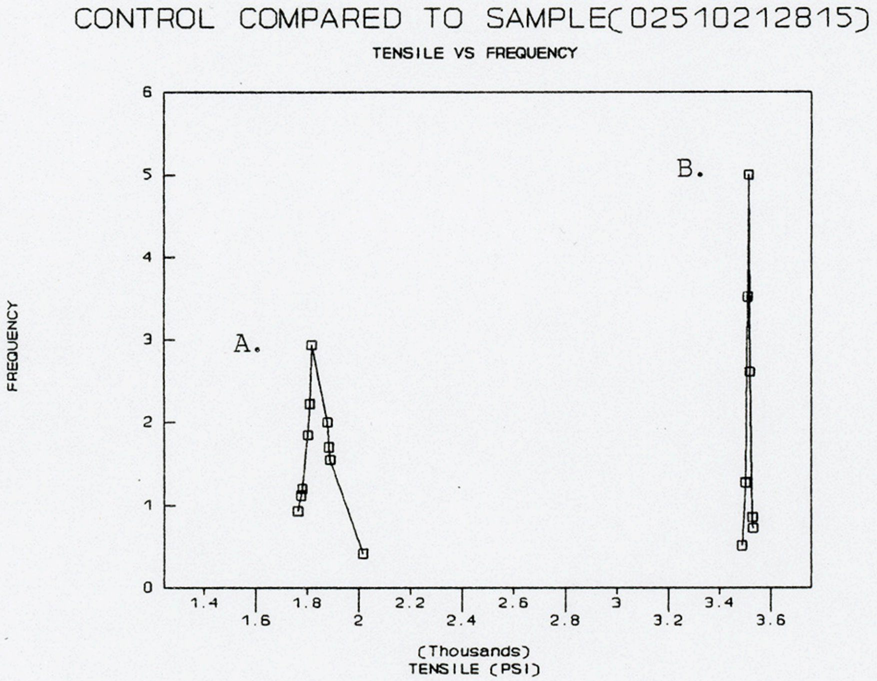


Figure 10 Sample (02510212815)

LEGEND

0	= 0 degrees (orientation angle of path)	**A = Sample Number**
25	= .025 inches (road width)	**B = Control**
10	= .010 inches (z slice)	
2	= .2 inches per second (speed)	
128	= 128 degrees C (temperature of tip & liquefier)	
15	= 15 degrees C (temperature of envelope)	

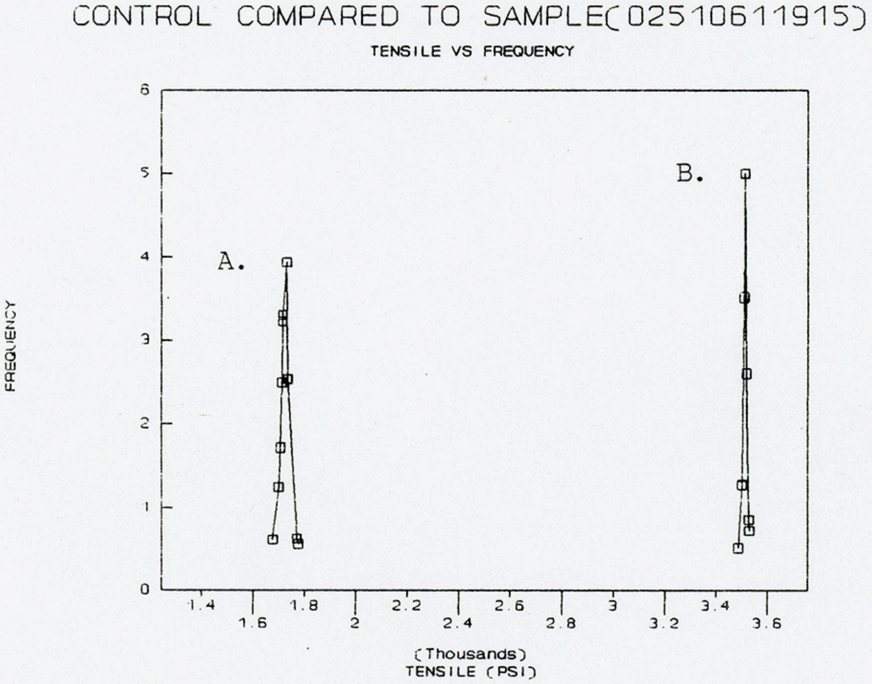


Figure 11 Sample (02510611915)

LEGEND

0	= 0 degrees (orientation angle of path)	**A = Sample Number**
25	= .025 inches (road width)	**B = Control**
10	= .010 inches (z slice)	
2	= .2 inches per second (speed)	
119	= 119 degrees C (temperature of tip & liquefier)	
15	= 15 degrees C (temperature of envelope)	

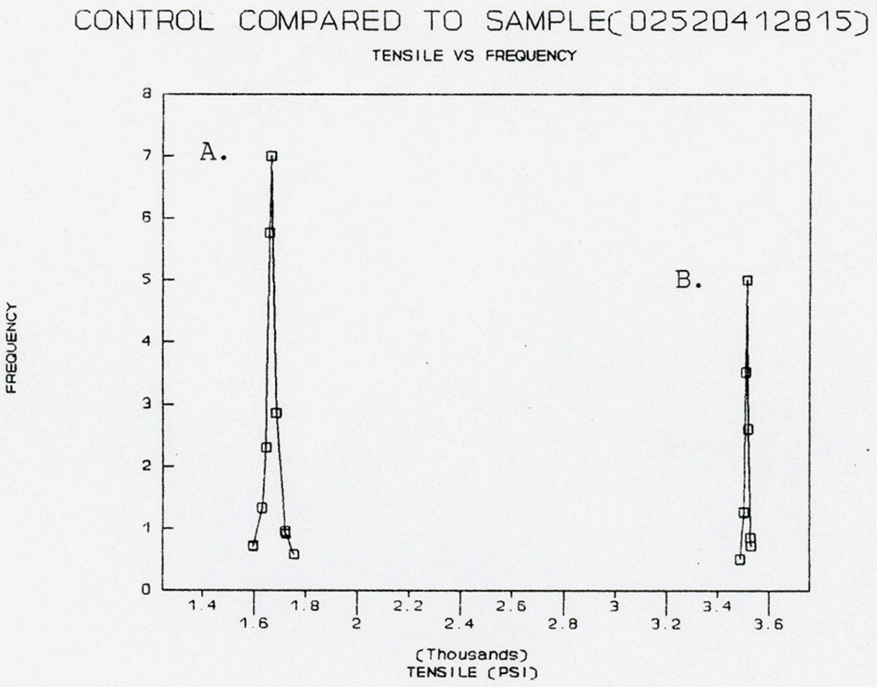


Figure 12 Sample (02520412815)

LEGEND

0	= 0 degrees (orientation angle of path)	**A = Sample Number**
25	= .025 inches (road width)	**B = Control**
20	= .020 inches (z slice)	
4	= .4 inches per second (speed)	
128	= 128 degrees C (temperature of tip & liquefier)	
15	= 15 degrees C (temperature of envelope)	

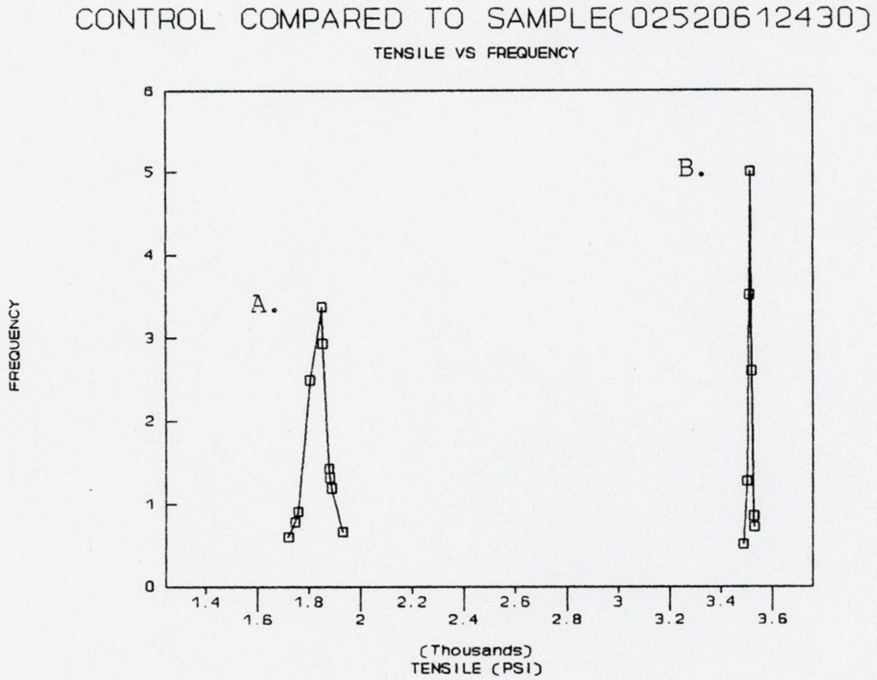


Figure 13 Sample (02520612430)

LEGEND

0	= 0 degrees (orientation angle of path)	**A = Sample Number**
25	= .025 inches (road width)	**B = Control**
20	= .020 inches (z slice)	
6	= .6 inches per second (speed)	
124	= 124 degrees C (temperature of tip & liquefier)	
30	= 30 degrees C (temperature of envelope)	

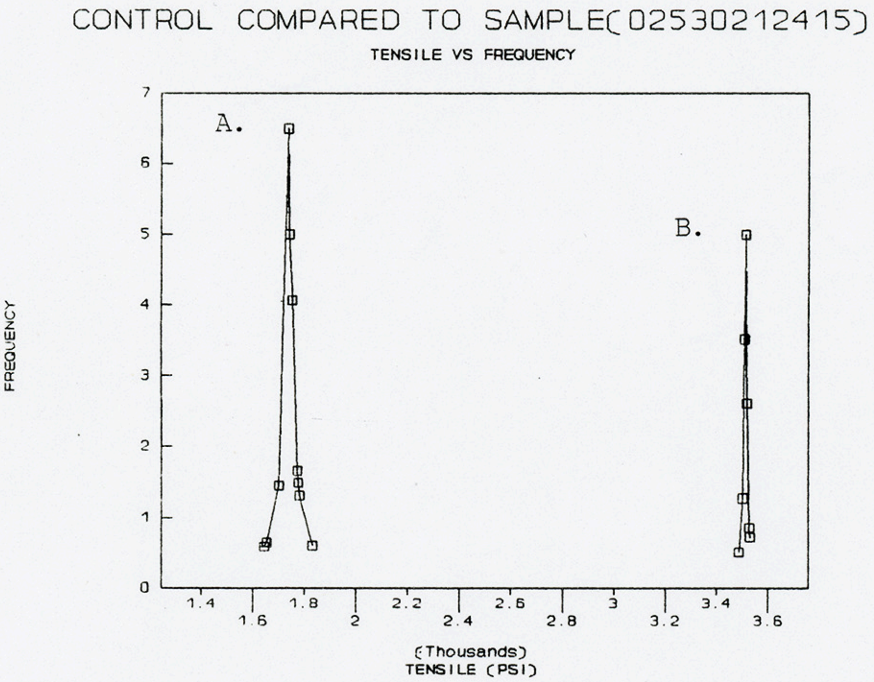


Figure 14 Sample (02530212415)

LEGEND

0	= 0 degrees (orientation angle of path)	**A = Sample Number**
25	= .025 inches (road width)	**B = Control**
30	= .030 inches (z slice)	
2	= .2 inches per second (speed)	
124	= 124 degrees C (temperature of tip & liquefier)	
15	= 15 degrees C (temperature of envelope)	

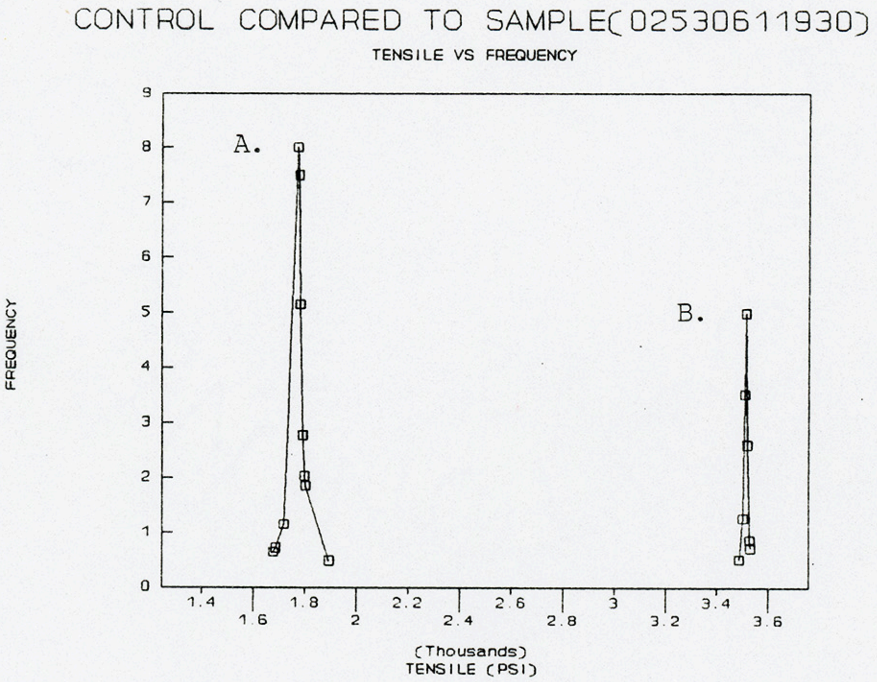


Figure 15 Sample (02530611930)

LEGEND

0	= 0 degrees (orientation angle of path)	**A = Sample Number**
25	= .025 inches (road width)	**B = Control**
30	= .030 inches (z slice)	
6	= .6 inches per second (speed)	
119	= 119 degrees C (temperature of tip & liquefier)	
30	= 30 degrees C (temperature of envelope)	

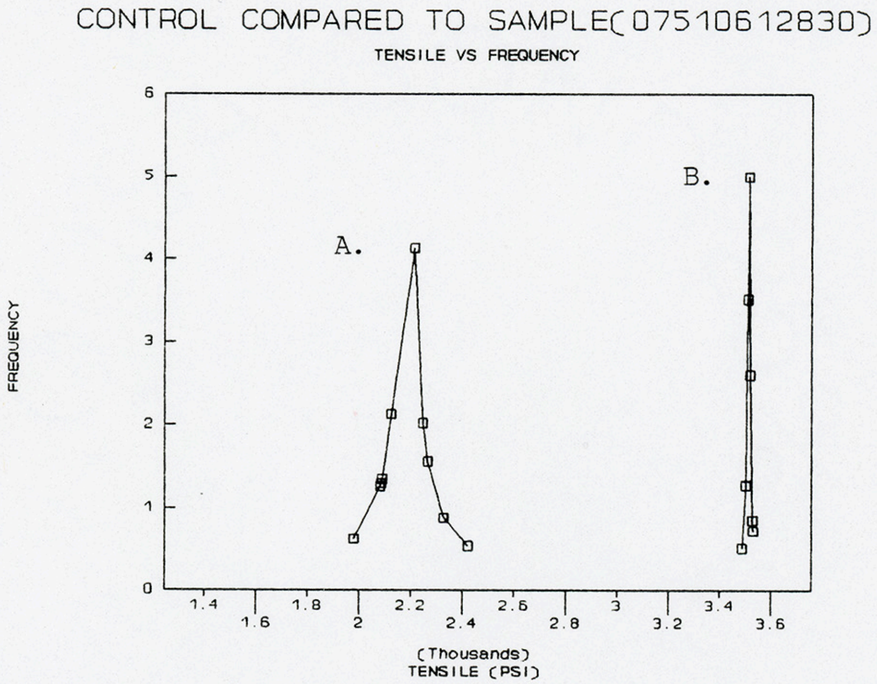


Figure 16 Sample (07510611930)

LEGEND

0	= 0 degrees (orientation angle of path)	**A = Sample Number**
75	= .075 inches (road width)	**B = Control**
10	= .010 inches (z slice)	
6	= .6 inches per second (speed)	
119	= 119 degrees C (temperature of tip & liquefier)	
30	= 30 degrees C (temperature of envelope)	

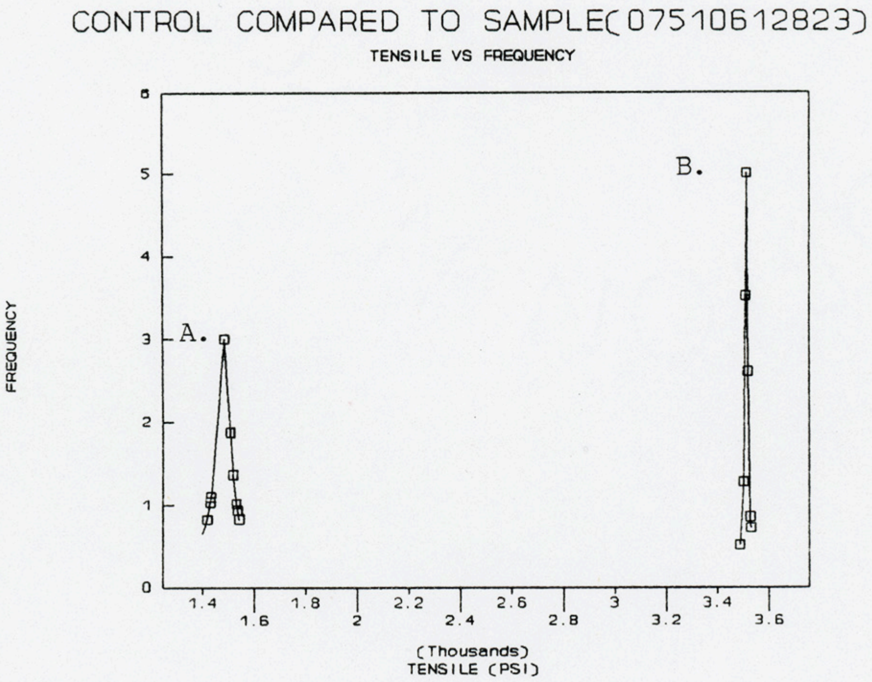


Figure 17 Sample (07510612823)

LEGEND

0	= 0 degrees (orientation angle of path)	A = Sample Number
75	= .025 inches (road width)	B = Control
10	= .010 inches (z slice)	
6	= .6 inches per second (speed)	
128	= 128 degrees C (temperature of tip & liquefier)	
23	= 23 degrees C (temperature of envelope)	

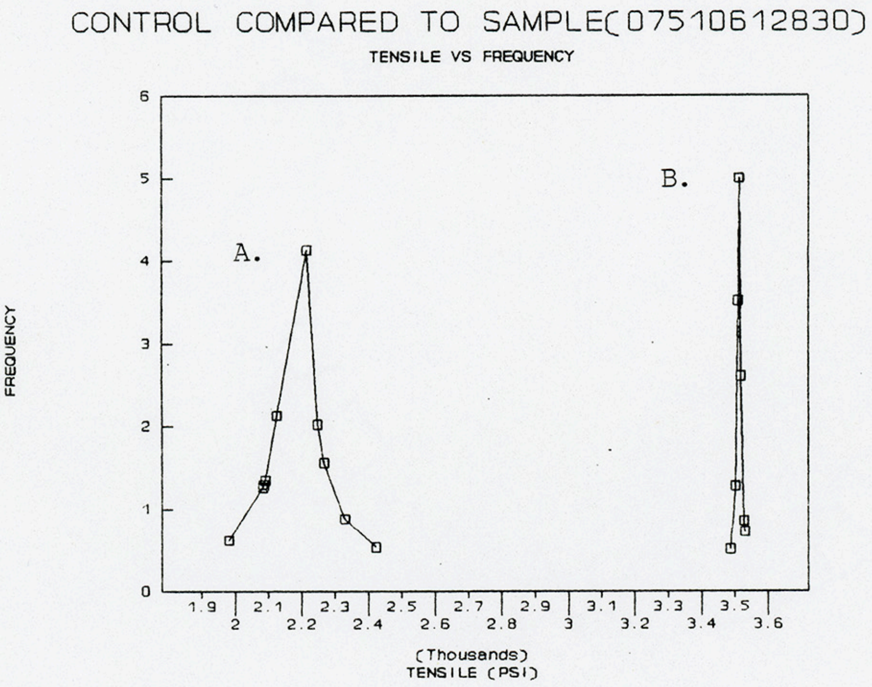


Figure 18 Sample (07510612830)

LEGEND

0	= 0 degrees (orientation angle of path)	**A = Sample Number**
75	= .075 inches (road width)	**B = Control**
10	= .010 inches (z slice)	
6	= .6 inches per second (speed)	
128	= 128 degrees C (temperature of tip & liquefier)	
30	= 30 degrees C (temperature of envelope)	

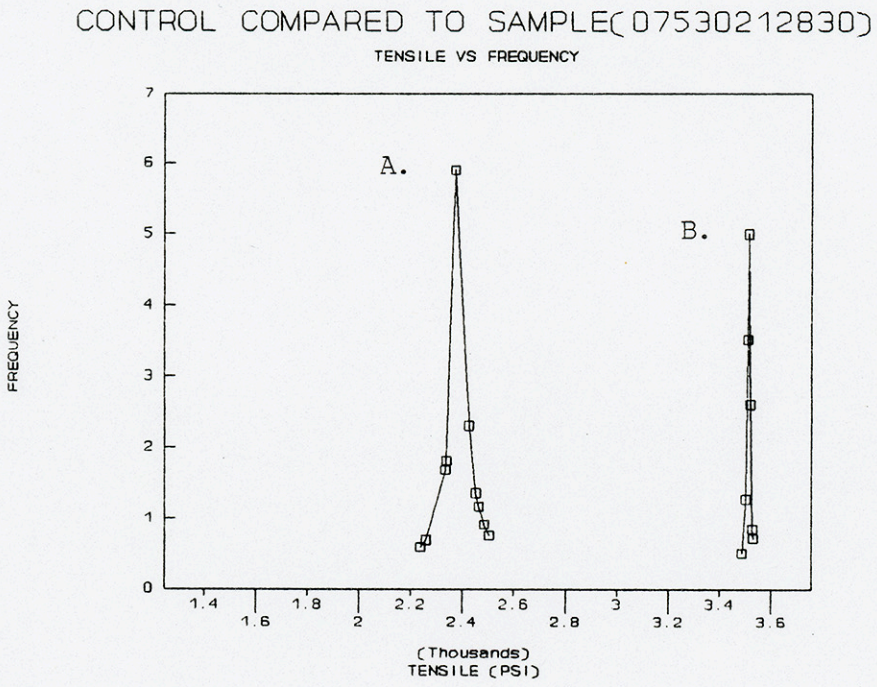


Figure 19 Sample (07530212830)

LEGEND

0	= 0 degrees (orientation angle of path)	**A = Sample Number**
75	= .075 inches (road width)	**B = Control**
30	= .030 inches (z slice)	
2	= .2 inches per second (speed)	
128	= 128 degrees C (temperature of tip & liquefier)	
30	= 30 degrees C (temperature of envelope)	

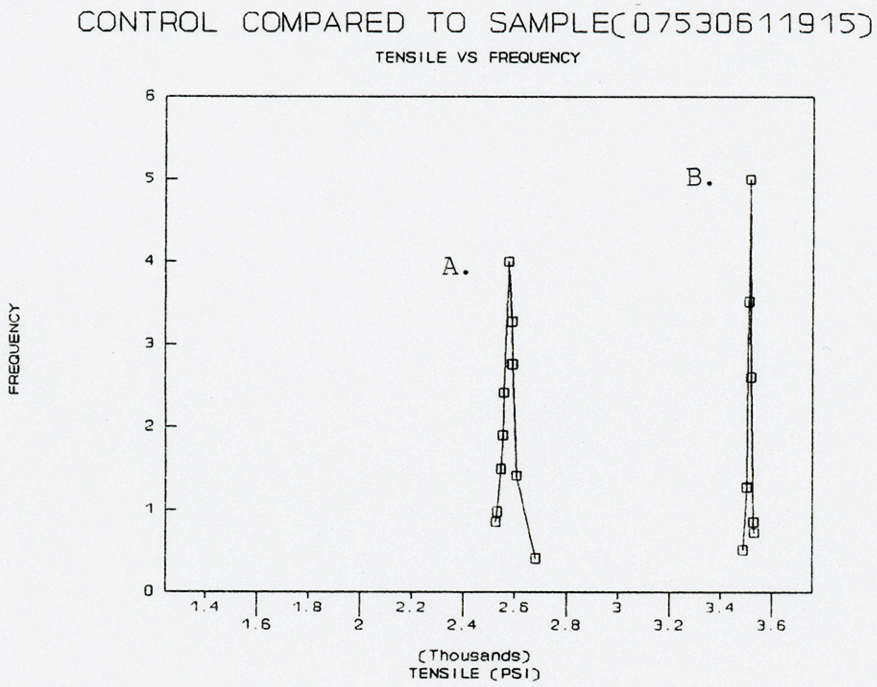


Figure 20 Sample (07530611915)

LEGEND

0	= 0 degrees (orientation angle of path)	A = Sample Number
75	= .075 inches (road width)	B = Control
30	= .030 inches (z slice)	
6	= .6 inches per second (speed)	
119	= 119 degrees C (temperature of tip & liquefier)	
15	= 15 degrees C (temperature of envelope)	

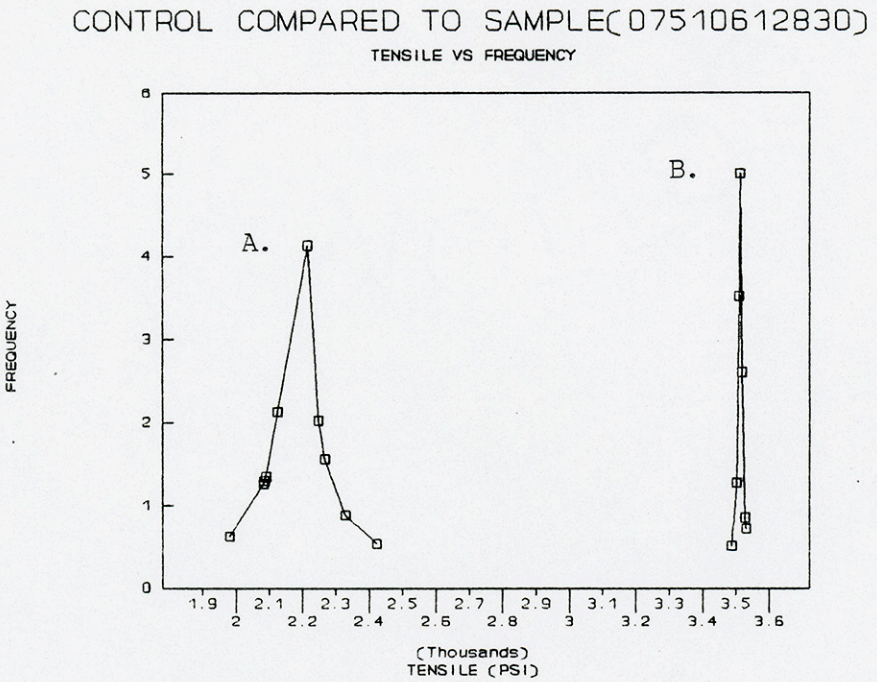


Figure 21 Sample (07530612815)

LEGEND

0	= 0 degrees (orientation angle of path)	**A = Sample Number**
75	= .075 inches (road width)	**B = Control**
30	= .030 inches (z slice)	
6	= .6 inches per second (speed)	
128	= 128 degrees C (temperature of tip & liquefier)	
15	= 15 degrees C (temperature of envelope)	

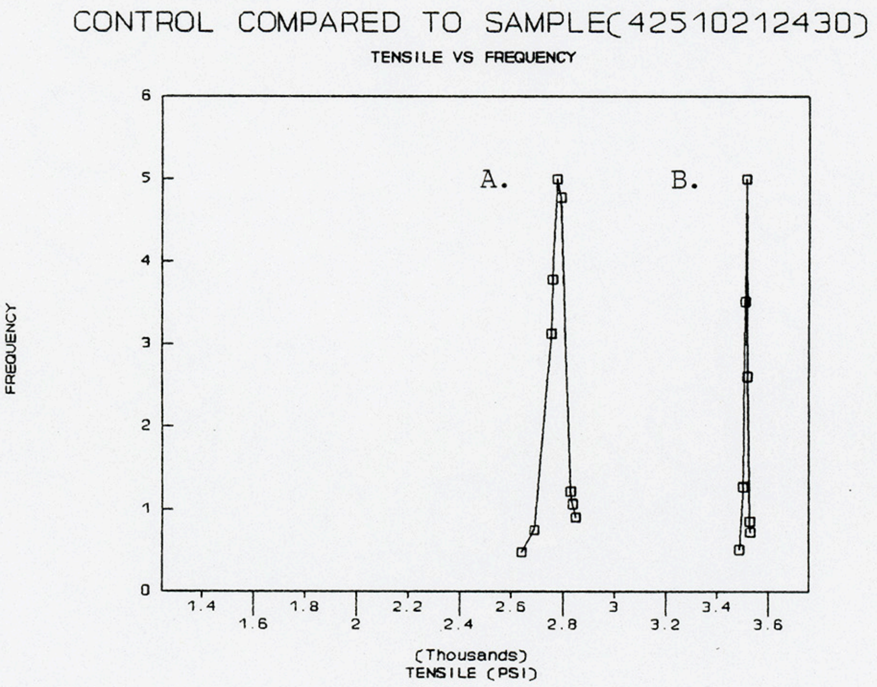


Figure 22 Sample (452510212430)

LEGEND

45	= 45 degrees (orientation angle of path)	**A = Sample Number**
25	= .025 inches (road width)	**B = Control**
10	= .010 inches (z slice)	
2	= .2 inches per second (speed)	
124	= 124 degrees C (temperature of tip & liquefier)	
30	= 30 degrees C (temperature of envelope)	

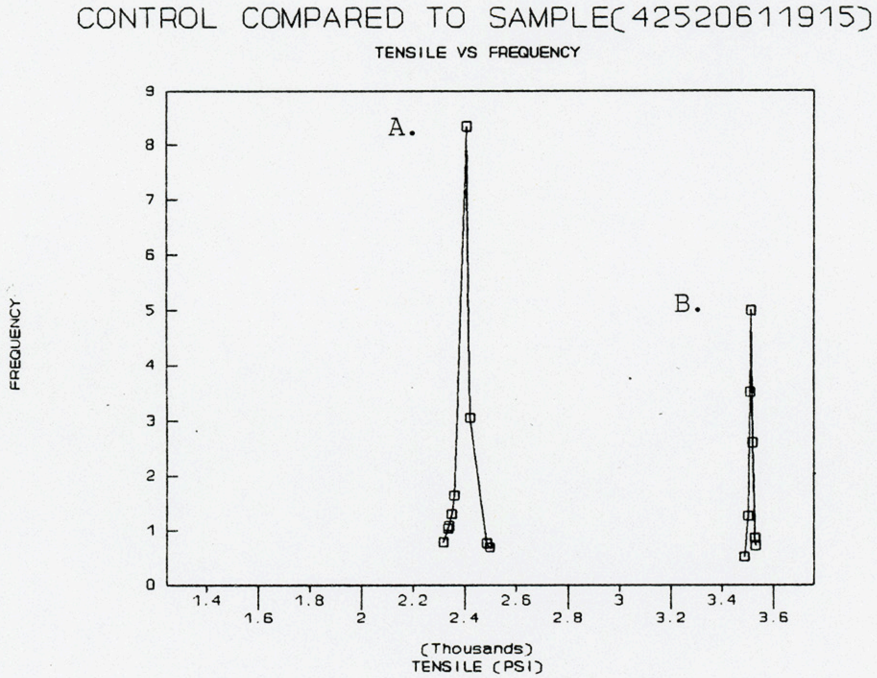


Figure 23 Sample (452520611915)

LEGEND

45	= 45 degrees (orientation angle of path)	**A = Sample Number**
25	= .025 inches (road width)	**B = Control**
20	= .020 inches (z slice)	
6	= .6 inches per second (speed)	
119	= 119 degrees C (temperature of tip & liquefier)	
15	= 15 degrees C (temperature of envelope)	

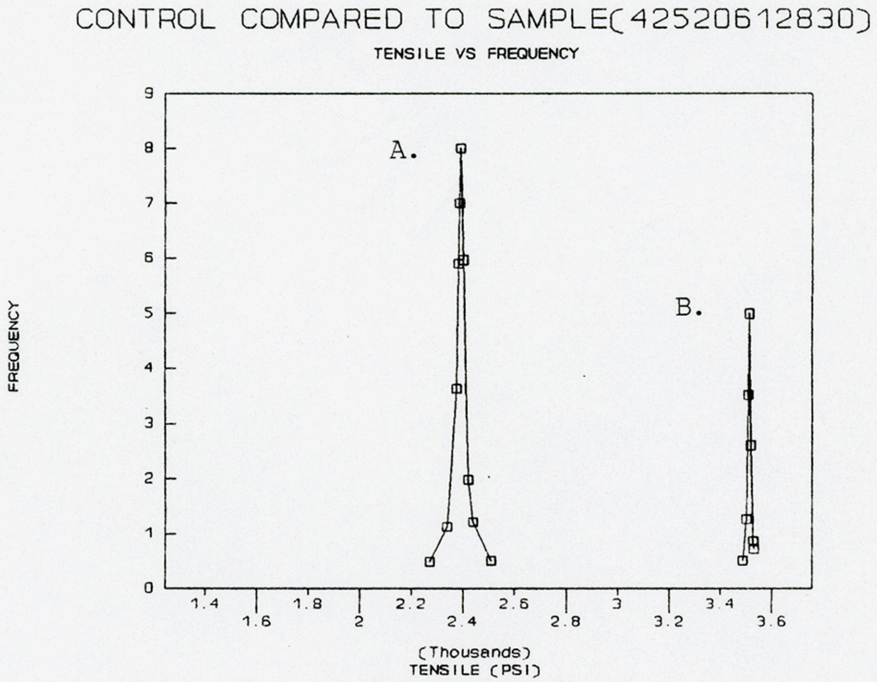


Figure 24 Sample (452520612830)

LEGEND

45	= 45 degrees (orientation angle of path)	**A = Sample Number**
25	= .025 inches (road width)	**B = Control**
20	= .020 inches (z slice)	
6	= .6 inches per second (speed)	
128	= 128 degrees C (temperature of tip & liquefier)	
30	= 30 degrees C (temperature of envelope)	

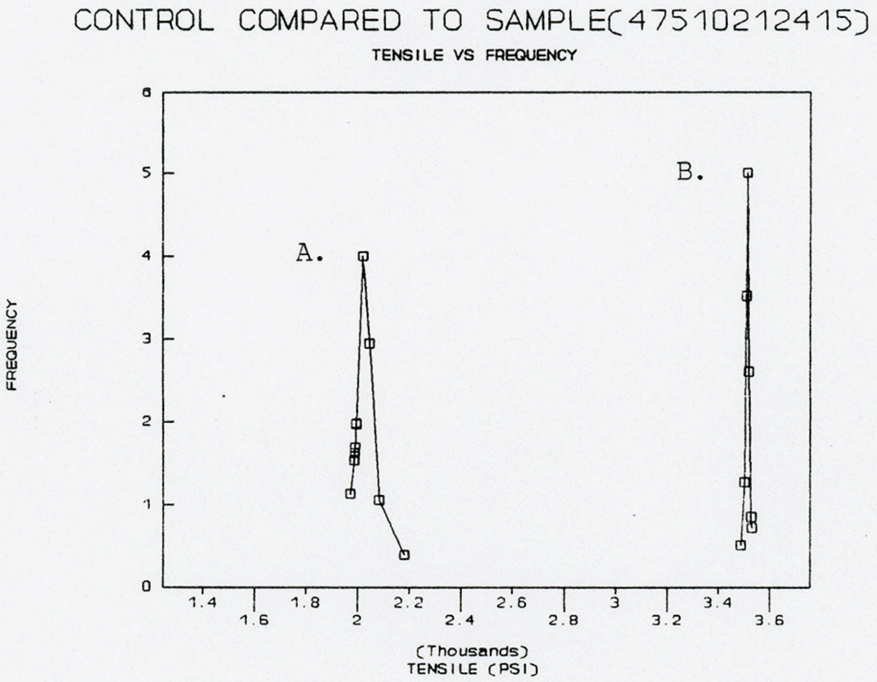


Figure 25 Sample (457510212415)

LEGEND

45	= 45 degrees (orientation angle of path)	**A = Sample Number**
75	= .075 inches (road width)	**B = Control**
10	= .010 inches (z slice)	
2	= .2 inches per second (speed)	
124	= 124 degrees C (temperature of tip & liquefier)	
15	= 15 degrees C (temperature of envelope)	

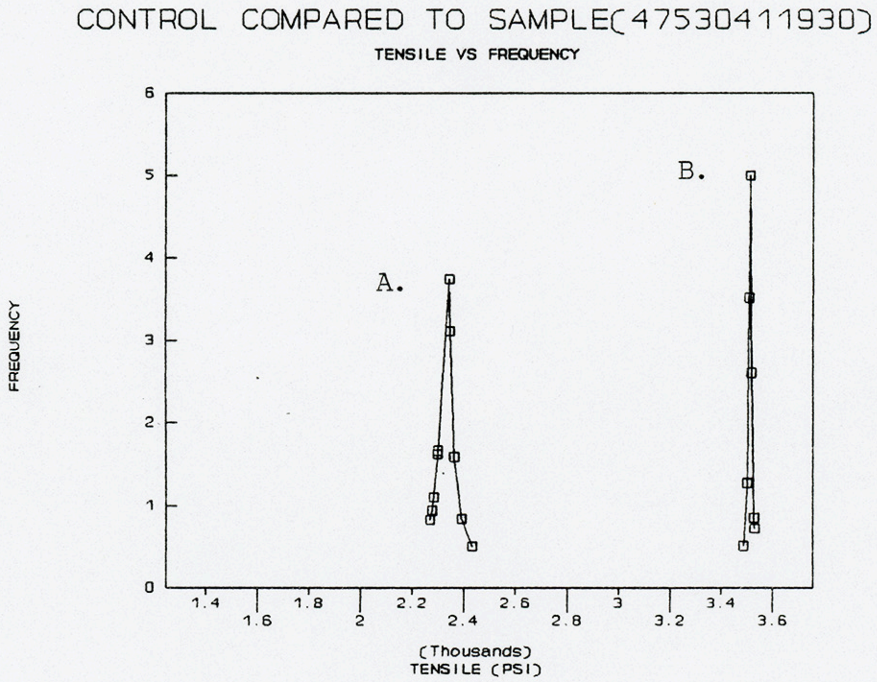


Figure 26 Sample (457530411930)

LEGEND

45	= 45 degrees (orientation angle of path)	**A = Sample Number**
75	= .075 inches (road width)	**B = Control**
30	= .030 inches (z slice)	
4	= .4 inches per second (speed)	
119	= 119 degrees C (temperature of tip & liquefier)	
30	= 30 degrees C (temperature of envelope)	

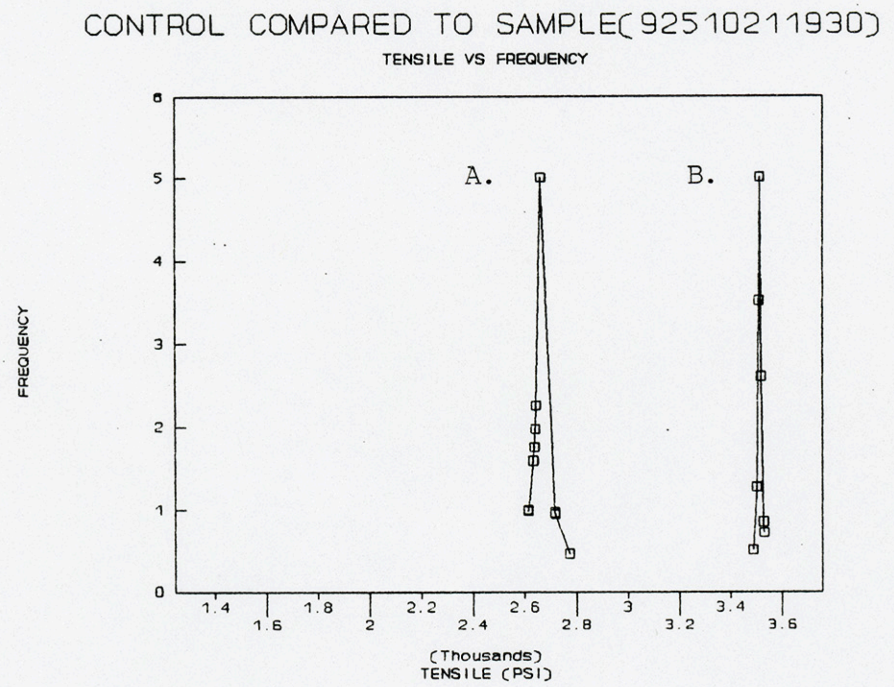


Figure 27 Sample (902510211930)

LEGEND

90	= 90 degrees (orientation angle of path)	**A = Sample Number**
25	= .025 inches (road width)	**B = Control**
10	= .010 inches (z slice)	
2	= .2 inches per second (speed)	
119	= 119 degrees C (temperature of tip & liquefier)	
30	= 30 degrees C (temperature of envelope)	

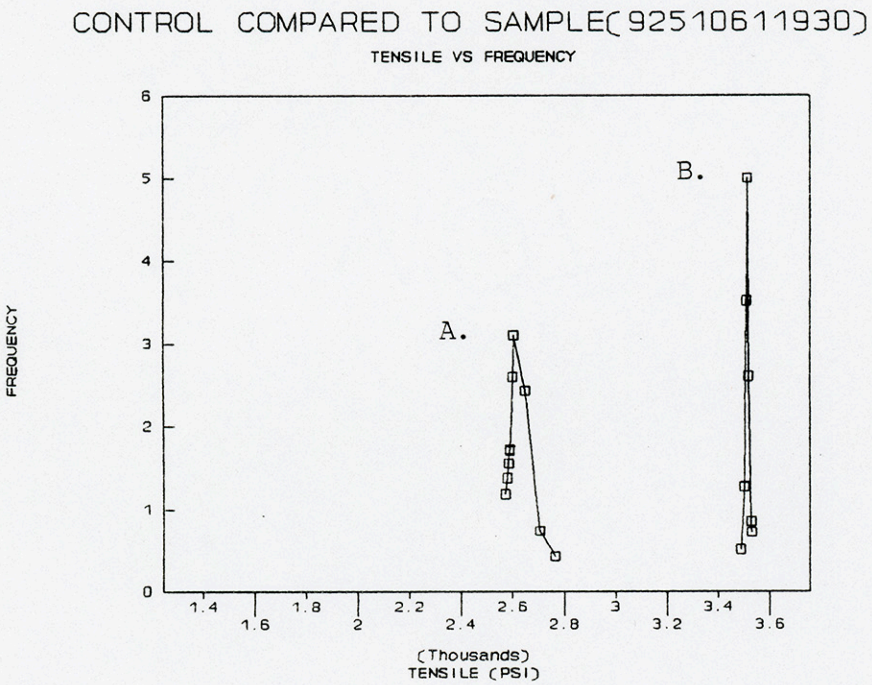


Figure 28 Sample (902510611930)

LEGEND

90	= 90 degrees (orientation angle of path)	**A = Sample Number**
25	= .025 inches (road width)	**B = Control**
10	= .010 inches (z slice)	
6	= .6 inches per second (speed)	
119	= 119 degrees C (temperature of tip & liquefier)	
30	= 30 degrees C (temperature of envelope)	

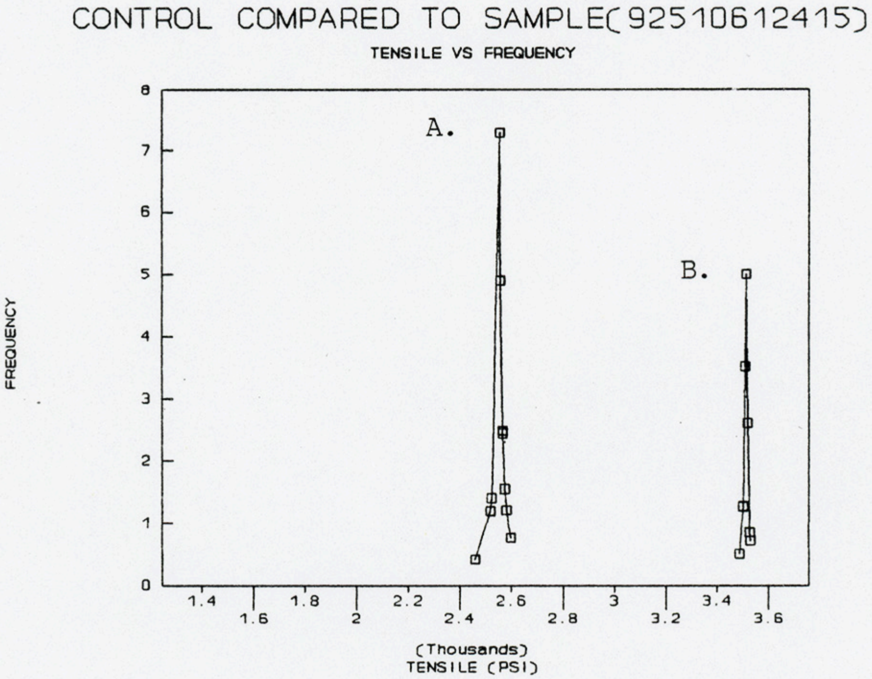


Figure 29 Sample (902510612415)

LEGEND

90	= 90 degrees (orientation angle of path)	**A = Sample Number**
25	= .025 inches (road width)	**B = Control**
10	= .010 inches (z slice)	
6	= .6 inches per second (speed)	
124	= 124 degrees C (temperature of tip & liquefier)	
15	= 15 degrees C (temperature of envelope)	

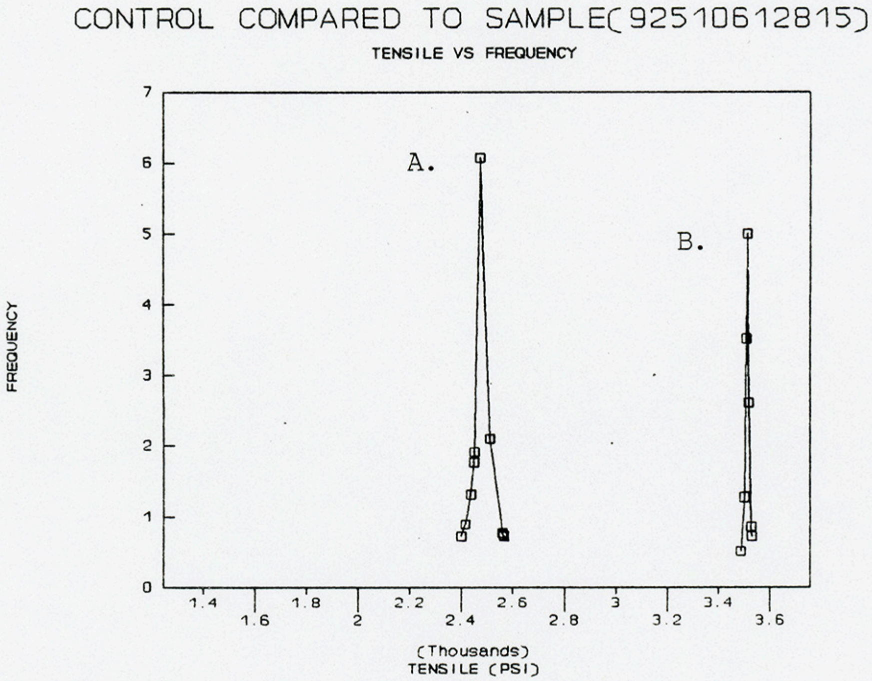


Figure 30 Sample (902510612815)

LEGEND

90	= 90 degrees (orientation angle of path)	**A = Sample Number**
25	= .025 inches (road width)	**B = Control**
10	= .010 inches (z slice)	
6	= .6 inches per second (speed)	
128	= 128 degrees C (temperature of tip & liquefier)	
15	= 15 degrees C (temperature of envelope)	

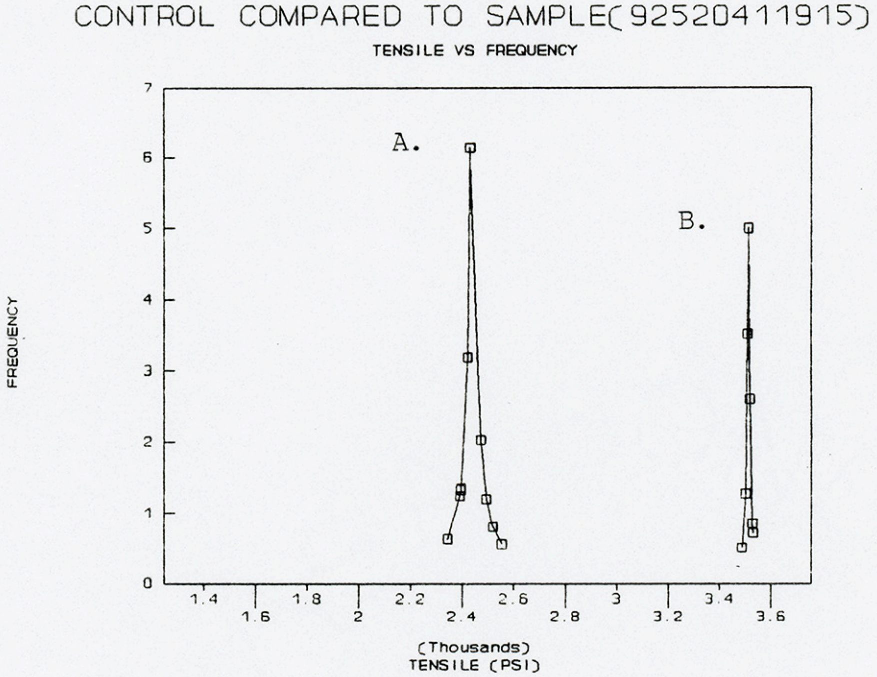


Figure 31 Sample (902520411915)

LEGEND

90	= 90 degrees (orientation angle of path)	**A = Sample Number**
25	= .025 inches (road width)	**B = Control**
20	= .020 inches (z slice)	
4	= .4 inches per second (speed)	
119	= 119 degrees C (temperature of tip & liquefier)	
15	= 15 degrees C (temperature of envelope)	

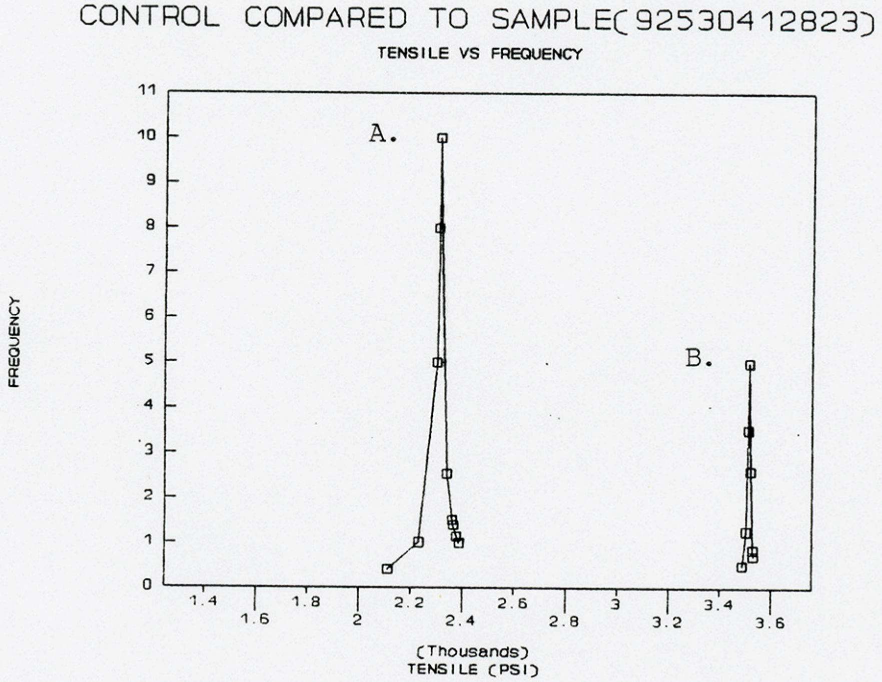


Figure 32 Sample (902530412823)

LEGEND

90	= 90 degrees (orientation angle of path)	**A = Sample Number**
25	= .025 inches (road width)	**B = Control**
30	= .030 inches (z slice)	
4	= .4 inches per second (speed)	
128	= 128 degrees C (temperature of tip & liquefier)	
23	= 23 degrees C (temperature of envelope)	

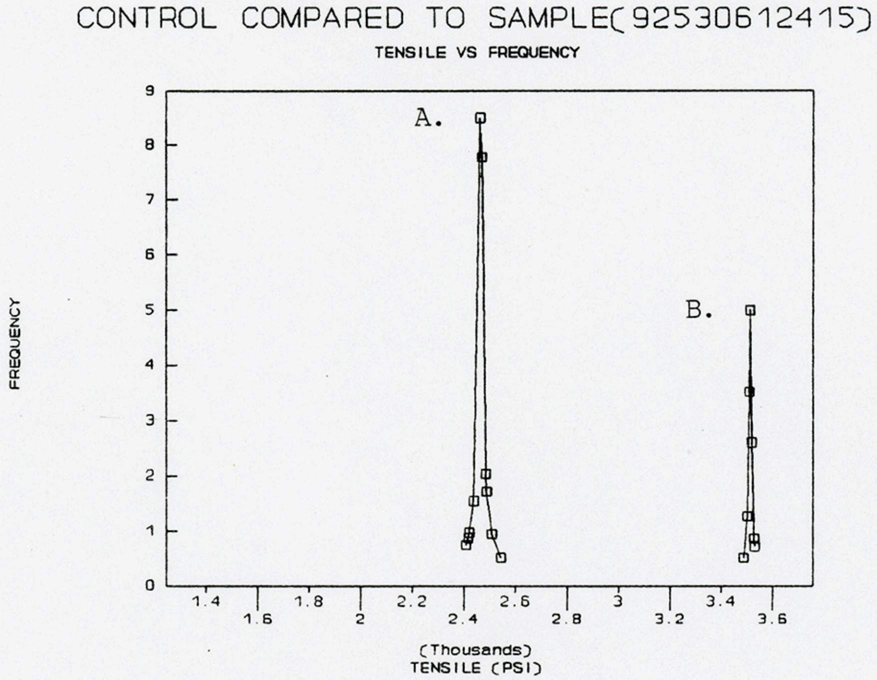


Figure 33 Sample (902530612415)

LEGEND

90	= 90 degrees (orientation angle of path)	**A = Sample Number**
25	= .025 inches (road width)	**B = Control**
30	= .030 inches (z slice)	
6	= .6 inches per second (speed)	
124	= 124 degrees C (temperature of tip & liquefier)	
15	= 15 degrees C (temperature of envelope)	

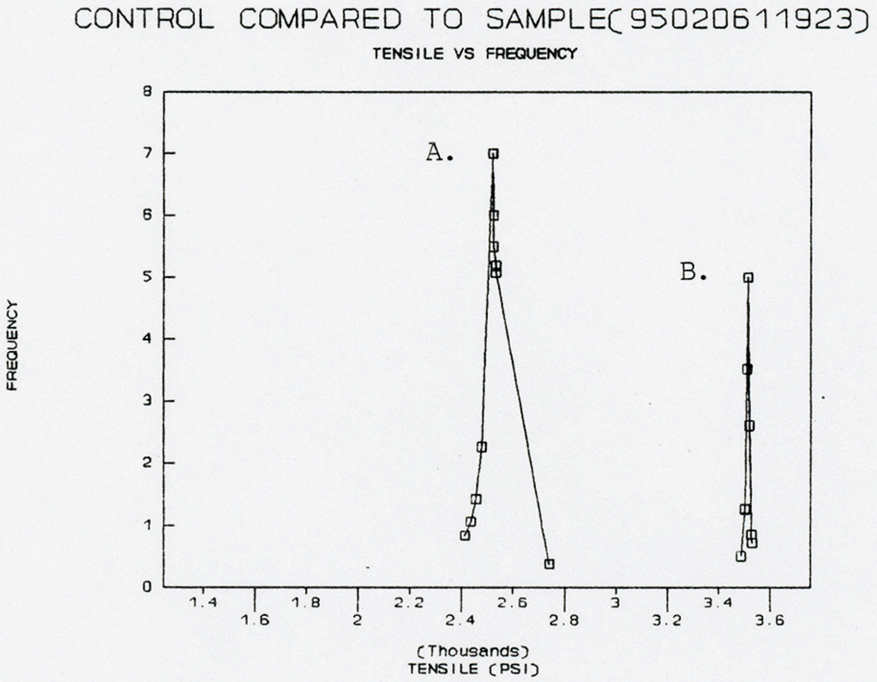


Figure 34 Sample (905020611923)

LEGEND

90	= 90 degrees (orientation angle of path)	**A = Sample Number**
50	= .050 inches (road width)	**B = Control**
20	= .020 inches (z slice)	
6	= .6 inches per second (speed)	
119	= 119 degrees C (temperature of tip & liquefier)	
23	= 23 degrees C (temperature of envelope)	

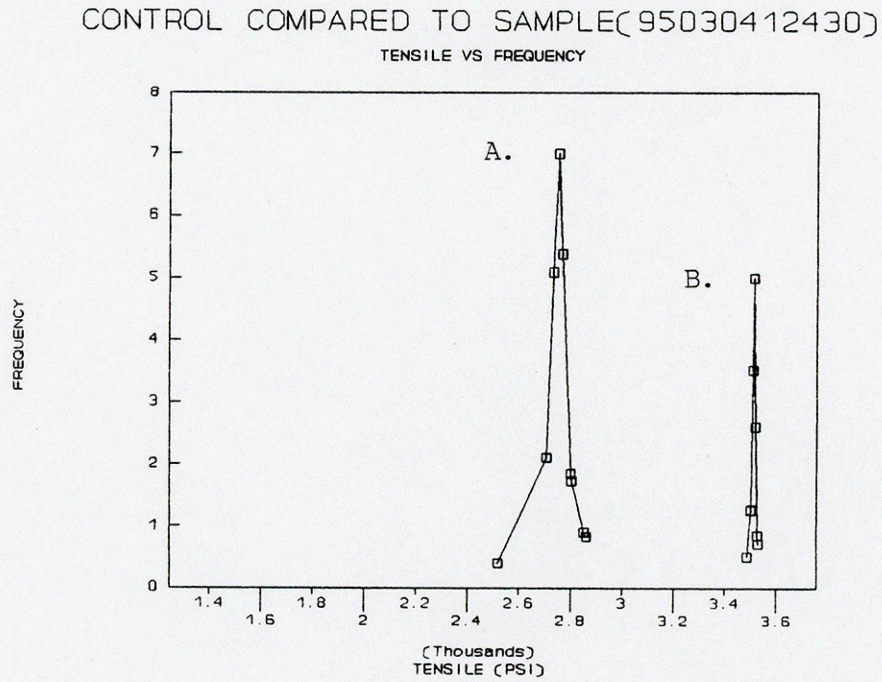


Figure 35 Sample (905030412415)

LEGEND

90	= 90 degrees (orientation angle of path)	**A = Sample Number**
50	= .050 inches (road width)	**B = Control**
30	= .030 inches (z slice)	
4	= .4 inches per second (speed)	
124	= 124 degrees C (temperature of tip & liquefier)	
30	= 30 degrees C (temperature of envelope)	

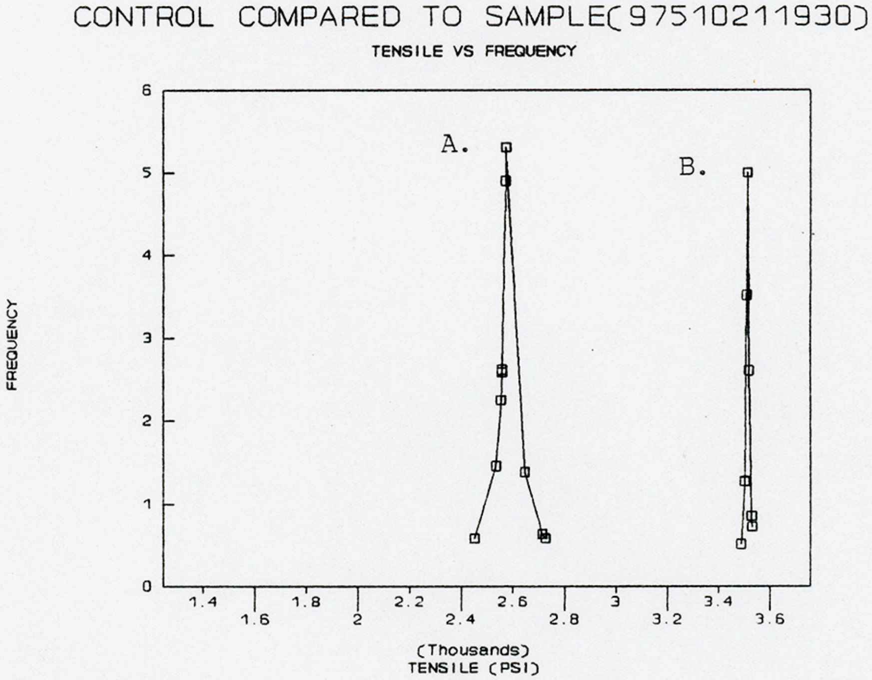


Figure 36 Sample (907510211930)

LEGEND

90	= 90 degrees (orientation angle of path)	**A = Sample Number**
75	= .075 inches (road width)	**B = Control**
10	= .010 inches (z slice)	
2	= .2 inches per second (speed)	
119	= 119 degrees C (temperature of tip & liquefier)	
30	= 30 degrees C (temperature of envelope)	

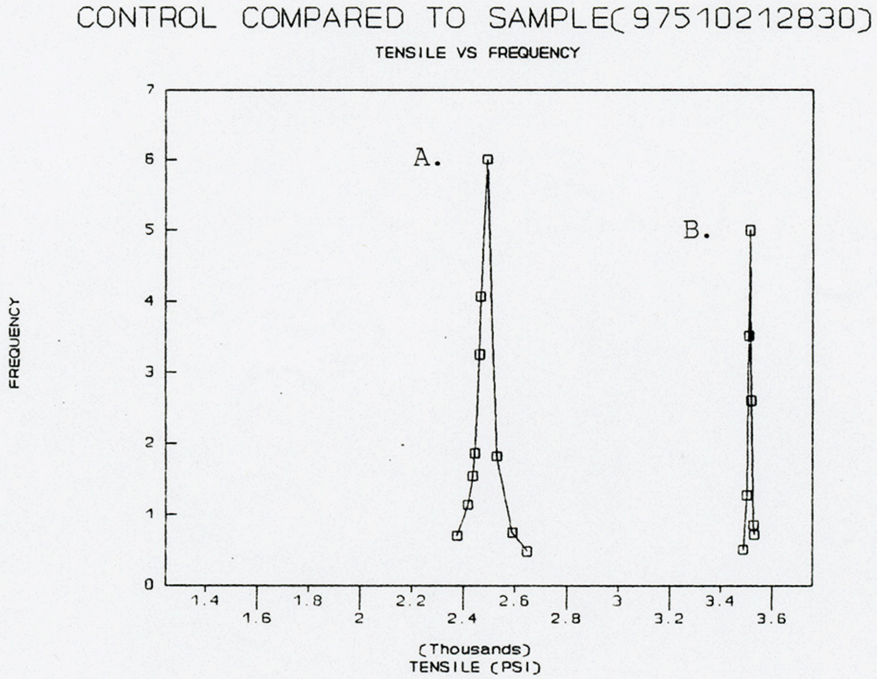


Figure 37 Sample (907510212830)

LEGEND

90	= 90 degrees (orientation angle of path)	**A = Sample Number**
75	= .075 inches (road width)	**B = Control**
10	= .010 inches (z slice)	
2	= .2 inches per second (speed)	
128	= 128 degrees C (temperature of tip & liquefier)	
30	= 30 degrees C (temperature of envelope)	

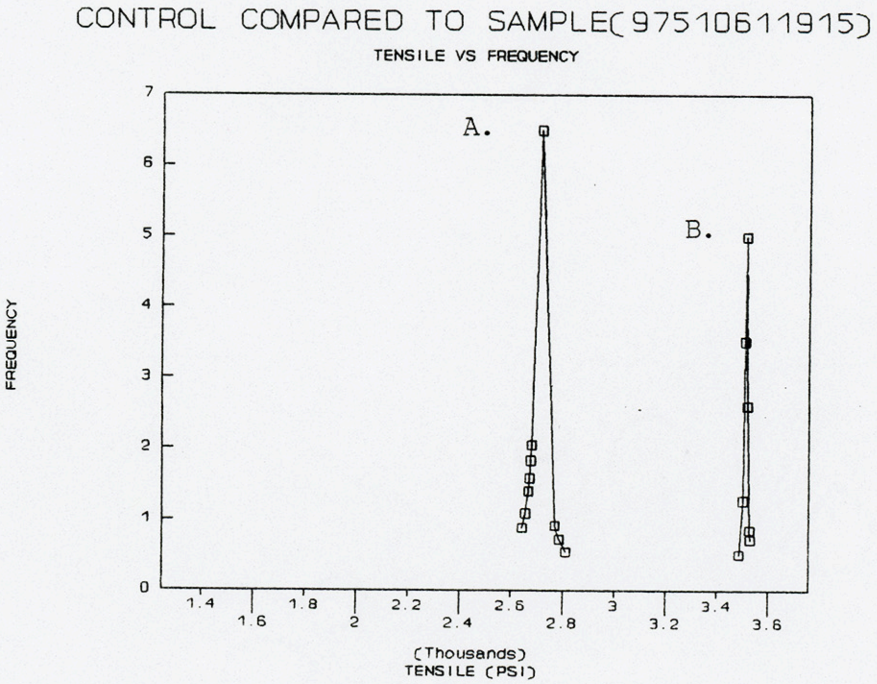


Figure 38 Sample (907510611915)

LEGEND

90	= 90 degrees (orientation angle of path)	**A = Sample Number**
75	= .075 inches (road width)	**B = Control**
10	= .010 inches (z slice)	
6	= .6 inches per second (speed)	
119	= 119 degrees C (temperature of tip & liquefier)	
15	= 15 degrees C (temperature of envelope)	

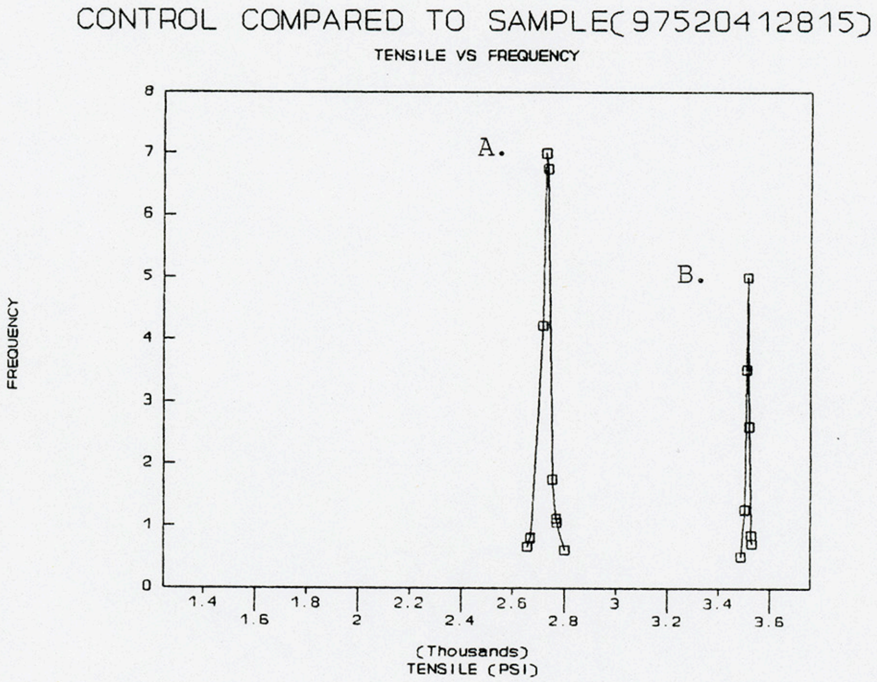


Figure 39 Sample (907520412815)

LEGEND

90	= 90 degrees (orientation angle of path)	**A = Sample Number**
75	= .075 inches (road width)	**B = Control**
20	= .020 inches (z slice)	
4	= .4 inches per second (speed)	
128	= 128 degrees C (temperature of tip & liquefier)	
15	= 15 degrees C (temperature of envelope)	

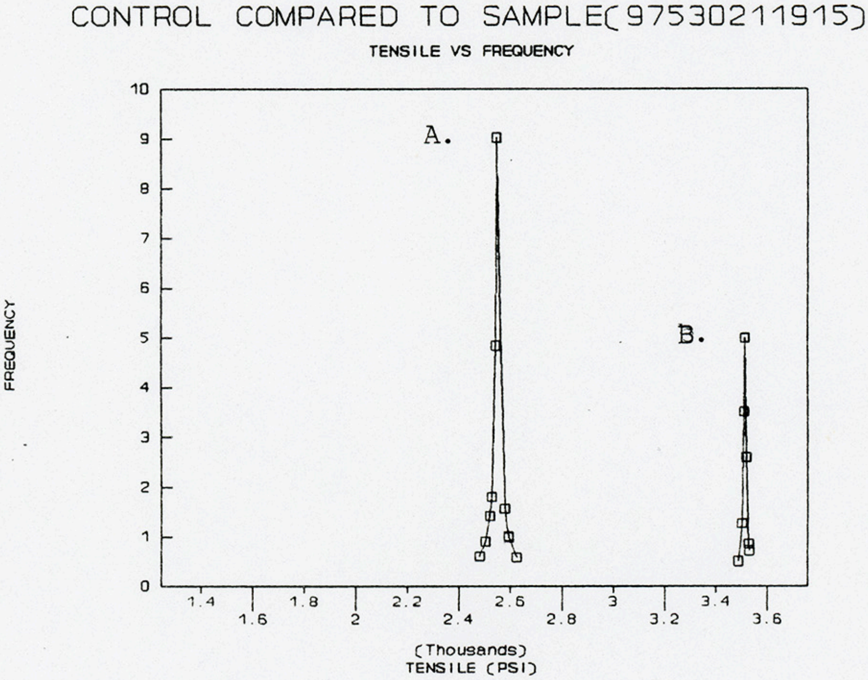


Figure 40 Sample (907530211915)

LEGEND

90	= 90 degrees (orientation angle of path)	**A = Sample Number**
75	= .075 inches (road width)	**B = Control**
30	= .030 inches (z slice)	
2	= .2 inches per second (speed)	
119	= 119 degrees C (temperature of tip & liquefier)	
15	= 15 degrees C (temperature of envelope)	

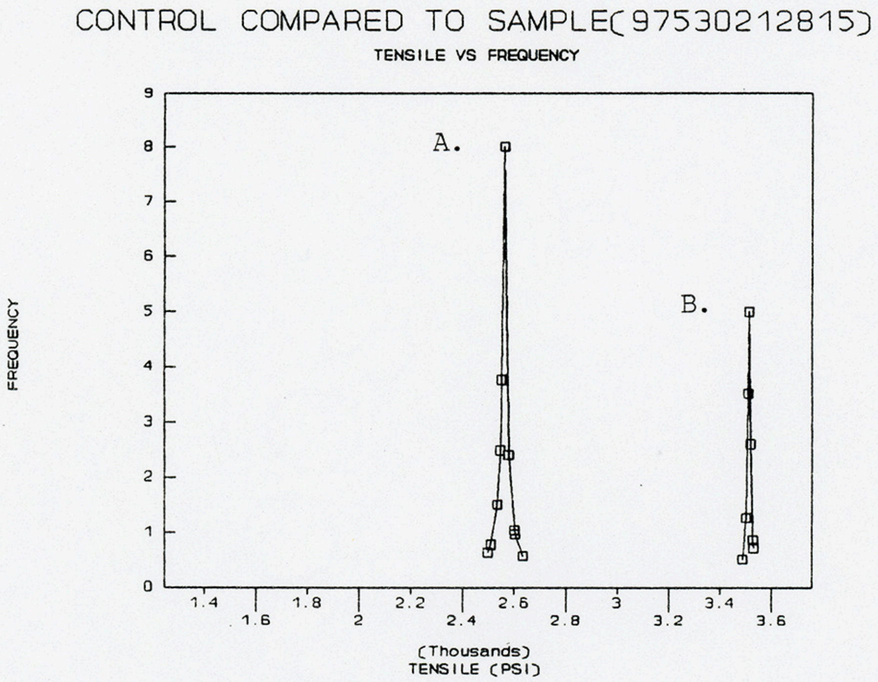


Figure 41 Sample (907530212815)

LEGEND

90	= 90 degrees (orientation angle of path)	**A = Sample Number**
75	= .075 inches (road width)	**B = Control**
30	= .030 inches (z slice)	
2	= .2 inches per second (speed)	
128	= 128 degrees C (temperature of tip & liquefier)	
15	= 15 degrees C (temperature of envelope)	

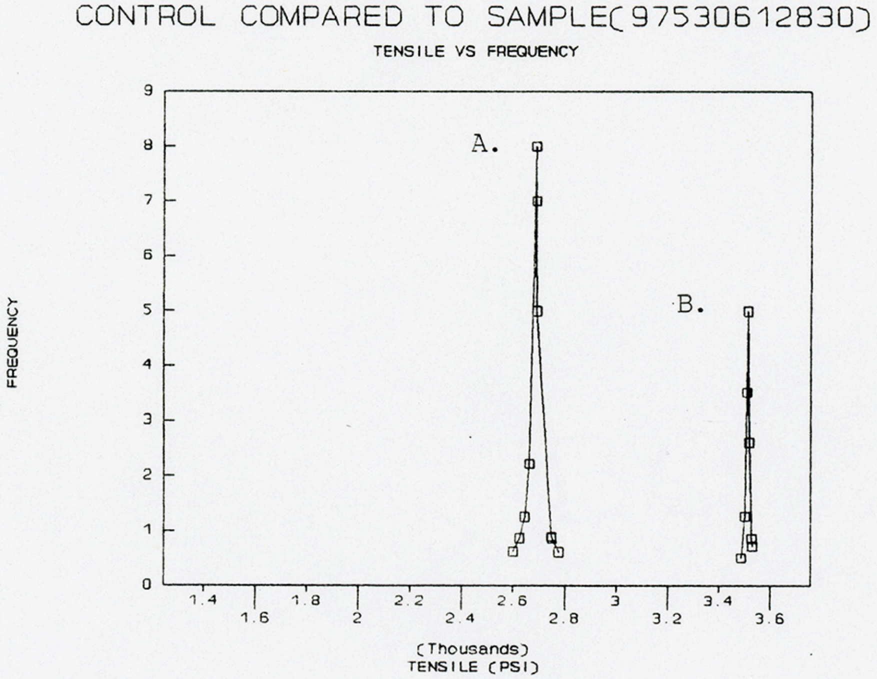


Figure 42 Sample (907530612830)

LEGEND

90	= 90 degrees (orientation angle of path)	**A = Sample Number**
75	= .075 inches (road width)	**B = Control**
30	= .030 inches (z slice)	
6	= .6 inches per second (speed)	
128	= 128 degrees C (temperature of tip & liquefier)	
30	= 30 degrees C (temperature of envelope)	

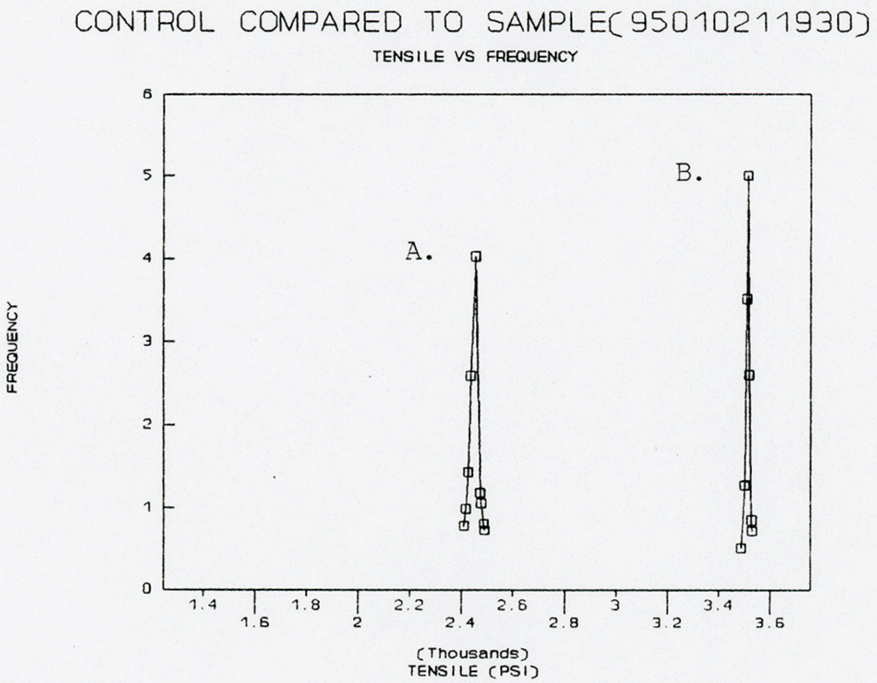


Figure 43 Sample (905010211930)

LEGEND

90	= 90 degrees (orientation angle of path)	**A = Sample Number**
50	= .050 inches (road width)	**B = Control**
10	= .010 inches (z slice)	
2	= .2 inches per second (speed)	
119	= 119 degrees C (temperature of tip & liquefier)	
30	= 30 degrees C (temperature of envelope)	

APPENDIX D

Table 1

Control VS 02510212815

Control Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)	02510212815 Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)
0.500	0.130	0.065	229.333	3528.200	0.490	0.137	0.067	121.452	1809.206
0.500	0.130	0.065	227.667	3502.569	0.489	0.138	0.067	126.774	1878.634
0.500	0.130	0.065	226.667	3487.185	0.489	0.137	0.067	126.290	1885.122
0.500	0.130	0.065	228.666	3517.938	0.496	0.140	0.069	125.161	1802.434
0.500	0.130	0.065	228.333	3512.815	0.495	0.139	0.069	122.258	1776.877
0.500	0.130	0.065	228.095	3509.154	0.500	0.140	0.070	124.677	1781.100
0.500	0.130	0.065	229.333	3528.200	0.500	0.139	0.070	122.581	1763.755
0.500	0.130	0.065	227.666	3502.554	0.497	0.125	0.062	125.323	2017.272
0.500	0.130	0.065	229.524	3531.138	0.498	0.130	0.065	122.315	1889.327
0.500	0.130	0.065	228.095	3509.154	0.499	0.135	0.067	122.415	1817.190
			Mean	3512.890				Mean	1842.091
			St. Dev.	13.15039				St. Dev.	73.13686

LEGEND

0 = 0 degrees (orientation angle of path)
25 = .025 inches (road width)
10 = .010 inches (z slice)
2 = .2 inches per second (speed)
128 = 128 degrees C (temperature of tip & liquefier)
15 = 15 degrees C (temperature of envelope)

Table 2

Analysis of Variance

Control VS 02510212815

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	13957848.348	13957848.34	4549.877
Within	18	55219.345425	3067.741412	
Total	19	14013067.694		

LEGEND

0 = 0 degrees (orientation angle of path)
25 = .025 inches (road width)
10 = .010 inches (z slice)
2 = .2 inches per second (speed)
128 = 128 degrees C (temperature of tip & liquefier)
15 = 15 degrees C (temperature of envelope)

Table 3

Control VS 02510611915

Control Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)	02510611915 Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)
0.500	0.130	0.065	229.333	3528.200	0.498	0.135	0.067	119.032	1770.519
0.500	0.130	0.065	227.667	3502.569	0.498	0.139	0.069	118.548	1712.577
0.500	0.130	0.065	226.667	3487.185	0.497	0.137	0.068	117.903	1731.601
0.500	0.130	0.065	228.666	3517.938	0.493	0.136	0.067	112.419	1676.694
0.500	0.130	0.065	228.333	3512.815	0.499	0.137	0.068	117.258	1715.226
0.500	0.130	0.065	228.095	3509.154	0.493	0.135	0.067	118.226	1776.365
0.500	0.130	0.065	229.333	3528.200	0.501	0.138	0.069	120.000	1735.659
0.500	0.130	0.065	227.666	3502.554	0.497	0.137	0.068	115.806	1700.803
0.500	0.130	0.065	229.524	3531.138	0.496	0.138	0.068	117.419	1715.448
0.500	0.130	0.065	228.095	3509.154	0.497	0.138	0.069	117.097	1707.302
			Mean	3512.890				Mean	1724.219
			St. Dev.	13.15039				St. Dev.	29.04262

LEGEND

0 = 0 degrees (orientation angle of path)
25 = .025 inches (road width)
10 = .010 inches (z slice)
6 = .6 inches per second (speed)
119 = 119 degrees C (temperature of tip & liquefier)
15 = 15 degrees C (temperature of envelope)

Table 4

Analysis of Variance

Control VS 02510611915

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	15996723.470	15996723.47	28329.30
Within	18	10164.071031	564.6706128	
Total	19	16006887.541		

LEGEND

0 = 0 degrees (orientation angle of path)
25 = .025 inches (road width)
10 = .010 inches (z slice)
6 = .6 inches per second (speed)
119 = 119 degrees C (temperature of tip & liquefier)
15 = 15 degrees C (temperature of envelope)

Table 5

Control VS 02520412815

Control Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)	02520412815 Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)
0.500	0.130	0.065	229.333	3528.200	0.502	0.135	0.068	112.419	1658.831
0.500	0.130	0.065	227.667	3502.569	0.502	0.140	0.070	115.645	1645.489
0.500	0.130	0.065	226.667	3487.185	0.509	0.138	0.070	112.194	1597.250
0.500	0.130	0.065	228.666	3517.938	0.504	0.140	0.071	112.581	1595.536
0.500	0.130	0.065	228.333	3512.815	0.502	0.140	0.070	114.516	1629.425
0.500	0.130	0.065	228.095	3509.154	0.504	0.132	0.067	114.516	1721.320
0.500	0.130	0.065	229.333	3528.200	0.505	0.132	0.067	110.968	1664.686
0.500	0.130	0.065	227.666	3502.554	0.498	0.132	0.066	110.806	1685.621
0.500	0.130	0.065	229.524	3531.138	0.482	0.133	0.064	110.484	1723.458
0.500	0.130	0.065	228.095	3509.154	0.486	0.131	0.064	111.774	1755.631
			Mean	3512.890				Mean	1667.724
			St. Dev.	13.15039				St. Dev.	51.23873

LEGEND

0 = 0 degrees (orientation angle of path)
25 = .025 inches (road width)
20 = .020 inches (z slice)
4 = .4 inches per second (speed)
128 = 128 degrees C (temperature of tip & liquefier)
15 = 15 degrees C (temperature of envelope)

Table 6

Analysis of Variance

Control VS 02520412815

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	17023186.806	17023186.80	10949.96
Within	18	27983.407775	1554.633765	
Total	19	17051170.214		

LEGEND

0 = 0 degrees (orientation angle of path)
25 = .025 inches (road width)
20 = .020 inches (z slice)
4 = .4 inches per second (speed)
128 = 128 degrees C (temperature of tip & liquefier)
15 = 15 degrees C (temperature of envelope)

Table 7

Control VS 02520612430

Control Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)	02520612430 Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)
0.500	0.130	0.065	229.333	3528.200	0.442	0.135	0.060	115.290	1932.127
0.500	0.130	0.065	227.667	3502.569	0.477	0.135	0.064	113.226	1758.304
0.500	0.130	0.065	226.667	3487.185	0.485	0.133	0.065	121.774	1887.823
0.500	0.130	0.065	228.666	3517.938	0.484	0.135	0.065	122.742	1878.512
0.500	0.130	0.065	228.333	3512.815	0.485	0.133	0.065	110.968	1720.301
0.500	0.130	0.065	228.095	3509.154	0.481	0.135	0.065	113.387	1746.162
0.500	0.130	0.065	229.333	3528.200	0.460	0.135	0.062	115.161	1854.444
0.500	0.130	0.065	227.666	3502.554	0.457	0.135	0.062	116.129	1882.308
0.500	0.130	0.065	229.524	3531.138	0.458	0.136	0.062	115.322	1851.432
0.500	0.130	0.065	228.095	3509.154	0.458	0.136	0.062	112.419	1804.826
			Mean	3512.890				Mean	1831.623
			St. Dev.	13.15039				St. Dev.	66.88066

LEGEND

0 = 0 degrees (orientation angle of path)
25 = .025 inches (road width)
20 = .020 inches (z slice)
6 = .6 inches per second (speed)
124 = 124 degrees C (temperature of tip & liquefier)
30 = 30 degrees C (temperature of envelope)

Table 8

Analysis of Variance

Control VS 02520612430

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	14133291.667	14133291.66	5475.712
Within	18	46459.566375	2581.087020	
Total	19	14179751.233		

LEGEND

0 = 0 degrees (orientation angle of path)
25 = .025 inches (road width)
20 = .020 inches (z slice)
6 = .6 inches per second (speed)
124 = 124 degrees C (temperature of tip & liquefier)
30 = 30 degrees C (temperature of envelope)

Table 9

Control VS 02530212415

Control Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)	02530212415 Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)
0.500	0.130	0.065	229.333	3528.200	0.492	0.139	0.068	121.290	1773.557
0.500	0.130	0.065	227.667	3502.569	0.520	0.130	0.068	118.548	1753.669
0.500	0.130	0.065	226.667	3487.185	0.492	0.139	0.068	121.548	1777.329
0.500	0.130	0.065	228.666	3517.938	0.499	0.134	0.067	122.499	1832.007
0.500	0.130	0.065	228.333	3512.815	0.499	0.140	0.070	124.516	1782.365
0.500	0.130	0.065	228.095	3509.154	0.498	0.140	0.070	118.645	1701.736
0.500	0.130	0.065	229.333	3528.200	0.523	0.134	0.070	122.097	1742.202
0.500	0.130	0.065	227.666	3502.554	0.511	0.134	0.068	119.032	1738.353
0.500	0.130	0.065	229.524	3531.138	0.495	0.145	0.072	118.065	1644.932
0.500	0.130	0.065	228.095	3509.154	0.499	0.145	0.072	119.681	1654.081
			Mean	3512.890				Mean	1740.023
			St. Dev.	13.15039				St. Dev.	55.55021

LEGEND

0 = 0 degrees (orientation angle of path)
25 = .025 inches (road width)
30 = .030 inches (z slice)
2 = .2 inches per second (speed)
124 = 124 degrees C (temperature of tip & liquefier)
15 = 15 degrees C (temperature of envelope)

Table 10

Analysis of Variance

Control VS 02530212415

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	15715300.298	15715300.29	8680.462
Within	18	32587.595417	1810.421967	
Total	19	15747887.893		

LEGEND

0 = 0 degrees (orientation angle of path)
25 = .025 inches (road width)
30 = .030 inches (z slice)
2 = .2 inches per second (speed)
124 = 124 degrees C (temperature of tip & liquefier)
15 = 15 degrees C (temperature of envelope)

Table 11

Control VS 02530611930

Control Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)	02530611930 Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)
0.500	0.130	0.065	229.333	3528.200	0.486	0.132	0.064	115.645	1802.672
0.500	0.130	0.065	227.667	3502.569	0.480	0.132	0.063	112.903	1781.929
0.500	0.130	0.065	226.667	3487.185	0.493	0.135	0.067	114.355	1718.203
0.500	0.130	0.065	228.666	3517.938	0.489	0.139	0.068	114.677	1687.146
0.500	0.130	0.065	228.333	3512.815	0.485	0.139	0.067	113.065	1677.149
0.500	0.130	0.065	228.095	3509.154	0.489	0.134	0.066	117.419	1791.945
0.500	0.130	0.065	229.333	3528.200	0.466	0.135	0.063	113.226	1799.809
0.500	0.130	0.065	227.666	3502.554	0.475	0.130	0.062	116.935	1893.684
0.500	0.130	0.065	229.524	3531.138	0.475	0.135	0.064	114.032	1778.277
0.500	0.130	0.065	228.095	3509.154	0.471	0.138	0.065	115.161	1771.762
			Mean	3512.890				Mean	1770.257
			St. Dev.	13.15039				St. Dev.	60.09798

LEGEND

0 = 0 degrees (orientation angle of path)
25 = .025 inches (road width)
30 = .030 inches (z slice)
6 = .6 inches per second (speed)
119 = 119 degrees C (temperature of tip & liquefier)
30 = 30 degrees C (temperature of envelope)

Table 12

Analysis of Variance

Control VS 02530611930

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	15183851.677	15183851.67	7221.425
Within	18	37847.006879	2102.611493	
Total	19	15221698.684		

LEGEND

0 = 0 degrees (orientation angle of path)
25 = .025 inches (road width)
30 = .030 inches (z slice)
6 = .6 inches per second (speed)
119 = 119 degrees C (temperature of tip & liquefier)
30 = 30 degrees C (temperature of envelope)

Table 13

Control VS 07510611930

Control Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)	07510611930 Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)
0.500	0.130	0.065	229.333	3528.200	0.488	0.136	0.066	107.581	1620.977
0.500	0.130	0.065	227.667	3502.569	0.491	0.136	0.067	108.789	1629.163
0.500	0.130	0.065	226.667	3487.185	0.487	0.140	0.068	106.578	1563.186
0.500	0.130	0.065	228.666	3517.938	0.486	0.135	0.066	109.798	1673.495
0.500	0.130	0.065	228.333	3512.815	0.491	0.135	0.066	110.708	1670.182
0.500	0.130	0.065	228.095	3509.154	0.495	0.134	0.066	107.491	1620.549
0.500	0.130	0.065	229.333	3528.200	0.480	0.138	0.066	107.010	1615.489
0.500	0.130	0.065	227.666	3502.554	0.483	0.138	0.067	108.091	1621.673
0.500	0.130	0.065	229.524	3531.138	0.485	0.137	0.066	107.017	1610.610
0.500	0.130	0.065	228.095	3509.154	0.490	0.136	0.067	109.045	1636.330
			Mean	3512.890				Mean	1626.165
			St. Dev.	13.15039				St. Dev.	29.48025

LEGEND

0 = 0 degrees (orientation angle of path)
75 = .075 inches (road width)
10 = .010 inches (z slice)
6 = .6 inches per second (speed)
119 = 119 degrees C (temperature of tip & liquefier)
30 = 30 degrees C (temperature of envelope)

Table 14

Analysis of Variance

Control VS 07510611930

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	17798664.322	17798664.32	30745.70
Within	18	10420.185670	578.8992039	
Total	19	17809084.507		

LEGEND

0 = 0 degrees (orientation angle of path)
75 = .075 inches (road width)
10 = .010 inches (z slice)
6 = .6 inches per second (speed)
119 = 119 degrees C (temperature of tip & liquefier)
30 = 30 degrees C (temperature of envelope)

Table 15

Control VS 07510612823

Control Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)	07510612823 Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)
0.500	0.130	0.065	229.333	3528.200	0.485	0.141	0.068	96.871	1416.553
0.500	0.130	0.065	227.667	3502.569	0.484	0.138	0.067	100.645	1506.842
0.500	0.130	0.065	226.667	3487.185	0.491	0.138	0.068	100.645	1485.360
0.500	0.130	0.065	228.666	3517.938	0.484	0.141	0.068	95.484	1399.156
0.500	0.130	0.065	228.333	3512.815	0.492	0.138	0.068	103.871	1529.854
0.500	0.130	0.065	228.095	3509.154	0.489	0.135	0.066	101.290	1534.348
0.500	0.130	0.065	229.333	3528.200	0.488	0.137	0.067	103.065	1541.597
0.500	0.130	0.065	227.666	3502.554	0.485	0.145	0.070	100.510	1429.221
0.500	0.130	0.065	229.524	3531.138	0.489	0.140	0.068	103.870	1517.236
0.500	0.130	0.065	228.095	3509.154	0.483	0.140	0.068	96.839	1432.106
			Mean	3512.890				Mean	1479.227
			St. Dev.	13.15039				St. Dev.	51.76554

LEGEND

0 = 0 degrees (orientation angle of path)
75 = .075 inches (road width)
10 = .010 inches (z slice)
6 = .6 inches per second (speed)
128 = 128 degrees C (temperature of tip & liquefier)
23 = 23 degrees C (temperature of envelope)

Table 16

Analysis of Variance

Control VS 07510612823

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	20678932.665	20678932.66	13048.45
Within	18	28526.050215	1584.780567	
Total	19	20707458.715		

LEGEND

0 = 0 degrees (orientation angle of path)
75 = .075 inches (road width)
10 = .010 inches (z slice)
6 = .6 inches per second (speed)
128 = 128 degrees C (temperature of tip & liquefier)
23 = 23 degrees C (temperature of envelope)

Table 17

Control VS 07510612830

Control Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)	07510612830 Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)
0.500	0.130	0.065	229.333	3528.200	0.486	0.136	0.066	146.429	2215.399
0.500	0.130	0.065	227.667	3502.569	0.487	0.144	0.070	157.619	2247.590
0.500	0.130	0.065	226.667	3487.185	0.488	0.141	0.069	155.952	2266.481
0.500	0.130	0.065	228.666	3517.938	0.481	0.148	0.071	148.492	2085.913
0.500	0.130	0.065	228.333	3512.815	0.490	0.140	0.069	166.190	2422.595
0.500	0.130	0.065	228.095	3509.154	0.485	0.151	0.073	145.048	1980.583
0.500	0.130	0.065	229.333	3528.200	0.484	0.144	0.070	145.190	2083.190
0.500	0.130	0.065	227.666	3502.554	0.489	0.142	0.069	145.095	2089.562
0.500	0.130	0.065	229.524	3531.138	0.486	0.138	0.067	156.190	2328.830
0.500	0.130	0.065	228.095	3509.154	0.483	0.146	0.071	149.810	2124.422
			Mean	3512.890				Mean	2184.456
			St. Dev.	13.15039				St. Dev.	127.8139

LEGEND

0 = 0 degrees (orientation angle of path)
75 = .075 inches (road width)
10 = .010 inches (z slice)
6 = .6 inches per second (speed)
128 = 128 degrees C (temperature of tip & liquefier)
30 = 30 degrees C (temperature of envelope)

Table 18

Analysis of Variance

Control VS 07510612830

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	8823687.9347	8823687.934	962.0395
Within	18	165093.40742	9171.855967	
Total	19	8988781.3421		

LEGEND

0 = 0 degrees (orientation angle of path)
75 = .075 inches (road width)
10 = .010 inches (z slice)
6 = .6 inches per second (speed)
128 = 128 degrees C (temperature of tip & liquefier)
30 = 30 degrees C (temperature of envelope)

Table 19

Control VS 07530212830

Control Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)	07530212830 Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)
0.500	0.130	0.065	229.333	3528.200	0.486	0.133	0.065	161.905	2504.796
0.500	0.130	0.065	227.667	3502.569	0.475	0.140	0.067	165.238	2484.782
0.500	0.130	0.065	226.667	3487.185	0.480	0.140	0.067	150.476	2239.226
0.500	0.130	0.065	228.666	3517.938	0.481	0.137	0.066	161.667	2453.329
0.500	0.130	0.065	228.333	3512.815	0.486	0.135	0.066	161.667	2464.060
0.500	0.130	0.065	228.095	3509.154	0.487	0.135	0.066	153.810	2339.493
0.500	0.130	0.065	229.333	3528.200	0.478	0.140	0.067	162.381	2426.494
0.500	0.130	0.065	227.666	3502.554	0.482	0.138	0.067	157.857	2373.218
0.500	0.130	0.065	229.524	3531.138	0.478	0.141	0.067	152.381	2260.913
0.500	0.130	0.065	228.095	3509.154	0.484	0.135	0.065	152.619	2335.767
			Mean	3512.890				Mean	2388.207
			St. Dev.	13.15039				St. Dev.	88.38943

LEGEND

0 = 0 degrees (orientation angle of path)
75 = .075 inches (road width)
30 = .030 inches (z slice)
2 = .2 inches per second (speed)
128 = 128 degrees C (temperature of tip & liquefier)
30 = 30 degrees C (temperature of envelope)

Table 20

Analysis of Variance

Control VS 07530212830

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	6324557.8264	6324557.826	1425.587
Within	18	79856.255226	4436.458623	
Total	19	6404414.0816		

LEGEND

0 = 0 degrees (orientation angle of path)
75 = .075 inches (road width)
30 = .030 inches (z slice)
2 = .2 inches per second (speed)
128 = 128 degrees C (temperature of tip & liquefier)
30 = 30 degrees C (temperature of envelope)

Table 21

Control VS 07530611915

Control Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)	07530611915 Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)
0.500	0.130	0.065	229.333	3528.200	0.485	0.137	0.066	167.857	2526.255
0.500	0.130	0.065	227.667	3502.569	0.480	0.133	0.064	165.476	2592.043
0.500	0.130	0.065	226.667	3487.185	0.481	0.138	0.066	170.952	2575.432
0.500	0.130	0.065	228.666	3517.938	0.477	0.135	0.064	164.762	2558.615
0.500	0.130	0.065	228.333	3512.815	0.480	0.136	0.065	169.048	2589.583
0.500	0.130	0.065	228.095	3509.154	0.482	0.134	0.065	163.571	2532.529
0.500	0.130	0.065	229.333	3528.200	0.491	0.130	0.064	162.619	2547.689
0.500	0.130	0.065	227.666	3502.554	0.480	0.137	0.066	171.429	2606.889
0.500	0.130	0.065	229.524	3531.138	0.475	0.137	0.065	166.190	2553.823
0.500	0.130	0.065	228.095	3509.154	0.488	0.131	0.064	171.429	2681.595
			Mean	3512.890				Mean	2576.445
			St. Dev.	13.15039				St. Dev.	43.01684

LEGEND

0 = 0 degrees (orientation angle of path)
75 = .075 inches (road width)
30 = .030 inches (z slice)
6 = .6 inches per second (speed)
119 = 119 degrees C (temperature of tip & liquefier)
15 = 15 degrees C (temperature of envelope)

Table 22

Analysis of Variance

Control VS 07530611915

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	4384651.7923	4384651.792	3900.584
Within	18	20233.820513	1124.101139	
Total	19	4404885.6128		

LEGEND

0 = 0 degrees (orientation angle of path)
75 = .075 inches (road width)
30 = .030 inches (z slice)
6 = .6 inches per second (speed)
119 = 119 degrees C (temperature of tip & liquefier)
15 = 15 degrees C (temperature of envelope)

Table 23

Control VS 07530612815

Control Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)	07530612815 Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)
0.500	0.130	0.065	229.333	3528.200	0.507	0.131	0.066	141.429	2129.410
0.500	0.130	0.065	227.667	3502.569	0.509	0.130	0.066	140.476	2122.956
0.500	0.130	0.065	226.667	3487.185	0.500	0.133	0.067	139.286	2094.526
0.500	0.130	0.065	228.666	3517.938	0.499	0.131	0.065	140.619	2151.157
0.500	0.130	0.065	228.333	3512.815	0.505	0.130	0.066	140.952	2147.022
0.500	0.130	0.065	228.095	3509.154	0.504	0.131	0.066	145.060	2197.080
0.500	0.130	0.065	229.333	3528.200	0.595	0.135	0.080	145.095	1806.349
0.500	0.130	0.065	227.666	3502.554	0.597	0.131	0.078	147.098	1880.880
0.500	0.130	0.065	229.524	3531.138	0.594	0.133	0.079	144.762	1832.384
0.500	0.130	0.065	228.095	3509.154	0.502	0.130	0.065	138.714	2125.559
			Mean	3512.890				Mean	2048.732
			St. Dev.	13.15039				St. Dev.	139.9666

LEGEND

0 = 0 degrees (orientation angle of path)
75 = .075 inches (road width)
30 = .030 inches (z slice)
6 = .6 inches per second (speed)
128 = 128 degrees C (temperature of tip & liquefier)
15 = 15 degrees C (temperature of envelope)

Table 24

Analysis of Variance

Control VS 07530612815

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	10718798.773	10718798.77	976.2307
Within	18	197636.03067	10979.77948	
Total	19	10916434.804		

LEGEND

0 = 0 degrees (orientation angle of path)
75 = .075 inches (road width)
30 = .030 inches (z slice)
6 = .6 inches per second (speed)
128 = 128 degrees C (temperature of tip & liquefier)
15 = 15 degrees C (temperature of envelope)

Table 25

Control VS 452510212430

Control Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)	452510212430 Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)
0.500	0.130	0.065	229.333	3528.200	0.499	0.129	0.064	173.095	2689.021
0.500	0.130	0.065	227.667	3502.569	0.500	0.124	0.062	176.667	2849.468
0.500	0.130	0.065	226.667	3487.185	0.501	0.129	0.065	178.333	2759.334
0.500	0.130	0.065	228.666	3517.938	0.501	0.126	0.063	175.238	2776.004
0.500	0.130	0.065	228.333	3512.815	0.501	0.129	0.065	178.095	2755.651
0.500	0.130	0.065	228.095	3509.154	0.491	0.130	0.064	181.190	2838.634
0.500	0.130	0.065	229.333	3528.200	0.504	0.127	0.064	181.190	2830.740
0.500	0.130	0.065	227.666	3502.554	0.503	0.124	0.062	174.048	2790.483
0.500	0.130	0.065	229.524	3531.138	0.500	0.127	0.064	180.238	2838.394
0.500	0.130	0.065	228.095	3509.154	0.518	0.128	0.066	175.000	2639.358
			Mean	3512.890				Mean	2776.708
			St. Dev.	13.15039				St. Dev.	65.83522

LEGEND

45 = 45 degrees (orientation angle of path)
25 = .025 inches (road width)
10 = .010 inches (z slice)
2 = .2 inches per second (speed)
124 = 124 degrees C (temperature of tip & liquefier)
30 = 30 degrees C (temperature of envelope)

Table 26

Analysis of Variance

Control VS 452510212430

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	2709820.362	2709820.362	1082.194
Within	18	45072.094779	2504.005265	
Total	19	2754892.4567		

LEGEND

45 = 45 degrees (orientation angle of path)
25 = .025 inches (road width)
10 = .010 inches (z slice)
2 = .2 inches per second (speed)
124 = 124 degrees C (temperature of tip & liquefier)
30 = 30 degrees C (temperature of envelope)

Table 27

Control VS 452520611915

Control Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)	452520611915 Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)
0.500	0.130	0.065	229.333	3528.200	0.500	0.130	0.065	161.667	2487.185
0.500	0.130	0.065	227.667	3502.569	0.492	0.132	0.065	162.143	2496.659
0.500	0.130	0.065	226.667	3487.185	0.498	0.131	0.065	153.333	2350.363
0.500	0.130	0.065	228.666	3517.938	0.496	0.134	0.066	165.238	2486.128
0.500	0.130	0.065	228.333	3512.815	0.492	0.130	0.064	154.048	2408.505
0.500	0.130	0.065	228.095	3509.154	0.493	0.130	0.064	155.238	2422.188
0.500	0.130	0.065	229.333	3528.200	0.492	0.132	0.065	150.476	2317.012
0.500	0.130	0.065	227.666	3502.554	0.495	0.134	0.066	155.238	2340.389
0.500	0.130	0.065	229.524	3531.138	0.491	0.133	0.065	152.619	2337.090
0.500	0.130	0.065	228.095	3509.154	0.494	0.137	0.068	159.762	2360.619
			Mean	3512.890				Mean	2400.613
			St. Dev.	13.15039				St. Dev.	65.82989

LEGEND

45 = 45 degrees (orientation angle of path)
25 = .025 inches (road width)
20 = .020 inches (z slice)
6 = .6 inches per second (speed)
119 = 119 degrees C (temperature of tip & liquefier)
15 = 15 degrees C (temperature of envelope)

Table 28

Analysis of Variance

Control VS 452520611915

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	6185800.9707	6185800.970	2470.747
Within	18	45065.081309	2503.615628	
Total	19	6230866.052		

LEGEND

45 = 45 degrees (orientation angle of path)
25 = .025 inches (road width)
20 = .020 inches (z slice)
6 = .6 inches per second (speed)
119 = 119 degrees C (temperature of tip & liquefier)
15 = 15 degrees C (temperature of envelope)

Table 29

Control VS 452520612830

Control Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)	452520612830 Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)
0.500	0.130	0.065	229.333	3528.200	0.490	0.130	0.064	154.286	2422.072
0.500	0.130	0.065	227.667	3502.569	0.492	0.130	0.064	152.381	2382.442
0.500	0.130	0.065	226.667	3487.185	0.488	0.131	0.064	151.905	2376.189
0.500	0.130	0.065	228.666	3517.938	0.489	0.130	0.064	159.524	2509.423
0.500	0.130	0.065	228.333	3512.815	0.487	0.131	0.064	149.286	2340.016
0.500	0.130	0.065	228.095	3509.154	0.483	0.132	0.064	152.143	2386.332
0.500	0.130	0.065	229.333	3528.200	0.485	0.135	0.065	157.286	2402.230
0.500	0.130	0.065	227.666	3502.554	0.490	0.131	0.064	156.667	2440.676
0.500	0.130	0.065	229.524	3531.138	0.485	0.133	0.065	154.286	2391.846
0.500	0.130	0.065	228.095	3509.154	0.492	0.135	0.066	150.952	2272.689
			Mean	3512.890				Mean	2392.391
			St. Dev.	13.15039				St. Dev.	58.71615

LEGEND

45 = 45 degrees (orientation angle of path)
25 = .025 inches (road width)
20 = .020 inches (z slice)
6 = .6 inches per second (speed)
128 = 128 degrees C (temperature of tip & liquefier)
30 = 30 degrees C (temperature of envelope)

Table 30

Analysis of Variance

Control VS 452520612830

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	6277593.4428	6277593.442	3121.007
Within	18	36205.193293	2011.399627	
Total	19	6313798.6361		

LEGEND

45 = 45 degrees (orientation angle of path)
25 = .025 inches (road width)
20 = .020 inches (z slice)
6 = .6 inches per second (speed)
128 = 128 degrees C (temperature of tip & liquefier)
30 = 30 degrees C (temperature of envelope)

Table 31

Control VS 457510212415

Control Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)	457510212415 Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)
0.500	0.130	0.065	229.333	3528.200	0.496	0.135	0.067	139.524	2083.692
0.500	0.130	0.065	227.667	3502.569	0.496	0.140	0.069	142.143	2046.990
0.500	0.130	0.065	226.667	3487.185	0.492	0.138	0.068	135.149	1990.530
0.500	0.130	0.065	228.666	3517.938	0.495	0.138	0.068	136.333	1995.799
0.500	0.130	0.065	228.333	3512.815	0.497	0.137	0.068	135.286	1986.899
0.500	0.130	0.065	228.095	3509.154	0.493	0.140	0.069	137.286	1989.076
0.500	0.130	0.065	229.333	3528.200	0.499	0.134	0.067	131.908	1972.722
0.500	0.130	0.065	227.666	3502.554	0.498	0.135	0.067	146.667	2181.571
0.500	0.130	0.065	229.524	3531.138	0.496	0.133	0.066	133.333	2021.177
0.500	0.130	0.065	228.095	3509.154	0.495	0.137	0.068	135.333	1995.620
			Mean	3512.890				Mean	2026.407
			St. Dev.	13.15039				St. Dev.	60.67686

LEGEND

45 = 45 degrees (orientation angle of path)
75 = .075 inches (road width)
10 = .010 inches (z slice)
2 = .2 inches per second (speed)
124 = 124 degrees C (temperature of tip & liquefier)
15 = 15 degrees C (temperature of envelope)

Table 32

Analysis of Variance

Control VS 457510212415

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	11048162.616	11048162.61	5159.190
Within	18	38546.151596	2141.452866	
Total	19	11086708.768		

LEGEND

45 = 45 degrees (orientation angle of path)
75 = .075 inches (road width)
10 = .010 inches (z slice)
2 = .2 inches per second (speed)
124 = 124 degrees C (temperature of tip & liquefier)
15 = 15 degrees C (temperature of envelope)

Table 33

Control VS 457530411930

Control Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)	457530411930 Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)
0.500	0.130	0.065	229.333	3528.200	0.496	0.138	0.068	155.952	2278.401
0.500	0.130	0.065	227.667	3502.569	0.499	0.135	0.067	159.286	2364.522
0.500	0.130	0.065	226.667	3487.185	0.490	0.138	0.068	153.571	2271.088
0.500	0.130	0.065	228.666	3517.938	0.500	0.136	0.068	159.524	2345.941
0.500	0.130	0.065	228.333	3512.815	0.485	0.135	0.065	156.667	2392.776
0.500	0.130	0.065	228.095	3509.154	0.490	0.134	0.066	159.762	2433.171
0.500	0.130	0.065	229.333	3528.200	0.494	0.137	0.068	155.714	2300.807
0.500	0.130	0.065	227.666	3502.554	0.494	0.138	0.068	156.905	2301.605
0.500	0.130	0.065	229.524	3531.138	0.493	0.135	0.067	152.143	2285.974
0.500	0.130	0.065	228.095	3509.154	0.494	0.134	0.066	155.476	2348.722
			Mean	3512.890				Mean	2332.300
			St. Dev.	13.15039				St. Dev.	51.04735

LEGEND

45 = 45 degrees (orientation angle of path)
75 = .075 inches (road width)
30 = .030 inches (z slice)
4 = .4 inches per second (speed)
119 = 119 degrees C (temperature of tip & liquefier)
30 = 30 degrees C (temperature of envelope)

Table 34

Analysis of Variance

Control VS 457530411930

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	6968964.9968	6968964.996	4514.283
Within	18	27787.655872	1543.758659	
Total	19	6996752.6527		

LEGEND

45 = 45 degrees (orientation angle of path)
75 = .075 inches (road width)
30 = .030 inches (z slice)
4 = .4 inches per second (speed)
119 = 119 degrees C (temperature of tip & liquefier)
30 = 30 degrees C (temperature of envelope)

Table 35

Control VS 902510211930

Control Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)	902510211930 Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)
0.500	0.130	0.065	229.333	3528.200	0.535	0.128	0.068	180.952	2642.407
0.500	0.130	0.065	227.667	3502.569	0.534	0.130	0.069	181.429	2613.498
0.500	0.130	0.065	226.667	3487.185	0.534	0.127	0.068	188.095	2773.526
0.500	0.130	0.065	228.666	3517.938	0.531	0.130	0.069	187.619	2717.934
0.500	0.130	0.065	228.333	3512.815	0.534	0.129	0.069	187.143	2716.706
0.500	0.130	0.065	228.095	3509.154	0.531	0.129	0.068	182.283	2661.105
0.500	0.130	0.065	229.333	3528.200	0.531	0.133	0.071	185.952	2633.023
0.500	0.130	0.065	227.666	3502.554	0.533	0.130	0.069	181.145	2614.302
0.500	0.130	0.065	229.524	3531.138	0.535	0.129	0.069	182.143	2639.180
0.500	0.130	0.065	228.095	3509.154	0.535	0.130	0.070	183.333	2635.988
			Mean	3512.890				Mean	2664.766
			St. Dev.	13.15039				St. Dev.	50.52938

LEGEND

90 = 90 degrees (orientation angle of path)
25 = .025 inches (road width)
10 = .010 inches (z slice)
2 = .2 inches per second (speed)
119 = 119 degrees C (temperature of tip & liquefier)
30 = 30 degrees C (temperature of envelope)

Table 36

Analysis of Variance

Control VS 902510211930

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	3596570.6907	3596570.690	2374.712
Within	18	27261.51824	1514.528791	
Total	19	3623832.2089		

LEGEND

90 = 90 degrees (orientation angle of path)
25 = .025 inches (road width)
10 = .010 inches (z slice)
2 = .2 inches per second (speed)
119 = 119 degrees C (temperature of tip & liquefier)
30 = 30 degrees C (temperature of envelope)

Table 37

Control VS 902510611930

Control Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)	902510611930 Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)
0.500	0.130	0.065	229.333	3528.200	0.531	0.135	0.072	186.429	2600.670
0.500	0.130	0.065	227.667	3502.569	0.532	0.136	0.072	186.667	2579.984
0.500	0.130	0.065	226.667	3487.185	0.531	0.132	0.070	181.429	2588.441
0.500	0.130	0.065	228.666	3517.938	0.528	0.135	0.071	188.810	2648.850
0.500	0.130	0.065	228.333	3512.815	0.528	0.129	0.068	184.286	2705.632
0.500	0.130	0.065	228.095	3509.154	0.535	0.141	0.075	195.286	2588.798
0.500	0.130	0.065	229.333	3528.200	0.527	0.133	0.070	181.190	2585.068
0.500	0.130	0.065	227.666	3502.554	0.526	0.136	0.072	184.048	2572.803
0.500	0.130	0.065	229.524	3531.138	0.526	0.134	0.070	183.571	2604.435
0.500	0.130	0.065	228.095	3509.154	0.525	0.134	0.070	194.524	2765.089
			Mean	3512.890				Mean	2623.976
			St. Dev.	13.15039				St. Dev.	60.57419

LEGEND

90 = 90 degrees (orientation angle of path)
25 = .025 inches (road width)
10 = .010 inches (z slice)
6 = .6 inches per second (speed)
119 = 119 degrees C (temperature of tip & liquefier)
30 = 30 degrees C (temperature of envelope)

Table 38

Analysis of Variance

Control VS 902510611930

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	3950839.6376	3950839.637	1850.912
Within	18	38421.656131	2134.536451	
Total	19	3989261.2937		

LEGEND

90 = 90 degrees (orientation angle of path)
25 = .025 inches (road width)
10 = .010 inches (z slice)
6 = .6 inches per second (speed)
119 = 119 degrees C (temperature of tip & liquefier)
30 = 30 degrees C (temperature of envelope)

Table 39

Control VS 902510612415

Control Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)	902510612415 Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)
0.500	0.130	0.065	229.333	3528.200	0.532	0.131	0.070	178.810	2565.718
0.500	0.130	0.065	227.667	3502.569	0.529	0.130	0.069	176.429	2565.494
0.500	0.130	0.065	226.667	3487.185	0.533	0.131	0.070	179.769	2574.639
0.500	0.130	0.065	228.666	3517.938	0.531	0.135	0.072	176.429	2461.170
0.500	0.130	0.065	228.333	3512.815	0.530	0.130	0.069	177.857	2581.379
0.500	0.130	0.065	228.095	3509.154	0.529	0.139	0.074	188.095	2558.037
0.500	0.130	0.065	229.333	3528.200	0.530	0.136	0.072	181.905	2523.654
0.500	0.130	0.065	227.666	3502.554	0.525	0.130	0.068	177.381	2598.989
0.500	0.130	0.065	229.524	3531.138	0.538	0.133	0.072	182.857	2555.511
0.500	0.130	0.065	228.095	3509.154	0.529	0.129	0.068	171.905	2519.087
			Mean	3512.890				Mean	2550.367
			St. Dev.	13.15039				St. Dev.	37.56693

LEGEND

90 = 90 degrees (orientation angle of path)
25 = .025 inches (road width)
10 = .010 inches (z slice)
6 = .6 inches per second (speed)
124 = 124 degrees C (temperature of tip & liquefier)
15 = 15 degrees C (temperature of envelope)

Table 40

Analysis of Variance

Control VS 902510612415

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	4632253.6199	4632253.619	5263.234
Within	18	15842.077664	880.1154258	
Total	19	4648095.6975		

LEGEND

90 = 90 degrees (orientation angle of path)
25 = .025 inches (road width)
10 = .010 inches (z slice)
6 = .6 inches per second (speed)
124 = 124 degrees C (temperature of tip & liquefier)
15 = 15 degrees C (temperature of envelope)

Table 41

Control VS 902510612815

Control Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)	902510612815 Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)
0.500	0.130	0.065	229.333	3528.200	0.527	0.141	0.074	190.333	2561.441
0.500	0.130	0.065	227.667	3502.569	0.526	0.131	0.069	170.476	2474.037
0.500	0.130	0.065	226.667	3487.185	0.530	0.149	0.079	190.857	2416.829
0.500	0.130	0.065	228.666	3517.938	0.528	0.135	0.071	171.190	2401.655
0.500	0.130	0.065	228.333	3512.815	0.521	0.134	0.070	170.238	2438.451
0.500	0.130	0.065	228.095	3509.154	0.523	0.131	0.069	175.714	2564.681
0.500	0.130	0.065	229.333	3528.200	0.528	0.130	0.069	176.190	2566.871
0.500	0.130	0.065	227.666	3502.554	0.527	0.133	0.070	171.905	2452.597
0.500	0.130	0.065	229.524	3531.138	0.522	0.132	0.069	168.810	2449.930
0.500	0.130	0.065	228.095	3509.154	0.529	0.134	0.071	178.095	2512.414
			Mean	3512.890				Mean	2483.890
			St. Dev.	13.15039				St. Dev.	59.82872

LEGEND

90 = 90 degrees (orientation angle of path)
25 = .025 inches (road width)
10 = .010 inches (z slice)
6 = .6 inches per second (speed)
128 = 128 degrees C (temperature of tip & liquefier)
15 = 15 degrees C (temperature of envelope)

Table 42

Analysis of Variance

Control VS 902510612815

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	5294205.4433	5294205.443	2539.586
Within	18	37524.098227	2084.672123	
Total	19	5331729.5415		

LEGEND

90 = 90 degrees (orientation angle of path)
25 = .025 inches (road width)
10 = .010 inches (z slice)
6 = .6 inches per second (speed)
128 = 128 degrees C (temperature of tip & liquefier)
15 = 15 degrees C (temperature of envelope)

Table 43

Control VS 902520411915

Control Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)	902520411915 Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)
0.500	0.130	0.065	229.333	3528.200	0.543	0.136	0.074	176.905	2395.529
0.500	0.130	0.065	227.667	3502.569	0.550	0.135	0.074	177.619	2392.175
0.500	0.130	0.065	226.667	3487.185	0.546	0.133	0.073	175.952	2422.981
0.500	0.130	0.065	228.666	3517.938	0.539	0.130	0.070	178.952	2553.903
0.500	0.130	0.065	228.333	3512.815	0.545	0.130	0.071	175.238	2473.366
0.500	0.130	0.065	228.095	3509.154	0.540	0.131	0.071	169.524	2396.438
0.500	0.130	0.065	229.333	3528.200	0.542	0.128	0.069	173.095	2495.027
0.500	0.130	0.065	227.666	3502.554	0.544	0.128	0.070	175.476	2520.048
0.500	0.130	0.065	229.524	3531.138	0.548	0.134	0.073	172.143	2344.250
0.500	0.130	0.065	228.095	3509.154	0.548	0.132	0.072	175.952	2432.426
			Mean	3512.890				Mean	2442.614
			St. Dev.	13.15039				St. Dev.	62.55574

LEGEND

90 = 90 degrees (orientation angle of path)
25 = .025 inches (road width)
20 = .020 inches (z slice)
4 = .4 inches per second (speed)
119 = 119 degrees C (temperature of tip & liquefier)
15 = 15 degrees C (temperature of envelope)

Table 44

Analysis of Variance

Control VS 902520411915

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	5727457.8527	5727457.852	2523.014
Within	18	40861.536503	2270.085361	
Total	19	5768319.3892		

LEGEND

90 = 90 degrees (orientation angle of path)
25 = .025 inches (road width)
20 = .020 inches (z slice)
4 = .4 inches per second (speed)
119 = 119 degrees C (temperature of tip & liquefier)
15 = 15 degrees C (temperature of envelope)

Table 45

Control VS 902530412823

Control Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)	902530412823 Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)
0.500	0.130	0.065	229.333	3528.200	0.541	0.132	0.071	167.143	2340.545
0.500	0.130	0.065	227.667	3502.569	0.542	0.133	0.072	171.429	2378.118
0.500	0.130	0.065	226.667	3487.185	0.561	0.139	0.078	164.762	2112.902
0.500	0.130	0.065	228.666	3517.938	0.546	0.130	0.071	169.524	2388.335
0.500	0.130	0.065	228.333	3512.815	0.568	0.133	0.076	168.571	2231.428
0.500	0.130	0.065	228.095	3509.154	0.553	0.134	0.074	170.476	2300.559
0.500	0.130	0.065	229.333	3528.200	0.545	0.137	0.075	172.143	2305.538
0.500	0.130	0.065	227.666	3502.554	0.549	0.134	0.074	174.048	2365.876
0.500	0.130	0.065	229.524	3531.138	0.541	0.134	0.072	171.190	2361.437
0.500	0.130	0.065	228.095	3509.154	0.541	0.138	0.075	172.381	2308.942
			Mean	3512.890				Mean	2309.367
			St. Dev.	13.15039				St. Dev.	79.12297

LEGEND

90 = 90 degrees (orientation angle of path)
25 = .025 inches (road width)
30 = .030 inches (z slice)
4 = .4 inches per second (speed)
128 = 128 degrees C (temperature of tip & liquefier)
23 = 23 degrees C (temperature of envelope)

Table 46

Analysis of Variance

Control VS 902530412823

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	7242336.4795	7242336.479	2026.338
Within	18	64333.785099	3574.099172	
Total	19	7306670.2646		

LEGEND

90 = 90 degrees (orientation angle of path)
25 = .025 inches (road width)
30 = .030 inches (z slice)
4 = .4 inches per second (speed)
128 = 128 degrees C (temperature of tip & liquefier)
23 = 23 degrees C (temperature of envelope)

Table 47

Control VS 902530612415

Control Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)	902530612415 Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)
0.500	0.130	0.065	229.333	3528.200	0.550	0.138	0.076	185.000	2437.418
0.500	0.130	0.065	227.667	3502.569	0.549	0.138	0.076	183.095	2416.713
0.500	0.130	0.065	226.667	3487.185	0.548	0.140	0.077	184.762	2408.264
0.500	0.130	0.065	228.666	3517.938	0.547	0.135	0.074	181.905	2463.335
0.500	0.130	0.065	228.333	3512.815	0.548	0.132	0.072	184.048	2544.349
0.500	0.130	0.065	228.095	3509.154	0.550	0.133	0.073	177.143	2421.640
0.500	0.130	0.065	229.333	3528.200	0.543	0.138	0.075	185.060	2469.640
0.500	0.130	0.065	227.666	3502.554	0.541	0.136	0.074	183.095	2488.515
0.500	0.130	0.065	229.524	3531.138	0.549	0.134	0.074	184.524	2508.278
0.500	0.130	0.065	228.095	3509.154	0.543	0.135	0.073	182.143	2484.728
			Mean	3512.890				Mean	2464.288
			St. Dev.	13.15039				St. Dev.	41.61981

LEGEND

90 = 90 degrees (orientation angle of path)
25 = .025 inches (road width)
30 = .0310 inches (z slice)
6 = .6 inches per second (speed)
124 = 124 degrees C (temperature of tip & liquefier)
15 = 15 degrees C (temperature of envelope)

Table 48

Analysis of Variance

Control VS 902530612415

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	5497838.3581	5497838.358	5194.421
Within	18	19051.417279	1058.412071	
Total	19	5516889.7754		

LEGEND

90 = 90 degrees (orientation angle of path)
25 = .025 inches (road width)
30 = .030 inches (z slice)
6 = .6 inches per second (speed)
124 = 124 degrees C (temperature of tip & liquefier)
15 = 15 degrees C (temperature of envelope)

Table 49

Control VS 905020611923

Control Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)	905020611923 Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)
0.500	0.130	0.065	229.333	3528.200	0.504	0.124	0.062	158.333	2533.490
0.500	0.130	0.065	227.667	3502.569	0.498	0.129	0.064	157.857	2457.224
0.500	0.130	0.065	226.667	3487.185	0.498	0.110	0.055	150.143	2740.836
0.500	0.130	0.065	228.666	3517.938	0.496	0.134	0.066	160.511	2415.007
0.500	0.130	0.065	228.333	3512.815	0.502	0.130	0.065	164.762	2524.701
0.500	0.130	0.065	228.095	3509.154	0.498	0.128	0.064	160.952	2524.975
0.500	0.130	0.065	229.333	3528.200	0.500	0.131	0.066	162.381	2479.099
0.500	0.130	0.065	227.666	3502.554	0.505	0.126	0.064	160.476	2522.018
0.500	0.130	0.065	229.524	3531.138	0.503	0.128	0.064	163.095	2533.160
0.500	0.130	0.065	228.095	3509.154	0.502	0.131	0.066	160.238	2436.635
			Mean	3512.890				Mean	2516.714
			St. Dev.	13.15039				St. Dev.	85.23714

LEGEND

90 = 90 degrees (orientation angle of path)
50 = .050 inches (road width)
20 = .020 inches (z slice)
6 = .6 inches per second (speed)
119 = 119 degrees C (temperature of tip & liquefier)
23 = 23 degrees C (temperature of envelope)

Table 50

Analysis of Variance

Control VS 905020611923

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	4961834.9205	4961834.920	1200.717
Within	18	74383.042022	4132.391223	
Total	19	5036217.9625		

LEGEND

90 = 90 degrees (orientation angle of path)
50 = .050 inches (road width)
20 = .020 inches (z slice)
6 = .6 inches per second (speed)
119 = 119 degrees C (temperature of tip & liquefier)
23 = 23 degrees C (temperature of envelope)

Table 51

Control VS 905030412430

Control Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)	905030412430 Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)
0.500	0.130	0.065	229.333	3528.200	0.515	0.138	0.071	179.048	2519.319
0.500	0.130	0.065	227.667	3502.569	0.510	0.127	0.065	179.286	2768.041
0.500	0.130	0.065	226.667	3487.185	0.500	0.125	0.063	178.333	2853.328
0.500	0.130	0.065	228.666	3517.938	0.512	0.129	0.066	180.476	2732.498
0.500	0.130	0.065	228.333	3512.815	0.503	0.127	0.064	182.857	2862.463
0.500	0.130	0.065	228.095	3509.154	0.500	0.127	0.064	177.857	2800.898
0.500	0.130	0.065	229.333	3528.200	0.506	0.129	0.065	176.667	2706.545
0.500	0.130	0.065	227.666	3502.554	0.504	0.128	0.065	177.619	2753.271
0.500	0.130	0.065	229.524	3531.138	0.504	0.126	0.064	178.095	2804.469
0.500	0.130	0.065	228.095	3509.154	0.498	0.130	0.065	175.238	2706.796
			Mean	3512.890				Mean	2750.762
			St. Dev.	13.15039				St. Dev.	92.99858

LEGEND

90 = 90 degrees (orientation angle of path)
50 = .050 inches (road width)
30 = .030 inches (z slice)
4 = .4 inches per second (speed)
124 = 124 degrees C (temperature of tip & liquefier)
30 = 30 degrees C (temperature of envelope)

Table 52

Analysis of Variance

Control VS 905030412430

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	2904196.1005	2904196.100	592.5808
Within	18	88216.706245	4900.928124	
Total	19	2992412.8068		

LEGEND

90 = 90 degrees (orientation angle of path)
50 = .050 inches (road width)
30 = .030 inches (z slice)
4 = .4 inches per second (speed)
124 = 124 degrees C (temperature of tip & liquefier)
30 = 30 degrees C (temperature of envelope)

Table 53

Control VS 907510211930

Control Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)	907510211930 Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)
0.500	0.130	0.065	229.333	3528.200	0.520	0.144	0.075	183.571	2451.536
0.500	0.130	0.065	227.667	3502.569	0.520	0.143	0.074	190.238	2558.338
0.500	0.130	0.065	226.667	3487.185	0.519	0.143	0.074	190.952	2572.888
0.500	0.130	0.065	228.666	3517.938	0.520	0.142	0.074	188.571	2553.778
0.500	0.130	0.065	228.333	3512.815	0.519	0.143	0.074	188.095	2534.392
0.500	0.130	0.065	228.095	3509.154	0.519	0.144	0.075	192.381	2574.141
0.500	0.130	0.065	229.333	3528.200	0.524	0.137	0.072	190.000	2646.682
0.500	0.130	0.065	227.666	3502.554	0.534	0.135	0.072	195.714	2714.856
0.500	0.130	0.065	229.524	3531.138	0.523	0.136	0.071	193.905	2726.142
0.500	0.130	0.065	228.095	3509.154	0.519	0.142	0.074	188.571	2558.699
			Mean	3512.890				Mean	2589.145
			St. Dev.	13.15039				St. Dev.	79.64441

LEGEND

90 = 90 degrees (orientation angle of path)
75 = .075 inches (road width)
10 = .010 inches (z slice)
2 = .2 inches per second (speed)
119 = 119 degrees C (temperature of tip & liquefier)
30 = 30 degrees C (temperature of envelope)

Table 54

Analysis of Variance

Control VS 907510211930

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	4266529.4103	4266529.410	1178.569
Within	18	65161.657712	3620.092095	
Total	19	4331691.068		

LEGEND

90 = 90 degrees (orientation angle of path)
75 = .075 inches (road width)
10 = .010 inches (z slice)
2 = .2 inches per second (speed)
119 = 119 degrees C (temperature of tip & liquefier)
30 = 30 degrees C (temperature of envelope)

Table 55

Control VS 907510212830

Control Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)	907510212830 Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)
0.500	0.130	0.065	229.333	3528.200	0.519	0.141	0.073	180.238	2462.974
0.500	0.130	0.065	227.667	3502.569	0.514	0.135	0.069	179.762	2590.604
0.500	0.130	0.065	226.667	3487.185	0.522	0.142	0.074	176.190	2376.963
0.500	0.130	0.065	228.666	3517.938	0.515	0.142	0.073	176.905	2419.048
0.500	0.130	0.065	228.333	3512.815	0.523	0.139	0.073	181.190	2492.400
0.500	0.130	0.065	228.095	3509.154	0.520	0.143	0.074	181.190	2436.659
0.500	0.130	0.065	229.333	3528.200	0.521	0.145	0.076	186.429	2467.787
0.500	0.130	0.065	227.666	3502.554	0.520	0.144	0.075	183.095	2445.179
0.500	0.130	0.065	229.524	3531.138	0.515	0.135	0.070	184.048	2647.220
0.500	0.130	0.065	228.095	3509.154	0.522	0.143	0.075	188.810	2529.405
			Mean	3512.890				Mean	2486.824
			St. Dev.	13.15039				St. Dev.	77.57997

LEGEND

90	= 90 degrees (orientation angle of path)
75	= .075 inches (road width)
10	= .010 inches (z slice)
2	= .2 inches per second (speed)
128	= 128 degrees C (temperature of tip & liquefier)
30	= 30 degrees C (temperature of envelope)

Table 56

Analysis of Variance

Control VS 907510112830

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	5264063.9601	5264063.960	1530.353
Within	18	61915.85875	3439.769930	
Total	19	5325979.8188		

LEGEND

90	= 90 degrees (orientation angle of path)
75	= .075 inches (road width)
10	= .010 inches (z slice)
2	= .2 inches per second (speed)
128	= 128 degrees C (temperature of tip & liquefier)
30	= 30 degrees C (temperature of envelope)

Table 57

Control VS 907510611915

Control Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)	907510611915 Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)
0.500	0.130	0.065	229.333	3528.200	0.524	0.132	0.069	194.524	2812.341
0.500	0.130	0.065	227.667	3502.569	0.520	0.136	0.071	186.905	2642.887
0.500	0.130	0.065	226.667	3487.185	0.521	0.139	0.072	193.095	2666.358
0.500	0.130	0.065	228.666	3517.938	0.524	0.132	0.069	184.762	2671.206
0.500	0.130	0.065	228.333	3512.815	0.522	0.134	0.070	185.714	2655.029
0.500	0.130	0.065	228.095	3509.154	0.523	0.130	0.068	188.333	2770.010
0.500	0.130	0.065	229.333	3528.200	0.518	0.135	0.070	187.143	2676.148
0.500	0.130	0.065	227.666	3502.554	0.531	0.131	0.070	193.810	2786.188
0.500	0.130	0.065	229.524	3531.138	0.521	0.132	0.069	186.667	2714.288
0.500	0.130	0.065	228.095	3509.154	0.520	0.135	0.070	188.095	2679.416
			Mean	3512.890				Mean	2707.387
			St. Dev.	13.15039				St. Dev.	57.31174

LEGEND

90	= 90 degrees (orientation angle of path)
75	= .075 inches (road width)
10	= .010 inches (z slice)
6	= .6 inches per second (speed)
119	= 119 degrees C (temperature of tip & liquefier)
15	= 15 degrees C (temperature of envelope)

Table 58

Analysis of Variance

Control VS 907510611915

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	3244180.1972	3244180.197	1688.910
Within	18	34575.690855	1920.871714	
Total	19	3278755.888		

LEGEND

90	= 90 degrees (orientation angle of path)
75	= .075 inches (road width)
10	= .010 inches (z slice)
6	= .6 inches per second (speed)
119	= 119 degrees C (temperature of tip & liquefier)
15	= 15 degrees C (temperature of envelope)

Table 59

Control VS 907520412815

Control Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)	907520412815 Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)
0.500	0.130	0.065	229.333	3528.200	0.531	0.131	0.070	185.667	2669.125
0.500	0.130	0.065	227.667	3502.569	0.532	0.128	0.068	180.952	2657.307
0.500	0.130	0.065	226.667	3487.185	0.534	0.125	0.067	184.762	2767.970
0.500	0.130	0.065	228.666	3517.938	0.540	0.126	0.068	181.667	2670.003
0.500	0.130	0.065	228.333	3512.815	0.539	0.122	0.066	184.286	2802.488
0.500	0.130	0.065	228.095	3509.154	0.540	0.125	0.068	184.524	2733.689
0.500	0.130	0.065	229.333	3528.200	0.530	0.125	0.066	183.571	2770.883
0.500	0.130	0.065	227.666	3502.554	0.531	0.128	0.068	187.143	2753.399
0.500	0.130	0.065	229.524	3531.138	0.540	0.124	0.067	182.619	2727.285
0.500	0.130	0.065	228.095	3509.154	0.535	0.127	0.068	184.524	2715.785
			Mean	3512.890				Mean	2726.793
			St. Dev.	13.15039				St. Dev.	46.50269

LEGEND

90 = 90 degrees (orientation angle of path)
75 = .075 inches (road width)
20 = .020 inches (z slice)
4 = .4 inches per second (speed)
128 = 128 degrees C (temperature of tip & liquefier)
15 = 15 degrees C (temperature of envelope)

Table 60

Analysis of Variance

Control VS 907520412815

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	3089745.7651	3089745.765	2381.374
Within	18	23354.338025	1297.463223	
Total	19	3113100.1032		

LEGEND

90 = 90 degrees (orientation angle of path)
75 = .075 inches (road width)
20 = .020 inches (z slice)
4 = .4 inches per second (speed)
128 = 128 degrees C (temperature of tip & liquefier)
15 = 15 degrees C (temperature of envelope)

Table 61

Control VS 907530211915

Control Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)	907530211915 Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)
0.500	0.130	0.065	229.333	3528.200	0.525	0.135	0.071	178.714	2521.538
0.500	0.130	0.065	227.667	3502.569	0.529	0.133	0.070	177.857	2527.922
0.500	0.130	0.065	226.667	3487.185	0.529	0.134	0.071	180.258	2542.928
0.500	0.130	0.065	228.666	3517.938	0.531	0.130	0.069	179.095	2594.452
0.500	0.130	0.065	228.333	3512.815	0.526	0.135	0.071	184.286	2595.212
0.500	0.130	0.065	228.095	3509.154	0.540	0.133	0.072	179.857	2504.275
0.500	0.130	0.065	229.333	3528.200	0.536	0.131	0.070	184.286	2624.559
0.500	0.130	0.065	227.666	3502.554	0.550	0.134	0.074	182.857	2481.099
0.500	0.130	0.065	229.524	3531.138	0.528	0.132	0.070	179.762	2579.230
0.500	0.130	0.065	228.095	3509.154	0.546	0.132	0.072	183.571	2547.050
			Mean	3512.890				Mean	2551.826
			St. Dev.	13.15039				St. Dev.	43.12130

LEGEND

90	= 90 degrees (orientation angle of path)
75	= .075 inches (road width)
30	= .030 inches (z slice)
2	= .2 inches per second (speed)
119	= 119 degrees C (temperature of tip & liquefier)
15	= 15 degrees C (temperature of envelope)

Table 62

Analysis of Variance

Control VS 907530211915

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	4618223.979	4618223.979	4090.181
Within	18	20323.800095	1129.100005	
Total	19	4638547.7791		

LEGEND

90	= 90 degrees (orientation angle of path)
75	= .075 inches (road width)
30	= .030 inches (z slice)
2	= .2 inches per second (speed)
119	= 119 degrees C (temperature of tip & liquefier)
15	= 15 degrees C (temperature of envelope)

Table 63

Control VS 907530212815

Control Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)	907530212815 Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)
0.500	0.130	0.065	229.333	3528.200	0.534	0.132	0.070	180.667	2563.089
0.500	0.130	0.065	227.667	3502.569	0.541	0.130	0.070	179.048	2545.827
0.500	0.130	0.065	226.667	3487.185	0.545	0.129	0.070	183.095	2604.296
0.500	0.130	0.065	228.666	3517.938	0.547	0.130	0.071	181.429	2551.385
0.500	0.130	0.065	228.333	3512.815	0.535	0.132	0.071	176.429	2498.287
0.500	0.130	0.065	228.095	3509.154	0.540	0.130	0.070	176.190	2509.829
0.500	0.130	0.065	229.333	3528.200	0.542	0.129	0.070	180.333	2579.207
0.500	0.130	0.065	227.666	3502.554	0.547	0.131	0.072	181.667	2535.230
0.500	0.130	0.065	229.524	3531.138	0.540	0.130	0.070	182.619	2601.410
0.500	0.130	0.065	228.095	3509.154	0.534	0.129	0.069	181.429	2633.757
			Mean	3512.890				Mean	2562.231
			St. Dev.	13.15039				St. Dev.	40.81663

LEGEND

90 = 90 degrees (orientation angle of path)
75 = .075 inches (road width)
30 = .030 inches (z slice)
2 = .2 inches per second (speed)
128 = 128 degrees C (temperature of tip & liquefier)
15 = 15 degrees C (temperature of envelope)

Table 64

Analysis of Variance

Control VS 907530212815

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	4518763.4593	4518763.459	4423.099
Within	18	18389.309372	1021.628298	
Total	19	4537152.7686		

LEGEND

90 = 90 degrees (orientation angle of path)
75 = .075 inches (road width)
30 = .030 inches (z slice)
2 = .2 inches per second (speed)
128 = 128 degrees C (temperature of tip & liquefier)
15 = 15 degrees C (temperature of envelope)

Table 65

Control VS 907530612830

Control Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)	907530612830 Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)
0.500	0.130	0.065	229.333	3528.200	0.518	0.135	0.070	188.095	2689.761
0.500	0.130	0.065	227.667	3502.569	0.530	0.133	0.070	186.429	2644.758
0.500	0.130	0.065	226.667	3487.185	0.520	0.132	0.069	188.810	2750.728
0.500	0.130	0.065	228.666	3517.938	0.515	0.131	0.067	185.476	2749.218
0.500	0.130	0.065	228.333	3512.815	0.521	0.135	0.070	189.286	2691.206
0.500	0.130	0.065	228.095	3509.154	0.515	0.138	0.071	189.286	2663.374
0.500	0.130	0.065	229.333	3528.200	0.519	0.133	0.069	191.667	2776.696
0.500	0.130	0.065	227.666	3502.554	0.521	0.136	0.071	190.476	2688.213
0.500	0.130	0.065	229.524	3531.138	0.515	0.140	0.072	189.286	2625.326
0.500	0.130	0.065	228.095	3509.154	0.519	0.136	0.071	183.571	2600.745
			Mean	3512.890				Mean	2688.002
			St. Dev.	13.15039				St. Dev.	54.38811

LEGEND

90 = 90 degrees (orientation angle of path)
75 = .075 inches (road width)
30 = .030 inches (z slice)
6 = .6 inches per second (speed)
128 = 128 degrees C (temperature of tip & liquefier)
30 = 30 degrees C (temperature of envelope)

Table 66

Analysis of Variance

Control VS 907530612830

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	3402202.2057	3402202.205	1955.913
Within	18	31309.995342	1739.444185	
Total	19	3433512.2011		

LEGEND

90 = 90 degrees (orientation angle of path)
75 = .075 inches (road width)
30 = .030 inches (z slice)
6 = .6 inches per second (speed)
128 = 128 degrees C (temperature of tip & liquefier)
30 = 30 degrees C (temperature of envelope)

Table 67

Control VS 905010211930

Control Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)	905010211930 Width (IN)	Thick (IN)	Area (IN^2)	Force (LB)	Tensile (PSI)
0.500	0.130	0.065	229.333	3528.200	0.559	0.129	0.072	177.143	2456.532
0.500	0.130	0.065	227.667	3502.569	0.553	0.133	0.074	178.571	2427.919
0.500	0.130	0.065	226.667	3487.185	0.553	0.129	0.071	177.381	2486.522
0.500	0.130	0.065	228.666	3517.938	0.553	0.130	0.072	179.048	2490.583
0.500	0.130	0.065	228.333	3512.815	0.557	0.128	0.071	176.429	2474.599
0.500	0.130	0.065	228.095	3509.154	0.550	0.133	0.073	176.905	2418.387
0.500	0.130	0.065	229.333	3528.200	0.556	0.131	0.073	180.452	2477.511
0.500	0.130	0.065	227.666	3502.554	0.558	0.132	0.074	179.524	2437.330
0.500	0.130	0.065	229.524	3531.138	0.559	0.132	0.074	177.857	2410.378
0.500	0.130	0.065	228.095	3509.154	0.553	0.132	0.073	175.952	2410.433
			Mean	3512.890				Mean	2449.019
			St. Dev.	13.15039				St. Dev.	30.26334

LEGEND

90 = 90 degrees (orientation angle of path)
50 = .050 inches (road width)
10 = .010 inches (z slice)
2 = .2 inches per second (speed)
119 = 119 degrees C (temperature of tip & liquefier)
30 = 30 degrees C (temperature of envelope)

Table 68

Analysis of Variance

Control VS 905010211930

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	5659110.7884	5659110.788	9355.595
Within	18	10888.029284	604.8905158	
Total	19	5669998.8176		

LEGEND

90 = 90 degrees (orientation angle of path)
50 = .050 inches (road width)
10 = .010 inches (z slice)
2 = .2 inches per second (speed)
119 = 119 degrees C (temperature of tip & liquefier)
30 = 30 degrees C (temperature of envelope)

Table 69

Analysis of Variance

Control VS All the .025 in. Road Width

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	15482529	15482529	110
Within	168	23600800	140481	
Total	169	39083329		

All of the specimens that had a .025 inches road width.

Table 70

Analysis of Variance

Control VS All of the .050 in. Road Width.

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	6637229	6637229	376
Within	38	671396	17668	
Total	39	7308625		

All the specimens that had a .050 inches road width.

Table 71

Analysis of Variance

Control VS All of the .075 in. Road Width

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	13082097	13082097	95
Within	158	21785622	137884	
Total	159	34867719		

All of the specimens that had a .075 inches road width.

Table 72

Analysis of Variance

Control VS All the 0 Degrees Specimens

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	23817015	23817015	7
Within	128	441853955	3451984	
Total	129	465670970		

All of the specimens that had 0 degrees of orientation angle.

Table 73

Analysis of Variance

Control VS All of the 45 Degrees Specimens

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	10588285	10588285	202
Within	58	3036735	52357	
Total	59	13625019		

All of the specimens with a 45 degree angle of orientation.

Table 74

Analysis of Variance

Control VS All of the 90 Degrees Specimens

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	8524839	8524839	517
Within	178	2937746	16504	
Total	179	11462585		

All of the specimens with a 90 degree orientation.

Table 75

Analysis of Variance

Control VS All of the .010 in. Z Slice Specimens

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	14227609	14227609	84
Within	158	26821872	169759	
Total	159	41049480		

All of the specimens with a z slice of .010 inches.

Table 76

Analysis of Variance

Control VS All of the .020 in. Z Slice Specimens

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	13243285	13243285	113
Within	78	9135479	117122	
Total	79	22378764		

All of the specimens with a z slice of .020 inches.

Table 77

Analysis of Variance

Control VS All of the .030 in. Z Slice Specimens

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	12514332	12514332	124 .
Within	128	12891607	100716	
Total	129	25405939		

All of the specimens with a z slice of .030 inches.

Table 78

Analysis of Variance

Control VS All of the Specimen with a Speed of .2 in. per Second

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	11959683	11959683	115
Within	118	12279635	104065	
Total	119	24239318		

All of the specimens with a speed of .2 inches per second.

Table 79

Analysis of Variance

Control VS All of the Specimens with a Speed of .4 in. per Second

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	11164786	11164786	95
Within	68	8022163	117973	
Total	69	19186949		

All of the specimens with a speed of .4 inches per second.

Table 80

Analysis of Variance

Control VS all of the Specimens with a Speed of .6 in. per Second

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	15318270	15318270	99
Within	178	27422937	154061	
Total	179	42741207		

All of the specimens with a speed of .6 inches per second.

Table 81

Analysis of Variance

Control VS All of the Specimens with 119 Degrees C for the Tip & Liquefier Temperatures

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	13339537	13339537	115
Within	148	17143440	115834	
Total	149	30482976		

All of the specimens with a tip & liquefier temperature of 119 degrees C.

Table 82

Analysis of Variance

Control VS All of the Specimens with 124 Degree C for the Tip & Liquefier Temperatures

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	13348361	13348361	84
Within	68	10839976	159411	
Total	69	24188338		

All of the specimens with a tip & liquefier temperature of 124 degree C.

Table 83

Analysis of Variance

Control VS All of the Specimens with 128 Degrees C for the Tip & Liquefier Temperatures

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	13501006	13501006	95
Within	148	21093202	142522	
Total	149	34594208		

All of the specimens with a tip & liquefier temperature of 128 degrees C.

Table 84

Analysis of Variance

Control VS All of the Specimens with a Envelope Temperature of 15 Degrees C

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	6968903	6968903	40
Within	168	29426259	175156	
Total	169	36395162		

All of the specimens with a envelope temperature of 15 degrees C.

Table 85

Analysis of Variance

Control VS All of the Specimens with a Envelope Temperature of 23 Degrees C

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	14934464	14934464	92
Within	38	6192136	162951	
Total	39	21126600		

All of the specimens with a envelope temperature of 23 degree C.

Table 86

Analysis of Variance

Control VS All of the Specimens with a Envelope Temperature of 30 Degrees C

	df	Sum of Squares	Mean Squares	F Ratio
Between	1	12439927	12439927	104
Within	158	18922606	119763	
Total	159	31362533		

All of the specimens with a envelope temperature of 30 degrees C.

APPENDIX E

Variance Ratio F Tables

Tables from "Simplified Statistical Analysis" by Harry Holscher.

G	n	m = 1	2	3	4	5	6	7	8	9	10	12	15	20	30	60	120	∞
0.90		39.9	49.5	53.6	55.8	57.2	58.2	58.9	59.4	59.9	60.2	60.7	61.2	61.7	62.3	62.8	63.1	63.3
0.95		161	200	216	225	230	234	237	239	241	242	244	246	248	250	252	253	254
0.975	1	648	800	864	900	922	937	948	957	963	969	977	985	993	1000	1010	1010	1020
0.99		4,050	5,000	5,400	5,620	5,760	5,860	5,930	5,980	6,020	6,060	6,110	6,160	6,210	6,260	6,310	6,340	6,370
0.995		16,200	20,000	21,600	22,500	23,100	23,400	23,700	23,900	24,100	24,200	24,400	24,600	24,800	25,000	25,200	25,400	25,500
0.90		8.53	9.00	9.16	9.24	9.29	9.33	9.35	9.37	9.38	9.39	9.41	9.42	9.44	9.46	9.47	9.48	9.49
0.95		18.5	19.0	19.2	19.2	19.3	19.3	19.4	19.4	19.4	19.4	19.4	19.4	19.5	19.5	19.5	19.5	19.5
0.975	2	38.5	39.0	39.2	39.2	39.3	39.3	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.5	39.5	39.5	39.5
0.99		98.5	99.0	99.2	99.2	99.3	99.3	99.4	99.4	99.4	99.4	99.4	99.4	99.4	99.5	99.5	99.5	99.5
0.995		199	199	199	199	199	199	199	199	199	199	199	199	199	199	199	199	199
0.90		5.54	5.46	5.39	5.34	5.31	5.28	5.27	5.25	5.24	5.23	5.22	5.20	5.18	5.17	5.15	5.14	5.13
0.95		10.1	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81	8.79	8.74	8.70	8.66	8.62	8.57	8.55	8.53
0.975	3	17.4	16.0	15.4	15.1	14.9	14.7	14.6	14.5	14.5	14.4	14.3	14.3	14.2	14.1	14.0	13.9	13.9
0.99		34.1	30.8	29.5	28.7	28.2	27.9	27.7	27.5	27.3	27.2	27.1	26.9	26.7	26.5	26.3	26.2	26.1
0.995		55.6	49.8	47.5	46.2	45.4	44.8	44.4	44.1	43.9	43.7	43.4	43.1	42.8	42.5	42.1	42.0	41.8
0.90		4.54	4.32	4.19	4.11	4.05	4.01	3.98	3.95	3.93	3.92	3.90	3.87	3.84	3.82	3.79	3.78	3.76
0.95		7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00	5.96	5.91	5.86	5.80	5.75	5.69	5.66	5.63
0.975	4	12.2	10.6	9.98	9.60	9.36	9.20	9.07	8.98	8.90	8.84	8.75	8.66	8.56	8.46	8.36	8.31	8.26
0.99		21.2	18.0	16.7	16.0	15.5	15.2	15.0	14.8	14.7	14.5	14.4	14.2	14.0	13.8	13.7	13.6	13.5
0.995		31.3	26.3	24.3	23.2	22.5	22.0	21.6	21.4	21.1	21.0	20.7	20.4	20.2	19.9	19.6	19.5	19.3
0.90		4.06	3.78	3.62	3.52	3.45	3.40	3.37	3.34	3.32	3.30	3.27	3.24	3.21	3.17	3.14	3.12	3.11
0.95		6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77	4.74	4.68	4.62	4.56	4.50	4.43	4.40	4.37
0.975	5	10.0	8.43	7.76	7.39	7.15	6.98	6.85	6.76	6.68	6.62	6.52	6.43	6.33	6.23	6.12	6.07	6.02
0.99		16.3	13.3	12.1	11.4	11.0	10.7	10.5	10.3	10.2	10.1	9.89	9.72	9.55	9.38	9.20	9.11	9.02
0.995		22.8	18.3	16.5	15.6	14.9	14.5	14.2	14.0	13.8	13.6	13.4	13.1	12.9	12.7	12.4	12.3	12.1

0.90		3.78	3.46	3.29	3.18	3.11	3.05	3.01	2.98	2.96	2.94	2.90	2.87	2.84	2.80	2.76	2.74	2.72
0.95		5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10	4.06	4.00	3.94	3.87	3.81	3.74	3.70	3.67
0.975	6	8.81	7.26	6.60	6.23	5.99	5.82	5.70	5.60	5.52	5.46	5.37	5.27	5.17	5.07	4.96	4.90	4.85
0.99		13.7	10.9	9.78	9.15	8.75	8.47	8.26	8.10	7.98	7.87	7.72	7.56	7.40	7.23	7.06	6.97	6.88
0.995		18.6	14.5	12.9	12.0	11.5	11.1	10.8	10.6	10.4	10.2	10.0	9.81	9.59	9.36	9.12	9.00	8.88
0.90		3.59	3.26	3.07	2.96	2.88	2.83	2.78	2.75	2.72	2.70	2.67	2.63	2.59	2.56	2.51	2.49	2.47
0.95		5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68	3.64	3.57	3.51	3.44	3.38	3.30	3.27	3.23
0.975	7	8.07	6.54	5.89	5.52	5.29	5.12	4.99	4.90	4.82	4.76	4.67	4.57	4.47	4.36	4.25	4.20	4.14
0.99		12.2	9.55	8.45	7.85	7.46	7.19	6.99	6.84	6.72	6.62	6.47	6.31	6.16	5.99	5.82	5.74	5.65
0.995		16.2	12.4	10.9	10.1	9.52	9.16	8.89	8.68	8.51	8.38	8.18	7.97	7.75	7.53	7.31	7.19	7.08
0.90		3.46	3.11	2.92	2.81	2.73	2.67	2.62	2.59	2.56	2.54	2.50	2.46	2.42	2.38	2.34	2.31	2.29
0.95		5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39	3.35	3.28	3.22	3.15	3.08	3.01	2.97	2.93
0.975	8	7.57	6.06	5.42	5.05	4.82	4.65	4.53	4.43	4.36	4.30	4.20	4.10	4.00	3.89	3.78	3.73	3.67
0.99		11.3	8.65	7.59	7.01	6.63	6.37	6.18	6.03	5.91	5.81	5.67	5.52	5.36	5.20	5.03	4.95	4.86
0.995		14.7	11.0	9.60	8.81	8.30	7.95	7.69	7.50	7.34	7.21	7.01	6.81	6.61	6.40	6.18	6.05	5.95
0.90		3.36	3.01	2.81	2.69	2.61	2.55	2.51	2.47	2.44	2.42	2.38	2.34	2.30	2.25	2.21	2.18	2.16
0.95		5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18	3.14	3.07	3.01	2.94	2.86	2.79	2.75	2.71
0.975	9	7.21	5.71	5.08	4.72	4.48	4.32	4.20	4.10	4.03	3.96	3.87	3.77	3.67	3.56	3.45	3.39	3.33
0.99		10.6	8.02	6.99	6.42	6.06	5.80	5.61	5.47	5.35	5.26	5.11	4.96	4.81	4.65	4.48	4.40	4.31
0.995		13.6	10.1	8.72	7.96	7.47	7.13	6.88	6.69	6.54	6.42	6.23	6.03	5.83	5.62	5.41	5.30	5.19
0.90		3.29	2.92	2.73	2.61	2.52	2.46	2.41	2.38	2.35	2.32	2.28	2.24	2.20	2.15	2.11	2.08	2.06
0.95		4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02	2.98	2.91	2.84	2.77	2.70	2.62	2.58	2.54
0.975	10	6.94	5.46	4.83	4.47	4.24	4.07	3.95	3.85	3.78	3.72	3.62	3.52	3.42	3.31	3.20	3.14	3.08
0.99		10.0	7.56	6.55	5.99	5.64	5.39	5.20	5.06	4.94	4.85	4.71	4.56	4.41	4.25	4.08	4.00	3.91
0.995		12.8	9.43	8.08	7.34	6.87	6.54	6.30	6.12	5.97	5.85	5.66	5.47	5.27	5.07	4.86	4.75	4.64
0.90		3.18	2.81	2.61	2.48	2.39	2.33	2.28	2.24	2.21	2.19	2.15	2.10	2.06	2.01	1.96	1.93	1.90
0.95		4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80	2.75	2.69	2.62	2.54	2.47	2.38	2.34	2.30
0.975	12	6.55	5.10	4.47	4.12	3.89	3.73	3.61	3.51	3.44	3.37	3.28	3.18	3.07	2.96	2.85	2.79	2.72
0.99		9.33	6.93	5.95	5.41	5.06	4.82	4.64	4.50	4.39	4.30	4.16	4.01	3.86	3.70	3.54	3.45	3.36
0.995		11.8	8.51	7.23	6.52	6.07	5.76	5.52	5.35	5.20	5.09	4.91	4.72	4.53	4.33	4.12	4.01	3.90

0.90		3.07	2.70	2.49	2.36	2.27	2.21	2.16	2.12	2.09	2.06	2.02	1.97	1.92	1.87	1.82	1.79	1.76
0.95		4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59	2.54	2.48	2.40	2.33	2.25	2.16	2.11	2.07
0.975	15	6.20	4.77	4.15	3.80	3.58	3.41	3.29	3.20	3.12	3.06	2.96	2.86	2.76	2.64	2.52	2.46	2.40
0.99		8.68	6.36	5.42	4.89	4.56	4.32	4.14	4.00	3.89	3.80	3.67	3.52	3.37	3.21	3.05	2.96	2.87
0.995		10.8	7.70	6.48	5.80	5.37	5.07	4.85	4.67	4.54	4.42	4.25	4.07	3.88	3.69	3.48	3.37	3.26
0.90		2.97	2.59	2.38	2.25	2.16	2.09	2.04	2.00	1.96	1.94	1.89	1.84	1.79	1.74	1.68	1.64	1.61
0.95		4.35	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39	2.35	2.28	2.20	2.12	2.04	1.95	1.90	1.84
0.975	20	5.87	4.46	3.86	3.51	3.29	3.13	3.01	2.91	2.84	2.77	2.68	2.57	2.46	2.35	2.22	2.16	2.09
0.99		8.10	5.85	4.94	4.43	4.10	3.87	3.70	3.56	3.46	3.37	3.23	3.09	2.94	2.78	2.61	2.52	2.42
0.995		9.94	6.99	5.82	5.17	4.76	4.47	4.26	4.09	3.96	3.85	3.68	3.50	3.32	3.12	2.92	2.81	2.69
0.90		2.88	2.49	2.28	2.14	2.05	1.98	1.93	1.88	1.85	1.82	1.77	1.72	1.67	1.61	1.54	1.50	1.46
0.95		4.17	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21	2.16	2.09	2.01	1.93	1.84	1.74	1.68	1.62
0.975	30	5.57	4.18	3.59	3.25	3.03	2.87	2.75	2.65	2.57	2.51	2.41	2.31	2.20	2.07	1.94	1.87	1.79
0.99		7.56	5.39	4.51	4.02	3.70	3.47	3.30	3.17	3.07	2.98	2.84	2.70	2.55	2.39	2.21	2.11	2.01
0.995		9.18	6.35	5.24	4.62	4.23	3.95	3.74	3.58	3.45	3.34	3.18	3.01	2.82	2.63	2.42	2.30	2.18
0.90		2.79	2.39	2.18	2.04	1.95	1.87	1.82	1.77	1.74	1.71	1.66	1.60	1.54	1.48	1.40	1.35	1.29
0.95		4.00	3.15	2.76	2.53	2.37	2.25	2.17	2.10	2.04	1.99	1.92	1.84	1.75	1.65	1.53	1.47	1.39
0.975	60	5.29	3.93	3.34	3.01	2.79	2.63	2.51	2.41	2.33	2.27	2.17	2.06	1.94	1.82	1.67	1.58	1.48
0.99		7.08	4.98	4.13	3.65	3.34	3.12	2.95	2.82	2.72	2.63	2.50	2.35	2.20	2.03	1.84	1.73	1.60
0.995		8.49	5.80	4.73	4.14	3.76	3.49	3.29	3.13	3.01	2.90	2.74	2.57	2.39	2.19	1.96	1.83	1.69
0.90		2.75	2.35	2.13	1.99	1.90	1.82	1.77	1.72	1.68	1.65	1.60	1.54	1.48	1.41	1.32	1.26	1.19
0.95		3.92	3.07	2.68	2.45	2.29	2.18	2.09	2.02	1.96	1.91	1.83	1.75	1.66	1.55	1.43	1.35	1.25
0.975	120	5.15	3.80	3.23	2.89	2.67	2.52	2.39	2.30	2.22	2.16	2.05	1.94	1.82	1.69	1.53	1.43	1.31
0.99		6.85	4.79	3.95	3.48	3.17	2.96	2.79	2.66	2.56	2.47	2.34	2.19	2.03	1.86	1.66	1.53	1.38
0.995		8.18	5.54	4.50	3.92	3.55	3.28	3.09	2.93	2.81	2.71	2.54	2.37	2.19	1.98	1.75	1.61	1.43
0.90		2.71	2.30	2.08	1.94	1.85	1.77	1.72	1.67	1.63	1.60	1.55	1.49	1.42	1.34	1.24	1.17	1.00
0.95		3.84	3.00	2.60	2.37	2.21	2.10	2.01	1.94	1.88	1.83	1.75	1.67	1.57	1.46	1.32	1.22	1.00
0.975		5.02	3.69	3.12	2.79	2.57	2.41	2.29	2.19	2.11	2.05	1.94	1.83	1.71	1.57	1.39	1.27	1.00
0.99		6.63	4.61	3.78	3.32	3.02	2.80	2.64	2.51	2.41	2.32	2.18	2.04	1.88	1.70	1.47	1.32	1.00
0.995		7.88	5.30	4.28	3.72	3.35	3.09	2.90	2.74	2.62	2.52	2.36	2.19	2.00	1.79	1.53	1.36	1.00