# A Method of Fabricating Coated Splices for Oilfield Applications

by

Lauren A. Killian

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Signature of Author..........................................................................................
Department of Mechanical Engineering
May 20, 2005

Certified by..........................................................................................
Kamal Youcef-Toumi
Professor of Mechanical Engineering
Thesis Supervisor

Accepted by..........................................................................................
Lallit Anand
Professor of Mechanical Engineering
Chairman, Committee on Graduate Studies

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## ABSTRACT

A method is needed to make a critical splice for a downhole tool in the petroleum industry. The goal is to connect two wires, cover the connection with a protective coating, and then assess the integrity of the finished splice. This project investigates how ultrasonic welding and injection molding can be employed in making the splice. After equipment and a process are designed, splices are produced and testing proceeds. Then an overall assessment of the method is made: connecting the wires in manufacturing should be done by ultrasonic welding and coating the wires using injection molding is a viable option. Further testing should investigate the reliability and failure modes of the coating at high pressures and temperatures along with how the coating method can be improved for quality assurance. Using the system designed during this project and the information gleaned, the plastic injection method should be compared with different methods, such as shrink-tubing, in order to make a final decision on the best coating method to be optimized for employment in manufacturing.

Thesis Supervisor: Kamal Youcef-Toumi
Title: Professor of Mechanical Engineering

**Biographical Note:**

Lauren Killian received a Bachelor of Science degree in Mechanical Engineering in 2003 from the Massachusetts Institute of Technology, after three years at M.I.T. and one year at Cambridge University. She was a joint recipient of the Sheridan Prize, an M.I.T. design team award. Following her undergraduate degree, she worked for a year at Schlumberger, an oilfield services company, as part of her master's thesis. She received a graduate fellowship from the Research Partnership to Secure Energy for America and is now finishing the final year of her Master of Science degree with M.I.T.'s Mechanical Engineering Department.

# Table of Contents

# Chapter 1: Introduction

## 1.1 Thesis Content

This thesis consists of seven chapters. Chapter 1 introduces the project. Chapter 2 provides background information on the materials involved in the splice, ultrasonic welding technology, and injection molding. Chapter 3 discusses the method employed to make the splice and test it. Chapter 4 provides experimental results from testing splices under different environmental conditions. Chapter 5 discusses and analyzes the results. Chapter 6 contains conclusions about what has been learned from this feasibility project and recommends the direction for future developments. Appendices follow.

## 1.2 The Problem

A splicing method must be devised for an application in the petroleum industry. The problem is better understood by discussing the goal, application, and requirements of the project.

### 1.2.1 The Goal

This project investigates how and if injection molding can be employed in making a suitable splice. A splice consists of two wires connected together with a protective coating over the connection. The goal for this project is to connect the wires, cover the connection with a protective coating, and then test the integrity of the finished splice.

### 1.2.2 The Application

Splices are used in petroleum industry applications. Petroleum products, such as oil, are extracted from the earth for society's demands, including powering automobiles and generating electricity to light homes and businesses. North America alone consumes over 24 million barrels of crude oil per day[1]. It is believed that only one third of the world's oil reserves have been tapped. Two thirds of our oil supply remains untouched but is difficult to

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[1] PennWell Corporation. International Petroleum Encyclopedia. Tulsa: PennWell Corporation. 1999.

locate and retrieve[2]. This drives energy service companies to research and develop new technologies and tools to help locate and extract these untapped petroleum reserves. Schlumberger, Halliburton, and Baker Hughes are some of the main players in the oilfield services market.

Schlumberger is in the research and development stage of designing a tool that will aid in faster communication with downhole tools while drilling for oil. The company is working to make it a manufacturable tool.

A splicing technique is a critical component for this tool. Two small wires of different sizes must be connected and be able to withstand the harsh downhole environment that is characterized by very high temperatures and pressures. The splice will be surrounded by a potting material, but liquids may leak through the potting, so the splice should be hermetic. The splices employed in this environment are critical.

### 1.2.3 The Requirements

A method must be developed for an unskilled operator to make a correct splice. The final method and final splice must satisfy certain requirements in order to be employed in manufacturing. The splice must meet geometric requirements by fitting into a small, curved groove. Each splice must be inexpensive. The method must produce a splice quickly, in addition to being independent of the operator's skill. Splices of consistent quality must be produced, and the quality must be testable. Splices must be waterproof at all times, including at high pressures and temperatures up to 20,000 psi and 300°F.

### 1.2.4 Focus of Thesis

The objective of this thesis is to evaluate methods of welding a wire connection and developing a manual system to mold a coating over it. It is also of interest to identify ways to test the integrity of the splice. The hypothesis states that:

> "By developing the equipment and process to make a critical waterproof splice, the splice will be ready for evaluation and the equipment ready for optimization for manufacturing."

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[2] DuMond, Todd. Massachusetts Institute of Technology thesis: "The Feasibility of Using Viscometers and Flowmeters in an Oilwell Environment." Cambridge, MA; June 2001.

### 1.3 Prior Art

The work in this thesis builds upon past research and procedures. The need for a wire connection covered by a protective coating has already been identified. A prototype exists where the wires are connected with a "winding and soldering" method, then coated with a heat-shrink-tubing. These methods will now be discussed, highlighting where improvements are needed.

#### 1.3.1 Connecting Wires with Winding and Soldering

Two wires of different sizes must be connected together (Figure 1). A "winding and soldering" method has been considered to accomplish this (Figure 2). Such a method consists of overlapping the ends of the two conductors, winding a small wire around the overlapping section, and then soldering the connection in place.

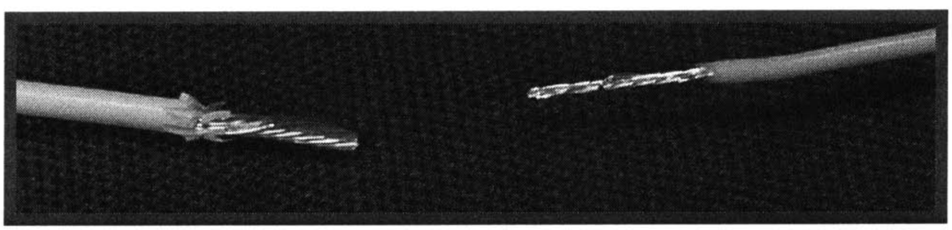

**Figure 1:** Two different size wires must be connected together.

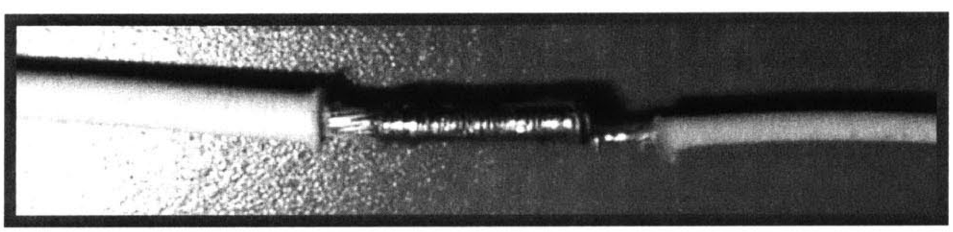

**Figure 2:** Two wires connected via the "winding and soldering" method

This method is commonly used in industry for small quantity applications. Though "winding and soldering" is appropriate for small numbers of splices, it is expensive and impractical for larger volume applications because of the time involved and the skill required. Also, using solder is not desirable because it has a low melting temperature. Solder melts at approximately 430°F [3], whereas Teflon®[4] FEP melts at approximately 500°F [5]. When heat is used to make the connection's Teflon over-coating, the solder can melt and flow. Melted solder can damage the coating and compromise its ability to form a watertight seal. A new type of wire connection is needed.

### 1.3.2 Insulating the Connection with Heat-Shrink-Tubing

The wire connection (Figure 2) must be protected with a coating. A heat-shrink-tubing has been considered to accomplish this (Figure 3). This method consists of wrapping Kapton®[6] tape, a high temperature tape, around the wires' insulation on either side of the connection. A heat gun is then used to slowly shrink a clear plastic tube from one end of the splice to the other. The tube consists of two types of plastic; the outside of the tube is made of Teflon PTFE and the inside of the tube is Teflon FEP. The outer plastic shrinks when heated and forces the inner plastic to melt and move towards the wire connection and insulation. Since both the insulation and the inner plastic are Teflon FEP, they should bond completely.

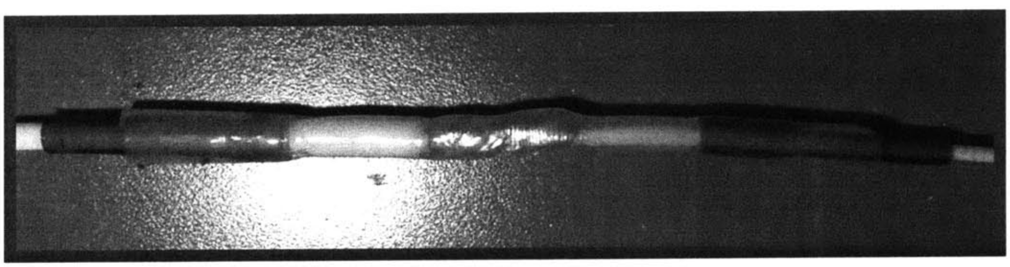

**Figure 3.** A heat-shrink-tube coating around a "wind and solder" wire connection, as used in prototypes. (The clear tube the length of the splice is the shrink-tube, and the orange tape at either end of the splice is the Kapton tape wound around that section of wire.)

As described, this method is not suitable for manufacturing downhole tools. Though the cost of supplies for the shrink tube method is minimal, the time required of a skilled operator makes this an expensive process. Skill sensitivity and reliability are issues when shrinking the plastic. Uneven shrinking can result in inconsistencies such as bubbles, or

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[3] http://shorinternational.com/Solders.htm (June 2004)
[4] Teflon is a registered trademark of DuPont. DuPont Corporate Information Center, Chestnut Run Plaza, 705/GS38, Wilmington, DE 19880-0705.
[5] DuPont. Injection Molding Guide for Teflon FEP, Teflon PFA, Tefzel. p 4.
[6] Kapton is a registered trademark of DuPont. DuPont Corporate Information Center, Chestnut Run Plaza, 705/GS38, Wilmington, DE 19880-0705.

thinly covered areas that could later turn into bubbles. Bubbles can pop as pressure increases, thus exposing the wire connection to the environment and creating a short circuit. Therefore, a better coating method is now being sought.

### 1.3.3 Initial Dialog

A welding method, to connect the wires, and a molding method, to coat the connection, was suggested. After reviewing various methods for connecting wires and coating them, welding and coating were determined to be good options based on the current understanding. They should be fully investigated to determine if such methods should be employed in manufacturing the downhole tool currently under development.

## 1.4 Approach

The process for producing a hermetic splice is chosen to proceed as follows: First, wires are welded together. Then, the connection is coated by placing and holding it in a mold, followed by injecting molten plastic around it. The integrity of the finished splice can be tested once it is cooled.

The approach for building the equipment and designing the precise procedure to accomplish this splice is as follows: To develop the connection method, ultrasonic welding research is done and a custom welder designed. The development of the coating method begins with optimizing the cavity shape of the mold and proceeds to design and build the rest of the injecting equipment. Experimenting with the system reveals appropriate operating parameters. Finally, methods of testing the integrity of the splice are identified and show whether an injection method can produce a hermetic splice.

## 1.5 Technical Issues

Technical issues arise concerning the wire connection, and involving the coating equipment and parameters.

For the connection, requirements for geometry and robustness must be determined, and then an ultrasonic welder must be customized to satisfy those requirements. Geometry requirements include accomplishing a straight, compact weld with a small maximum cross section. It must be robust and able to withstand high tensions and bending.

For coating, a design must be determined and equipment built, so that splices can be tested. Coating development issues include determining the methods for applying tension to the wire, heating plastic, and injecting plastic, along with designing the mold. The mold's outer dimensions, the flow pattern for the plastic, and the material of the mold must be determined. They must be designed to avoid contamination, incomplete coating of the splice, and excess heat loss.

The settings of the coating system must be determined in addition to simply building the system. The main settings arise as a temperature profile, tension setting, and pressure profile. The temperature profile must avoid causing bubbles, hot spots, melted insulation, or an unfilled cavity. A correct tension setting will assist in centering the wire in the cavity so that the wire connection is completely coated. The pressure profile also influences the centering of the wire.

## Chapter 2: Background

This chapter provides an overview on key elements of the project. The materials used to form a splice are discussed. Background on the connection method of ultrasonic welding and the coating method of injection molding is then given.

### 2.1 The Materials

The splice materials consist of the wires that must be connected along with the plastic injected around that connection (Figure 4).

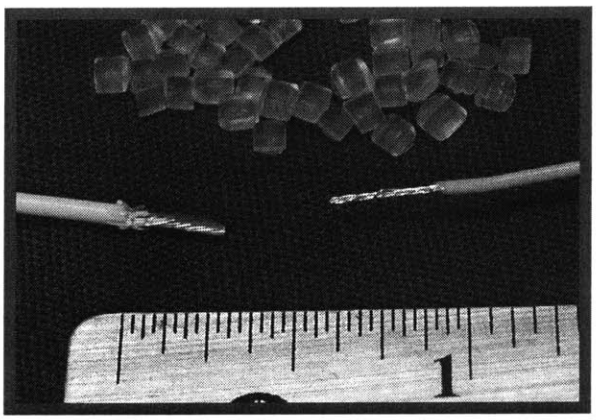


**Figure 4:** Wires and Teflon pellets. This shows the two wires that will be connected and the pellets that will be melted to coat the splice. The larger (20 AWG) wire is on the left and the smaller (26 AWG) wire is on the right. The wire's insulation (white Teflon) is stripped off the end of each wire so the conductors (visible where the insulation is stripped) are ready to be connected.

#### 2.1.1 The Wires

Two different size wires (Figure 4) meet at the connection. Here we discuss the characteristics of each wire.

The larger of the two wires has a size designation of 20 American Wire Gauge (20 AWG). The wire's conductor consists of 19 silver coated copper strands, each 32 AWG in size. All 19 strands are twisted together into a conductor with a diameter of 0.037 – 0.062

inches. This conductor is insulated with a Teflon FEP NP-101[7] coating, resulting in the wire having an outer diameter of 0.054 – 0.062 inches. (See Appendices A.1 and A.2.)

The smaller wire is 26 AWG. Its conductor consists of 19 strands of silver coated copper, each of which is 38 AWG (0.004 inches in diameter). The strands form a conductor with a diameter of 0.019 inches. Again, the conductor is insulated with a Teflon FEP NP-101 coating. The outer diameter of this wire, including insulation, is 0.035 – 0.043 inches. The pull strength of the conductor is 7.88 lbs (see Appendix C.4) and the voltage rating of the wire is 600 volts. Though a 19 strand wire is electrically optimal for use in the downhole tool, a similar 26 AWG wire with only 7 strands is available as an option[8]. (See Appendix A.1)

Because the 26 AWG wire is the smaller of the two wires, its ratings (e.g. pull strength and maximum allowable voltage) are the limiting ratings of the full connection (when the two wires are connected). Also, regarding the pull strength, it should be noted that the pull strength of copper changes with temperature. This correlation with temperature is examined later in section 5.1.

### 2.1.2 Injected Plastic

The plastic injected around the connection (Figure 4) is Teflon FEP 100, supplied by the DuPont company. (See Appendices A.3, A.4, and A.5 for information on the Teflon pellets.) Quantitative properties of this polymer are as follows:

| | |
|---|---|
| Upper Service Temperature[9] | 390°F |
| Nominal Melting Point[10] | 491-510°F |

Teflon FEP is a thermoplastic[11], meaning that once it is formed it can be heated and reformed over and over again[12]. It is a good insulator and can be used at high temperatures; in addition, it has high melt strength and stability at recommended processing temperatures. It has chemical inertness to nearly all industrial chemicals and solvents. It is valued for its toughness, flexibility, negligible moisture absorption, weather resistance, and performance at

[7] Quirk Wire Co. Route 9, P.O. Box 1180, West Brookfield, MA 01585.
[8] Geophysical Supply Co.12021 Britmoore Park Dr, Houston, TX 77041. (713) 666-4100
[9] DuPont. Product Information: Teflon FEP 100-J, Fluoropolymer resin, Extrusion and Molding Resin. p 2.
[10] DuPont. Product Information: Teflon FEP 100-J, Fluoropolymer resin, Extrusion and Molding Resin. p 2.
[11] DuPont. Product Information: Teflon FEP 100-J, Fluoropolymer resin, Extrusion and Molding Resin. p 1.
[12] Plastics Resource. Plastics 101: Plastics-The Basics. www.PlasticsResource.com

extreme temperatures. Molded products have moderate stiffness and high ultimate elongation. Teflon FEP 100 is often selected for products made by injection molding because it offers high available flow rates[13] (Figure 5). Compared with other types of Teflon FEP, Teflon FEP 100 has a higher flow rate and the best balance between end-product performance and ease of processing.

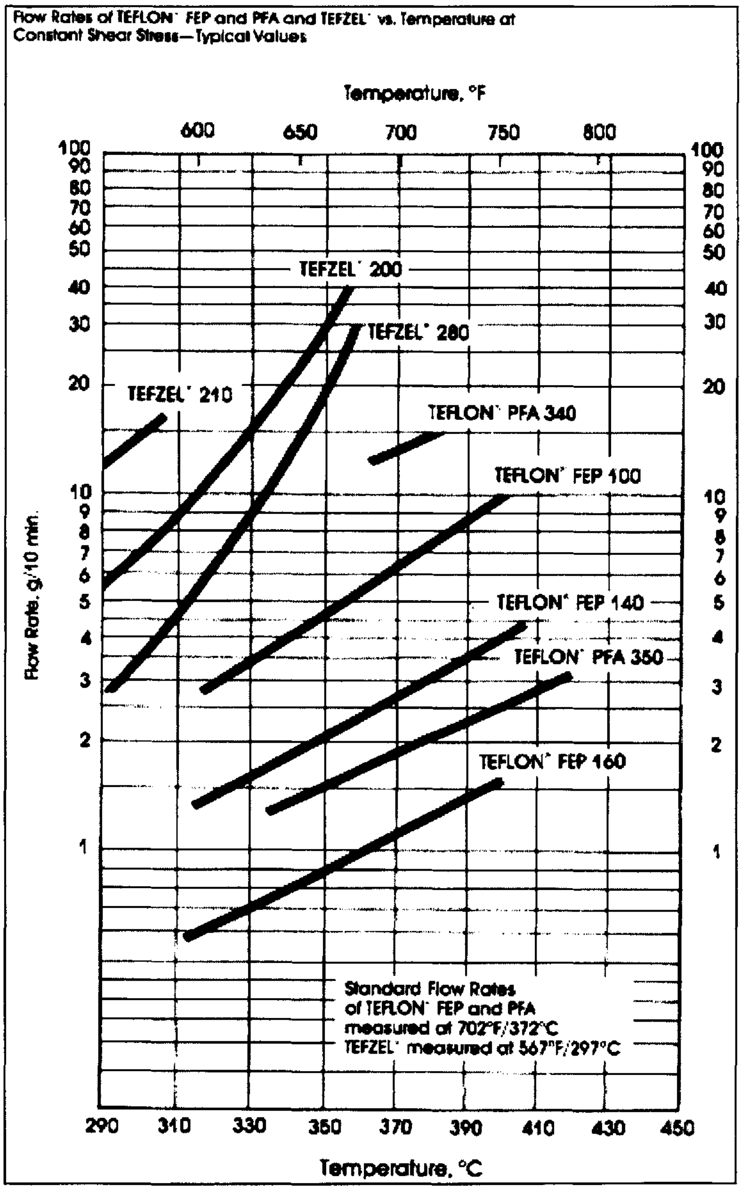


**Figure 5[14].** Flow Rates of Teflon versus Temperature. This shows the increase in flow rate of Teflon FEP 100 with thermal exposure.

[13] DuPont. Product Information: Teflon FEP 100-J, Fluoropolymer resin, Extrusion and Molding Resin. p 1.
[14] DuPont. Injection Molding Guide for Teflon FEP, Teflon PFA, Tefzel. pp 5,6.

Concerns with Teflon do exist, but can be alleviated when care is taken. Storage conditions should be designed to avoid airborne contamination and formation of water condensation on the resin. Also, molten Teflon resins are corrosive to many metals. Therefore, special corrosion-resistant materials must be used for all equipment that comes into contact with the melt. Nickel-based alloys such as Hastelloy® [15], Inconel®, Monel® [16], Xaloy® [17,18] and Duranickel [19,20] are the materials of choice. Additionally, adequate ventilation of the workspace is necessary due to vapors and fumes liberated during hot processing.[21]

In addition to Teflon's many desirable characteristics, Teflon FEP was selected because Teflon FEP is also used in the wires' insulation. It was therefore expected to be optimal for achieving full bonding and creating a hermetic seal. Teflon FEP 100 is a general-purpose resin available in translucent, 2.5mm pellets.[22] (Teflon FEP 100 is also available in a powdered form, "fluff," designated Teflon FEP TE 9050.)

### 2.2 Ultrasonic Welding Connects Wires

Ultrasonic welding (Figure 6) is chosen to connect the wires (Figure 7). In ultrasonic welding, the exposed ends of the wires (conductors) are first overlapped (for a length of approximately 0.19 inches, see Appendix C.1) and clamped together. One of the conductors is vibrated at an ultrasonic frequency. Oxides are dispersed by the scrubbing action between the two conductors, the molecules of the two conductors vibrate into one another's lattices, the conductor's materials commingle, and a pure metallurgical bond forms[23].

This process is accomplished with an ultrasonic welding machine (Figure 6, 8). Overlapped wires are placed onto the flat platform created by the sonotrode. The parts of

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[15] Hastelloy is a registered trademark of Haynes International, Inc. 1020 W. Park Avenue, Kokomo, IN 46901. www.haynesintl.com (May 2004).
[16] Inconel and Monel are registered trademarks of Special Metals Corporation. Huntington, West Virginia. www.specialmetals.com (January 2005).
[17] Xaloy is a registered trademark of Xaloy, Inc. 3 Terminal Road, New Brunswick, NJ 08903. www.xaloy.com (January 2005).
[18] DuPont. Teflon FEP 100 Fluorocarbon Resin: Technical Information. p 2.
[19] Duranickel is a registered trademark of International Nickel Company, P.O. Box 1958, Huntington, WV 25720.
[20] DuPont. Injection Molding Guide for Teflon FEP, Teflon PFA, Tefzel. p 7.
[21] DuPont. Product Information: Teflon FEP 100-J, Fluoropolymer resin, Extrusion and Molding Resin. p 1.
[22] DuPont. Product Information: Teflon FEP 100-J, Fluoropolymer resin, Extrusion and Molding Resin. p 1.
[23] Personal Communication: Shane Beam, Application Engineer. Stapla Ultrasonics Corporation; Wilmington, MA; May 2005.

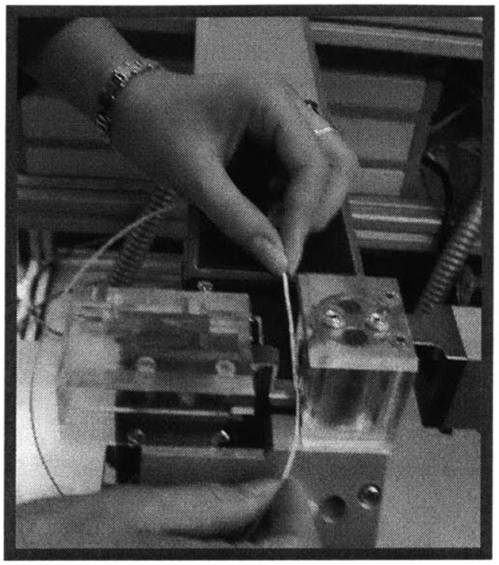

**Figure 6.** An ultrasonic welder will connect the two wires being held in place by the operator.

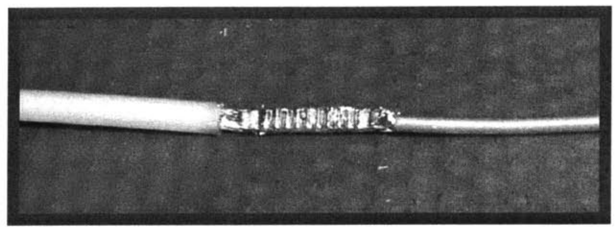

**Figure 7**. Two wires connected by ultrasonic welding.

Interest, while welding (Figure 8b), include a vertical anvil that moves downward to force the upper conductor down onto the lower conductor. A horizontal anvil also pushes the conductors sideways against a stationary wall to secure them in place. Moderate pressure is applied during the joining process to maintain intimate contact between the parts (the pressure does not cause significant deformation in the weld zone—seldom more than 10%).The sonotrode (Figure 8b) then oscillates horizontally. This arises from ultrasonic energy being produced through a transducer, which converts high frequency electrical vibrations to mechanical vibrations of the same frequency (20,000 Hz). Mechanical vibrations are transmitted through a coupling system to the welding tip and the work pieces. The tip vibrates laterally, essentially parallel to the weld interface, while the static force is applied perpendicular to the interface. The surface of the sonotrode in contact with the lower conductor is rough and therefore grips the bottom conductor. The sonotrode's energy transfers to the lower conductor, which then vibrates across the surface of the upper conductor until the metals commingle and the weld is complete. No significant heating is involved; the maximum temperature at the interface is usually in the range of 35-50% of the

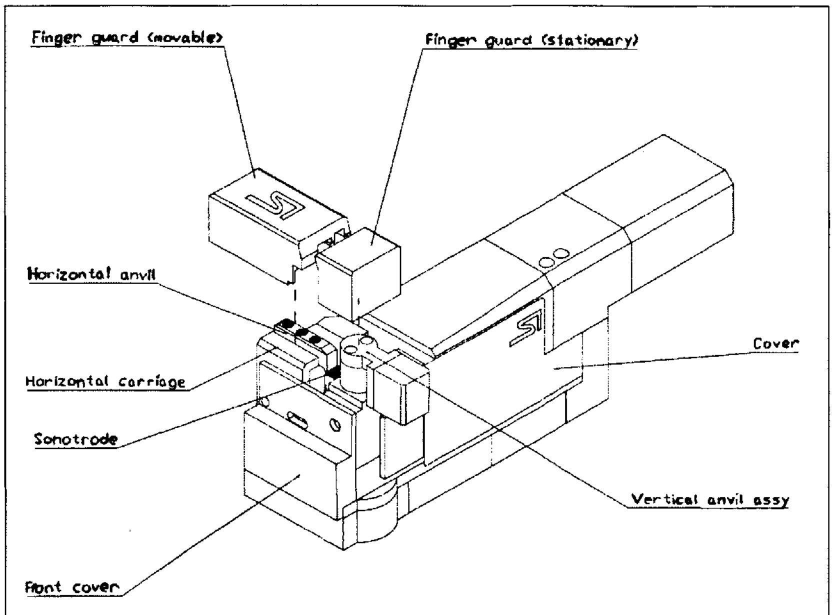


**Figure 8a** [24]**.** Key aspects of the ultrasonic welder.

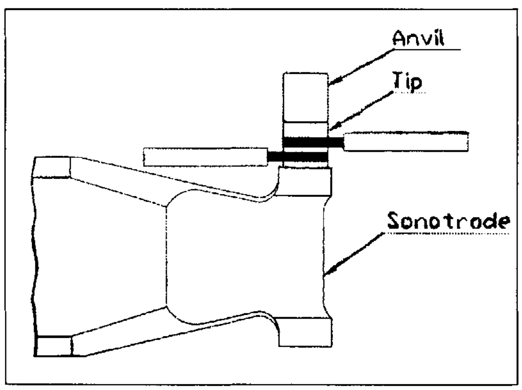


**Figure 8b** [25] **.** Parts involved in welding. The Anvils hold and clamp the wires in place. The sonotrode oscillates (along the length of the wires) and transmits vibrations to the welding tip and wires.

absolute melting point of the metal.[26] The clamping and welding process occurs in less than three seconds.

The machine operates according to the profile that is set and selected on the welder's controller. The welding profile includes specified weld-time, energy, and width of the weld nugget, as well as pre- and post-weld heights. If the weld is not within the allowable range set for each of these parameters an alarm will sound.

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[24] Stapla Ultrasonics, Manual: Ultrasonic Welder—Alfa Automatic, 2004, pp 15, 27.
[25] Stapla Ultrasonics, Manual: Ultrasonic Welder—Alfa Automatic, 2004, pp 15, 27.
[26] Janet Devine. Metals Handbook Ninth Edition, Volume 6 Welding , Brazing, and Soldering. "Ultrasonic Welding" pg746. American Society For Metals, Ohio, 1983.

Several companies make ultrasonic welders for welding metals and plastics. Suppliers were researched and visited to choose the best supplier for the application. The two companies of most interest produced similar products and welds. Stapla Ultrasonics[27] was selected based on service quality and technical expertise, including their ability to detect missing strands and to offer suggestions for customizations appropriate for this application. (Missing strands are detected using an internal height sensor that measures pre-compaction height prior to welding, and then measures the final compaction height after welding.) (See Appendices B.1 and B.2 for more information on the ultrasonic welder.)

### 2.3 Coating the Connection using Plastic Injection

Molding a coating (Figure 9) consists of melting plastic and injecting it into a mold around the wire connection. It is possible to injection-mold Teflon in ram-type equipment or in machinery with a reciprocating screw[28]. Examples of each method were researched and observed in use. Taking quantity and cost considerations into account, ram-type equipment was chosen as the best method for this prototype.

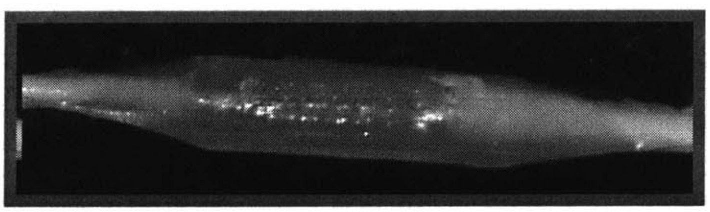

**Figure 9:** A molded coating around an ultrasonically welded wire connection. (This photograph was taken of a sample made later on into this project.)

#### 2.3.1 Ram Injection

Ram injection is the simpler method of injecting. The ram method involves pushing a plunger through a tube full of plastic and injecting it out into the mold. It has been suggested that this simple method is best designed by trial and error. There is little written information available beyond this; however a simple injecting unit for occasional repairs of nicked insulation is available, which provides a good starting point to begin design. The insulation

[27] STAPLA Ultrasonics Corporation, 375 Ballardvale Street, Wilmington, MA 01887. www.staplaultrasonics.com (January 2005)
[28] DuPont. Injection Molding Guide for Teflon FEP, Teflon PFA, Tefzel. p 7.

repair machine demonstrates that a simple injection machine is capable of melting and injecting Teflon.

Positive features of the ram method of injection include design simplicity resulting in lower cost and quicker prototyping than for screw injection. Negative aspects to overcome include little available design literature, as well as concern about the uniformity of the melt and consistency of quality from shot to shot. Initial concerns with the ram method were allayed because the method was able to deliver molten Teflon in the SCD machine. Ram machinery was chosen over screw injection because it is the most suitable for the low volume runs in this prototype and testing phase.

### 2.3.2 Applying aspects of Screw Injection to a Ram Injection Process

Understanding screw injection is still useful for designing a ram injection unit. Screw injection is the primary method of forming thermoplastics, particularly in large quantities. In this process, plastic material is loaded into a hopper. The plastic then proceeds into a heated injection unit. A reciprocating screw moves the plastic along the length of a heating cylinder, where the material is melted to a homogenized fluid state. When the softened plastic reaches the end of the chamber, it is forced at high pressures through a nozzle and into a mold. As soon as the material solidifies, the mold opens, and the press ejects the formed plastic.[29]

An abundance of literature discusses designing optimized screw injection units for various applications. DuPont provides information on the optimized screw injection design for Teflon FEP in their injection molding guide for Teflon. Specific geometry is recommended for the screw and cylinder, as well as machine materials, temperature ranges from 600°F to 700°F along the length of the cylinder, and "troubleshooting" help.

Though not applicable for this prototype, screw injection is recommended by Teflon's manufacturer because it produces a thoroughly plasticated, uniform melt as well as a more efficient transmission of pressure to the molten resin flowing into the mold. Other positive aspects include less resin hold-time and higher possible melt temperatures, with less thermal degradation.[30] Having design standards set and available, the uniformity of the melt, and control over the general process are also desirable characteristics of screw injection.

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[29] Thomas Regional Industrial Buying Guides Newsletter. "A Primer on Plastics Processing." www.ThomasRegional.com/newsletter.com (September 2004)

[30] DuPont. Injection Molding Guide for Teflon FEP, Teflon PFA, Tefzel. pp 7-9, 16.

However, purchasing an injection molding machine is very costly, making it inappropriate for low volume production. Other negative aspects of screw injection, resulting from the complicated design, include: the difficulty to machine parts which affects the ease, time, and cost to obtain them while prototyping, as well as the lack of ease in experimenting, cleaning, modifying, and repairing.

Literature primarily geared towards screw injection is still useful. Guidelines for screw injection can be adapted. Recommended screw machinery materials that prevent corrosion are applicable to ram materials as well. Also, recommended temperatures and pressures for screw injection can be interpreted as maximum temperatures and pressures for ram injection (a process that typically uses lower pressures and temperatures than screw injection). DuPont's injection molding guide includes applicable information such as the fact that degeneration of the plastic is both time and temperature dependent. The injection molding process, particularly screw injection though applicable to all methods of injection, is ideally suited to manufacturing mass produced parts of complex shapes requiring precise dimensions[31]. The steps in the injection molding cycle highlight the many steps and components of any injecting machine.

The Injection Molding Cycle[32]:

1. The mold clamps close.
2. The polymer is injected into the mold cavity.
3. A holding pressure is maintained to compensate for material shrinkage.
4. The screw turns, feeding the next shot to the front of the screw; this causes the screw to retract as the next shot is prepared.
5. Once the part is sufficiently cool, the mold opens and the part is ejected.

The main components of an injection molding machine are the plasticating unit, the clamp, and the mold. The purpose of these components is best seen by noting their roles in a screw injection molding cycle. The major tasks of the plasticating unit are to melt the polymer, allow the melt to accumulate in the screw chamber, eject the melt into the cavity, and maintain the holding pressure during cooling. Elements of the plasticating extruder,

[31] Osswald, Tim A. Polymer processing fundamentals. Cincinnati: Hanser/Gardner Publications, 1998. p 117.

[32] Osswald, Tim A. Polymer processing fundamentals. Cincinnati: Hanser/Gardner Publications, 1998. p 118.

applicable to ram injection, include: the hopper, screw (or ram), and heater bands. The task of the clamping unit in an injection molding machine is to open and close the mold at the beginning of each cycle, and to clamp the mold tightly to avoid flash during filling and holding. There are predominantly two types of clamping methods, mechanical and hydraulic. The mold distributes the polymer melt into and through the cavities, shapes the part, cools the melt, and ejects the finished product. Important elements of the mold include: the sprue (hole through which molten material is channeled into the mold) and runners (connect sprue to mold cavities[33]), gate, the mold cavity, the cooling system, and the ejector system.[34]

### 2.3.3 Obtaining details on Ram Injection through Observation and Experimentation

As mentioned previously, there is a machine (the "SCD Machine") employing ram injection (Figure 10). The machine was handmade many years previously and design and procedural documentation no longer exist. But by observing and experimenting with the SCD machine, it contributes to beginning my own design.

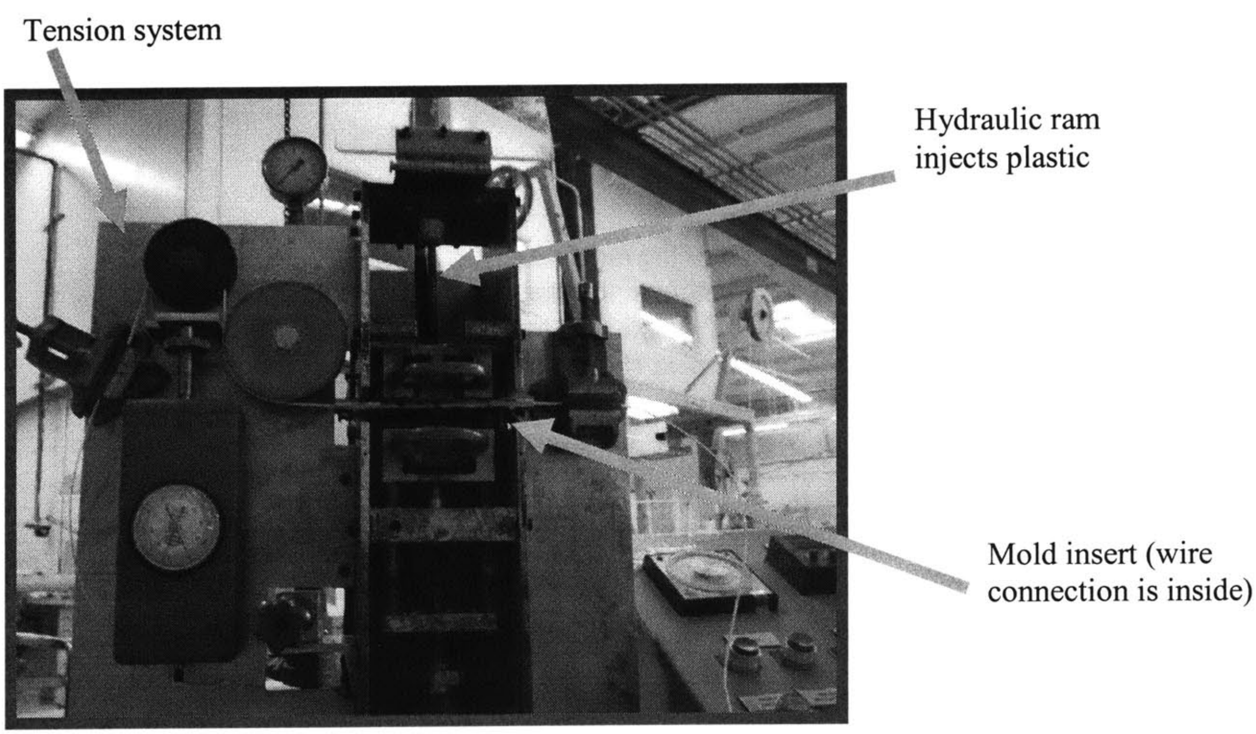


**Figure 10.** The "SCD Machine," an example of ram injection with Teflon.

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[33] http://www.what-is-injection-molding.com/Default.aspx?tabid=40 (January 2005).
[34] Osswald, Tim A. Polymer processing fundamentals. Cincinnati: Hanser/Gardner Publications, 1998. pp 126-28.

**Figure 11.** A "mold insert" used in the SCD machine. Custom mold inserts, that fit in the SCD machine, assist in the development of an optimal cavity profile (designating the coating's shape). (See Appendix B.4 for part drawings of mold inserts designed for this project.)

Studying the geometry and process is useful in understanding the main components of a ram injection unit and important issues, such as the significance of applying tension when heating the area around a wire. Mold inserts (Figure 11, Appendix B.4), that fit into the SCD machine, were designed with the shape of the inside "trough" modified to accommodate the two different size wires involved in this project. (The "trough" refers to the indentation running along the length of a mold insert, for the purpose of holding the wires in place.) Designing custom mold inserts allowed the cavity shape (the widened section of the trough which designates the plastic coating's shape) to be optimized for use in the thesis project's machine simultaneously with the development of the heating and injection components of this new machine.

### 2.4 Chapter Summary

Chapter 2 has given an overview of the project. The primary materials (wire and Teflon), have been discussed. An introduction to ultrasonic welding has been provided. And finally, background research and decisions on injection molding have been presented to illustrate where the design of a ram injection unit begins. Chapter 3 will proceed to illustrate how the designed splicing system is used.

## Chapter 3: Method

Chapter 3 discusses the method of fabricating and testing splices. Splices are made by first welding a wire connection with an ultrasonic welder. Then, the connection is coated by applying tension to the wire, applying a pressure cycle to Teflon pellets, and applying a heating the cycle to the system. The wire connections are tested in Tension Tests and Bend Tests. The coated splices are tested with Water Tests, Spark Tests, and Pressure-Temperature Well Tests.

### 3.1 Making Splices

An overview of the final splicing process will be presented along with the corresponding components. Then, the two steps of the process, welding a connection followed by coating it, will be discussed in more detail.

#### 3.1.1 Overview of Splicing

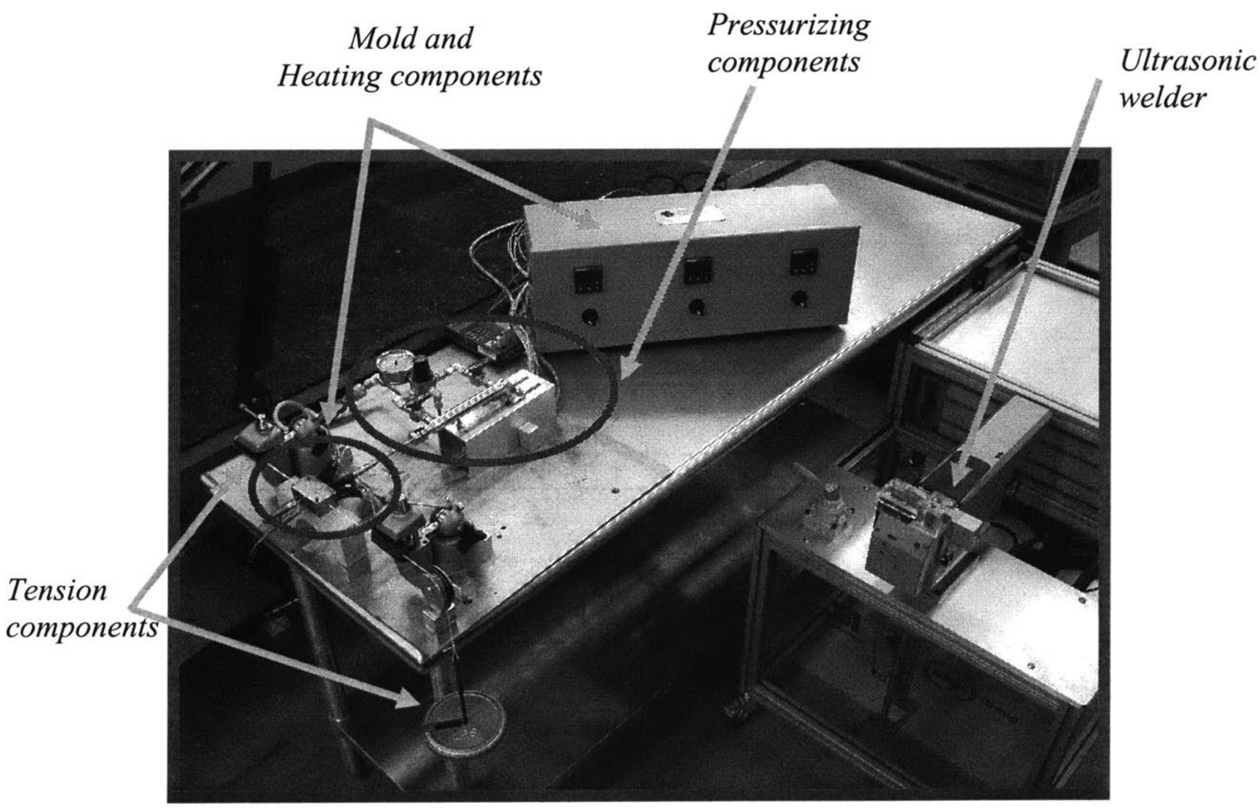



**Figure 12.** The main components involved in splicing: the welder, mold, tension components, pressurizing components, and heating components.

**Splicing Equipment:**

Splicing is accomplished using several **main components** (Figure 12):

1. The welder
2. The mold
3. The tension components
4. The pressurizing components
5. The heating components

Figure 13 should be consulted for a full list of parts involved in the splicing process.

**Parts list of Splicing Equipment:**

| FINAL EQUIPMENT | COMPONENT CATEGORY |
|---|---|
| **Materials:** | |
| Wires (20 and 26 AWG) | Materials |
| Teflon Pellets | Materials |
| **Connecting Wires:** | |
| Ultrasonic Welder | Welder |
| **Coating:** | |
| Monel Mold (top) | Mold |
| Monel Mold (bottom) | Mold |
| Monel Tube | Pressure component |
| Monel Plunger | Pressure component |
| Cylinder Platform | Pressure component |
| Block Supports | Pressure, tension, mold components |
| Insulator Support | Mold |
| Controller | Heating components |
| Cable Heater | Heating components |
| Cartridge Heaters (2 plugs w/ 4 heaters ea.) | Heating components |
| Thermocouples ("rod tipped") | Heating components |
| Thermocouples ("wire tipped") | Heating components |
| Air Filter | Heating component |
| Double-Acting Pneumatic Cylinder | Pressure components |
| Wire Clamps | Tension components |
| Weight Hanger & Weights | Tension components |

**Figure 13.** Parts primarily fall into five component categories: the welder, mold, tension, pressure and heating components or are materials that make up the splice itself. (See Appendix B.4 for part drawings and Appendices B.5 and B.6 for information on the design of the mold.)

**Using the Equipment:**

The **splicing process** (Figures 14 and 15) is carried out in the following steps:

1. Connect the wires with the ultrasonic welder
2. Coat the connection with the plastic injection system
   a. Place the wire in the mold
   b. Apply tension to the wires
   c. Melt the plastic
   d. Apply pressure and inject the plastic
   e. Cool
3. Remove the splice and prepare for the next cycle

Figure 15 should be consulted for full step-by-step instructions on the splicing process.

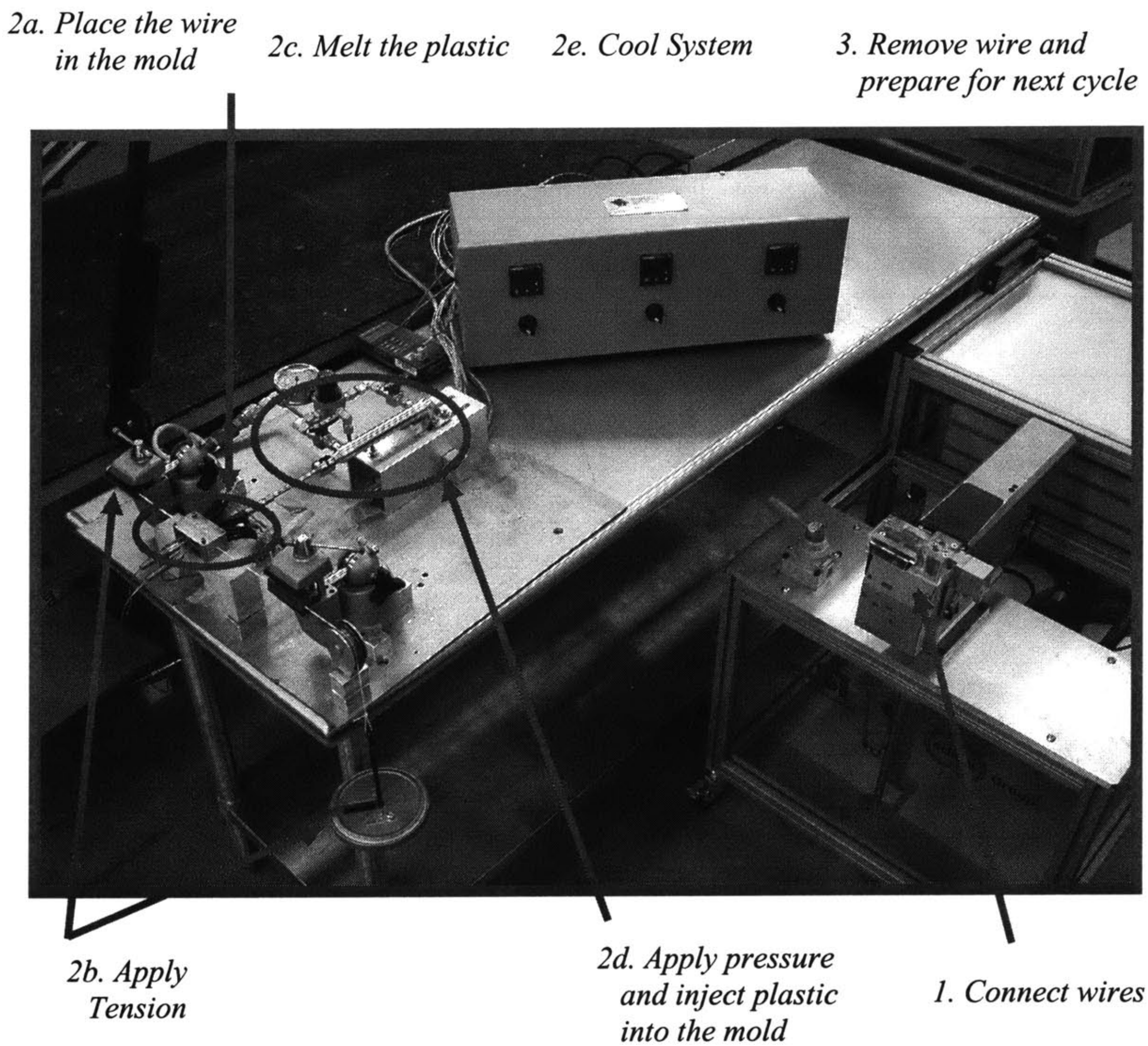



**Figure 14.** The splicing processes' steps and the corresponding location for each.

### Steps of the Splicing Process

| Step | Summary | If... | Then... |
|---|---|---|---|
| 1 | Prepare connection | Beginning | Strip ends and weld wires (large wire on bottom, "Splice 1" setting) |
| 2 | | | Wipe wire with towel if dust very visible |
| 3 | Prepare for heating | | Use back clamp to align splice in cavity |
| 4 | | | Straighten splice or wire if very off center |
| 5 | | | Fan on |
| 6 | | | Check that thermocouples are in place |
| 7 | | | Pressure: 20 psi |
| 8 | | | Tension: 2.5 lbs |
| 9 | Begin heating | | Heat change: ( --- , 200, 200) °F * |
| | | | Heat change: (200, --- , --- ) °F |
| 10 | Preheat | {B** or T**} > 175 F | Heat change: ( --- , 300, 300) °F |
| | | | Heat change: (300, --- , --- ) °F |
| 11 | | {B or T} > 275 F | Heat change: (450, 450, --- ) °F |
| | | | Pressure: 25 psi |
| 12 | Melt plastic | B > 425 F | Heat change: (500, 500, --- ) °F |
| 13 | | {Coil** or B} > 490 F | Heat change: (520, --- , --- ) °F |
| 14 | | -IF- settles at {Coil & B} < 500 & not injecting | Heat change: ( --- , 510, --- ) °F |
| 15 | Inject plastic | Begins to inject &/or {Coil & B} > 504 F | Pressure: 30 psi |
| 16 | Cool | Melted plastic visible | Heat off |
| | | | Pressure: 15 psi (range: 10-19 psi) |
| 17 | | -IF- pressure begins to drop | Turn up to 15 psi (10-19 psi range) (Do not let drop below 10 psi!) |
| 18 | Remove splice | {B & T} < 375 F | Tension off |
| | | | Unscrew clamping screws, open mold |
| 19 | | | Cut out splice & remove |
| 20 | Prepare for next cycle | | Cut out excess plastic & remove |
| 21 | | | If any plastic residue, use scraper to loosen it |
| 22 | | | Wipe cavity with paper towel & replace top mold |
| 23 | | | Remove plunger from tube (~40psi; begin with 300°F, increase by 50°F's, with a max of 500°F until comes out) |

* NOTE: **( # , #, # )** refers to changing the settings to the **(Coil Heater Zone, Bottom Heater Zone,** and/or **Top Heater Zone)**; **"---"** indicates that **no change of setting** is necessary in that step

** NOTE: **"B," "T,"** and **"Coil"** refer to the actual temperatures of the **Bottom Heater Zone, Top Heater Zone**, and **Coil** (or "tube") **Heater Zone** respectively

**Figure 15.** Step-by-step instructions for an operator to complete the splicing process.

### 3.1.2 Connecting the Wires

To begin the splicing process the wires' ends should be striped longer than 0.315 inches, with thermal wire strippers. Next, each stripped section is cut down to a length of 0.315 inches (+/-0.010 inches). (Special attention should be given so that the stripped section is not too long. This will prevent the creation of a "fringe" of misaligned wire tips, at the end of the weld, and prevent the risk of wire later protruding beyond the molded coating).

The ultrasonic welder, using the "Splice 1" setting, connects the two wires. Overlapped wires are placed (Figure 16) on the platform created by the sonotrode (Figure 8). The larger of the two wires is kept on the bottom to prevent over-welding. The foot pedal is used to actuate the welder. If no alarm sounds after the short welding process, the connection is complete (Figure 17). If the alarm sounds, the operator should redo the weld. If the alarm begins to sound more often than usual, recalibrate the weld-height (see Appendix B.3 for calibration instructions, as well as Appendices B.1 and B.2 for welder specifications and customizations).

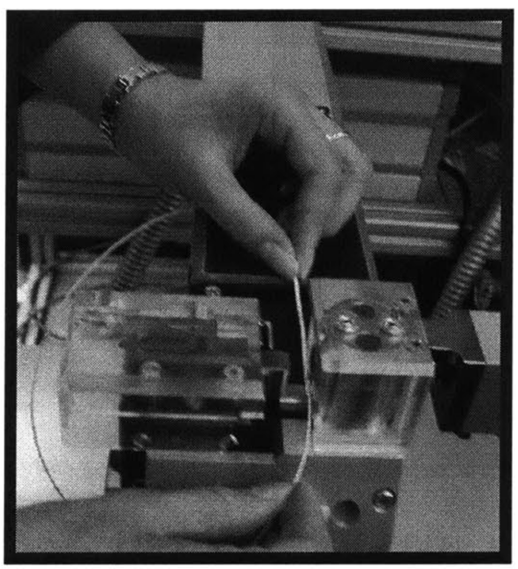


**Figure 16.** An ultrasonic welder will connect the two wires being held in place by the operator. The larger wire is placed on the bottom to prevent over-welding.

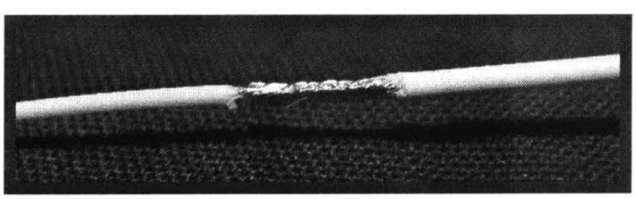


**Figure 17.** A wire connection done by an ultrasonic welder.

### 3.1.3 Coating the Connection

After the connection is made, it is placed in the mold to be coated. The wire is held in tension, and pressure and temperature cycles run to facilitate coating the wire connection. (See Appendices C.1, C.2, and C.3 for drawings of the splice and information on the development of the coating process.)

**Applying Tension to the Wires:**

After the wires are welded together, any significant amount of dust or particles that have collected on them should be wiped off with a dry paper towel. The connection and surrounding wires are then placed in the mold (Figure 18), noting that the "troughs" on each side of the mold's cavity are sized to correspond with the two different gauge wires.

The welded section should be centered in the mold cavity (the tension method secures it horizontally). The wire connection should be straightened by hand if it appears bent or off-center in the mold's cavity.

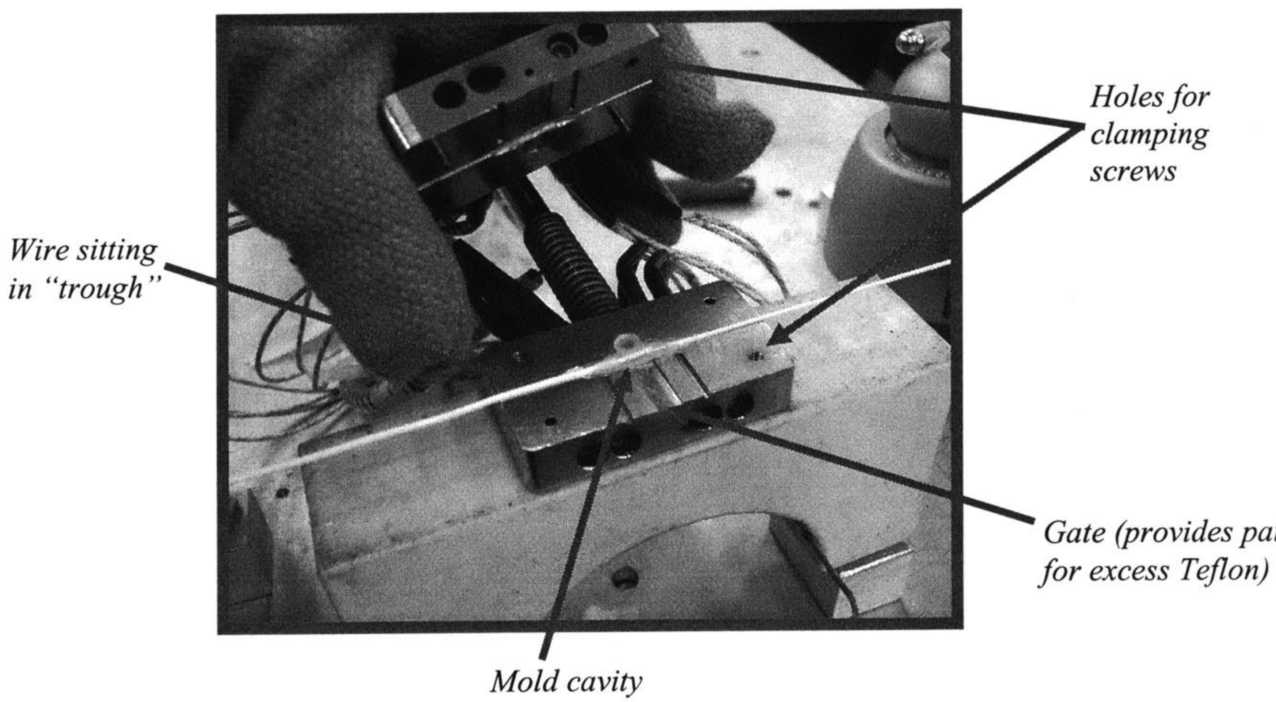



**Figure 18.** The connected wire is in the mold. The wires (white) are resting in the mold's troughs. The wire connection is centered over the cavity (widest section of the trough). After the cavity is filled, the gate provides a path for the excess Teflon.

Tension for alignment is applied using the "rear" clamp and weights (Figure 19). The "front" clamp is useful to temporarily aid in alignment. Foam or rubber pieces should always be placed between the clamp and the wire to distribute the clamping force and to prevent wire damage. Weights apply tension during the heating process to prevent off-centering of the wire connection in the mold cavity. (If insufficient tension is provided, the wire connection will be pushed to one side of the mold cavity by the Teflon melt. If the connection remains off-center in the cavity, the wire may not be fully coated on all sides, and thus the splice may not be properly insulated.) To apply the tension, weights are placed on a weight hanger, which hooks into a loop on the end of the smaller wire. (Note that the weight hanger and small aluminum piece around the hanger's rod weigh 0.50 lbs; thus for the desired total applied weight of 2.5 lbs, a 2 lb metal weight should be put onto the 0.5 lb weight hanger.)

Tension is applied before, during, and after heating to contribute to radial centering. The smallest wire is rated to withstand approximately 6 lbs of weight at room temperature. Note that the wire can withstand higher weights at room temperature than at elevated temperatures (Figure 29 and 30).

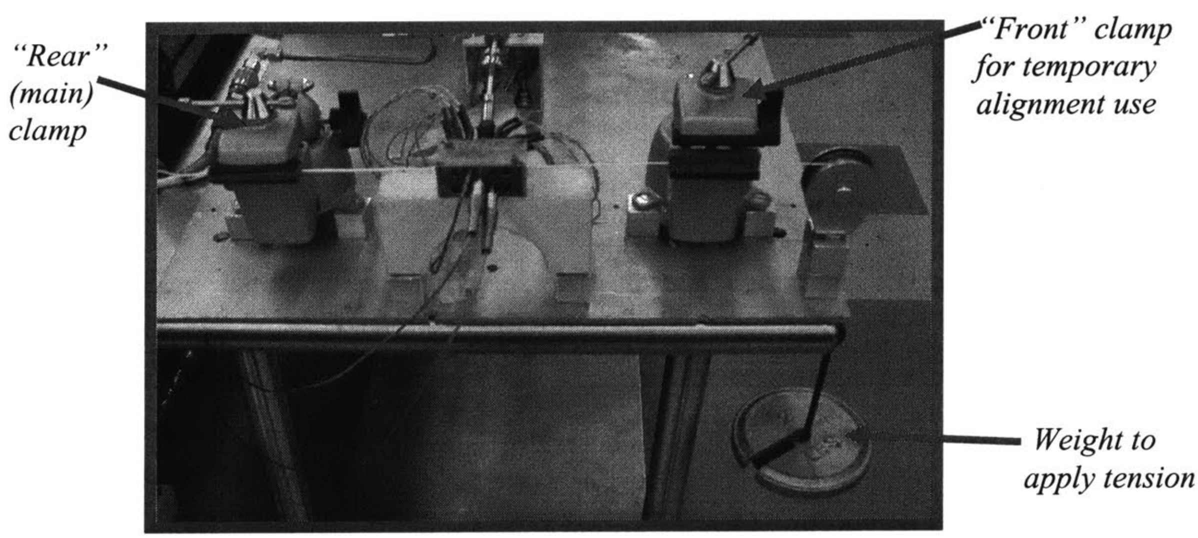



**Figure 19.** The tension system. The "rear" clamp is the main clamp that holds the larger (20 AWG) wire. The "front" clamp is temporarily used for alignment. The weights apply tension and allow for adjustment of the force applied to the wire.

Once the wire connection is aligned, the top piece of the mold is closed and screwed down onto the bottom piece of the mold (Figure 18). With the wire secured, the connection is prepared for the coating process. The mold is now ready to be heated and to have the molten plastic injected into the back of the mold, then up into the mold cavity. Once the mold is filled, excess plastic will flow out through the gate. The operator knows the cavity is sufficiently filled with plastic and is coating the connection when plastic becomes visible in the gate (Figure 18).

**Applying Pressure to the Plastic:**

Pressure is applied to the Teflon with a pneumatic cylinder. The double acting cylinder allows the plunger to push the Teflon from the heating tube into the mold during injection, as well as to retract afterwards. Two air valves are used to actuate the cylinder, and the gauge displays the pressure in the cylinder (as specified in the process steps in Figure 15).

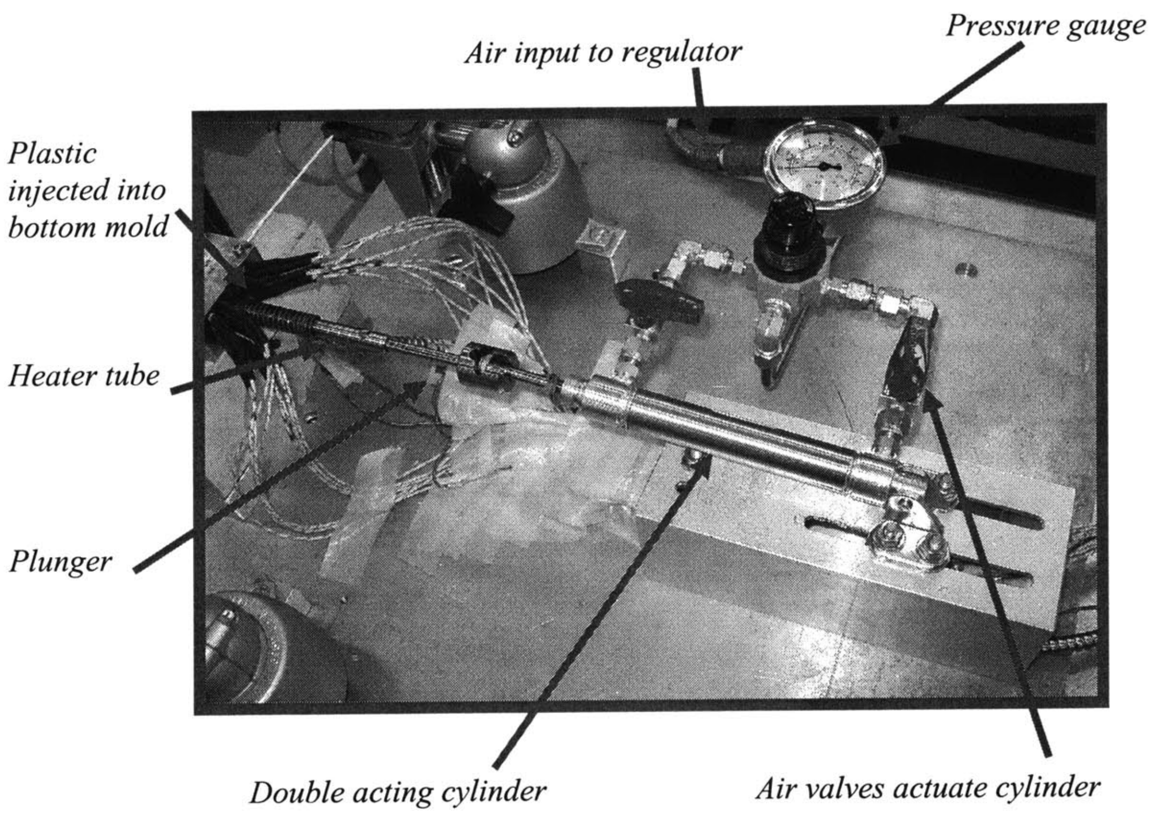



**Figure 20.** Pressure is applied to the Teflon pellets in the heater tube. The operator uses the valves and pressure gauge to actuate a double acting pneumatic cylinder. The cylinder pushes the plunger, which in turn applies pressure to the Teflon in the heating tube and eventually injects melted Teflon into the mold.

A pressure profile (Figures 21 and 15) corresponds to the temperature profile of the injecting unit. A pre-pressure (of 20 psi) is first applied to the cold system. As the Teflon begins to melt, the pressure is increased (to 25 psi). Once the plunger begins to move the Teflon towards the mold, the highest pressure in the cycle (30 psi) is briefly applied until the cavity is filled and melted plastic is visible at the gate. The heat is immediately turned off and a low post-pressure (15 psi) is maintained during cooling.

Each part of the pressure profile has a purpose. A pre-pressure is employed to make the process less skill sensitive. By applying a moderate pressure at the beginning, any operator delay or error later on in the process (i.e. at times of crucial temperature monitoring when demands on the operator are highest), is less likely to significantly affect the quality of the final splice. The lowest pressure possible that will still move the melt is desired. The profile steps up to higher pressures rather than going there directly. Over-pressurizing can push the wire connection against one of the cavity walls (Figure 22). To prevent gross off-centering of the splice, pressure should never exceed 30 psi with the current process. (It should be noted that higher pressures require higher tensions to achieve the same centering of the splice.) If pressure is not maintained during cooling, air bubbles may form in the cavity.

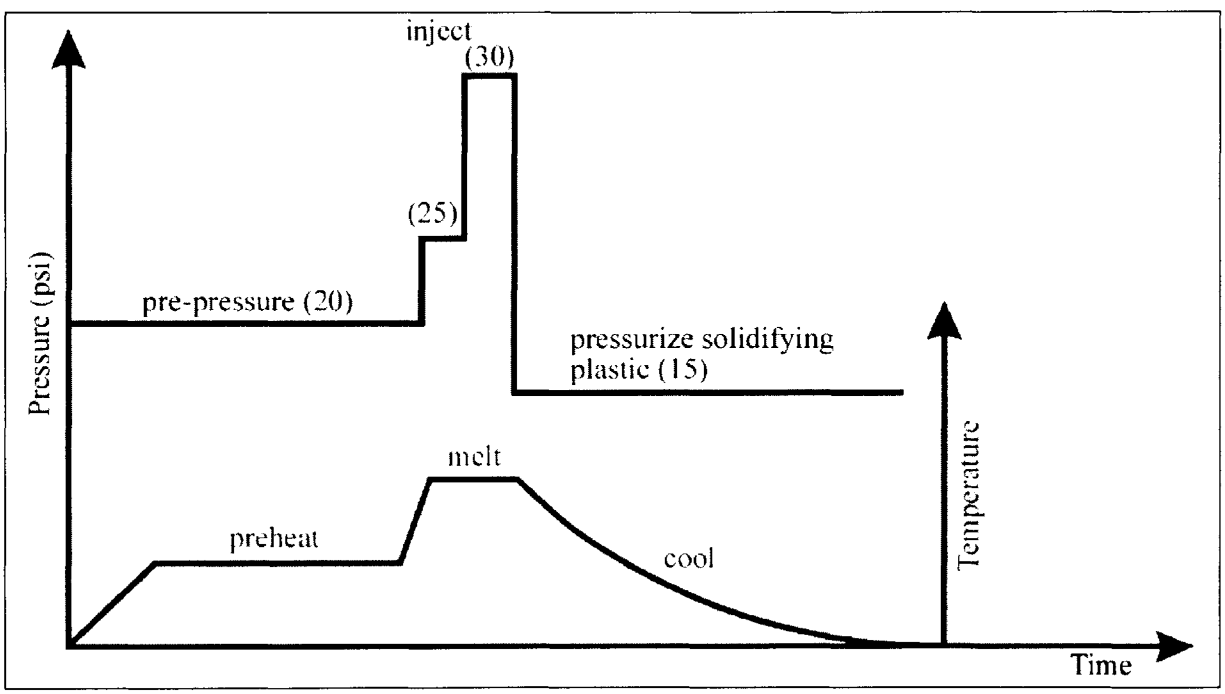



**Figure 21.** Pressure and Temperature Profiles.

(However, note that if bubbles exist in a splice, they may also be caused by overheating of the Teflon.) The plunger should be removed from the tube after the melt re-solidifies but while the tube is still warm; re-warming of the heater around the tube is often required.

**Heating:**

Heating is accomplished by setting the controller (Figure 23a) which directs three heating zones (Figure 23b). These zones are: the Top Mold Zone (consisting of the four cartridge heaters in the top half of the mold), the Bottom Mold Zone (consisting of the four cartridge heaters in the bottom half of the mold), and the Tube Zone (consisting of the coil heater around the heating tube, as seen in Figure 20). Thermocouples (Figure 23b) in each zone allow the controller to regulate the temperatures according to the settings entered by the operator. (Note that having the controller's thermocouples for the top and bottom heater zones in the mold itself, rather than directly on the heaters, make the system more controllable.)

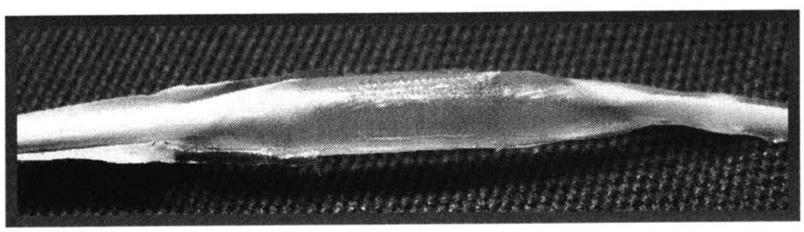
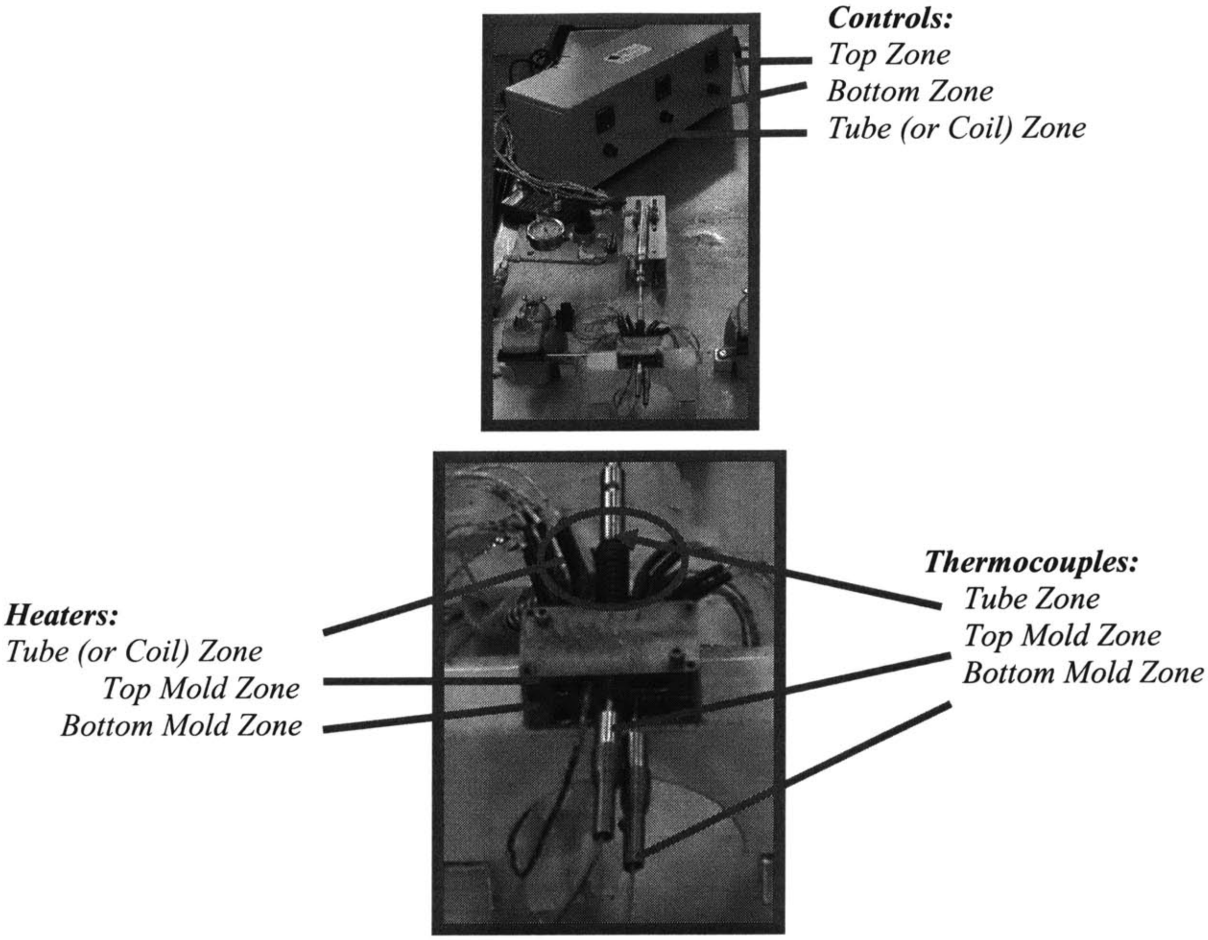


**Figure 22.** If the pressure is too high, significant off centering can occur and the coating will be of insufficient thickness to insulate the splice.

The heating profile (Figures 21 and 15) consists of: preheating the Teflon pellets, melting them, and then cooling the system. The heating profile works in conjunction with the pressure profile (Figures 21 and 15). Preheating (heating below the "upper service temperature" of 390°F) eliminates humidity while the pre-pressure is applied to the pellets. The Teflon is then melted (between 491°F and 509°F) and applied pressure forces it into the mold and around the wire connection. As soon as the cavity is filled and melted Teflon is visible in the gate, all heat is shut off and the Teflon coating solidifies around the connection. After the splice is taken out of the mold, the plunger is removed. This usually requires




**Figures 23a** and **23b.** The controller (23a) as well as the heater zones with their heaters and thermocouples (23b).

reheating the Tube Zone to between 300°F and 500°F, in order to soften the Teflon but not to melt or degrade it.

The heating profile (as specified in Figure 15) aims to quickly coat the splice while keeping the Teflon-melt's temperature as low as possible. The heating profile was determined from a combination of experiments done around the known "upper service temperature" (390°F) and the melting range (491°F - 509°F) of Teflon. Keeping the melt at the lowest temperature possible, without re-solidifying and trapping air pockets, is desired to preserve the integrity of the wires' insulation. The insulation will bubble if it gets too hot for too long. Having both plastics (the Teflon pellets and the wire insulation) composed of Teflon FEP, aims at obtaining complete bonding between the two; while the slightly different melting characteristics of the two different FEPs allow heating of the Teflon pellets without damaging the wire insulation.

Note that bubbles will appear when temperatures are either too high or too low. Though such bubbles look similar, they stem from very different issues. If the melt is too cold, escaping air during pressurizing is trapped. If the melt is too hot, gas pockets form and cause the coating or wires' insulation to be damaged (Figure 24). Hotspots, as opposed to trapped air, can be detected by observing that the bubbles are localized near heaters.

**Figure 24.** Gas bubbles form if the melt is too hot (example: hot temperatures cause insulation damage and bubbles in the cavity).

Desired temperatures are maintained by controlling the three heating zones separately and managing overshoot. The plastic in the heater tube (Figure 20) is heated thoroughly, while the bottom mold is set to be slightly cooler, and the top mold is set cooler still. This helps achieve a balance between melting the plastic pellets sufficiently to flow and not trapping bubbles or damaging the wires' insulation with heat. The steps of the heating profile have also been designed to manage temperature overshoot. The heat is elevated in steps to prevent unacceptable amounts of overshoot. The heating profile is designed to leave room for expected overshoot while still meeting basic heating objectives. An example of this is evident in the preheat setting of 300°F, when 392°F is actually the maximum allowable preheat temperature.

After the heating settings have been carried out, the mold temperature cools to under 375°F and the mold is opened. The splice (Figure 25) is cut out; here a razor blade is useful. Excess plastic is also removed, using a plastic scraper as necessary, and the mold is wiped with a paper towel. Finally the top half of the mold is replaced to keep the mold clean. (Additionally, the plunger may also be examined periodically for plastic buildup when the plunger is still slightly warm. Any thin film of buildup may be scraped off effectively using one's fingernail.) After the plunger is removed from the heating tube, the equipment is ready for the next cycle.

**Figure 25.** A finished splice (the smaller wire, 26 AWG, is shown on the left and the larger wire, 20 AWG, is shown on the right).

### 3.2 Testing Splices

Splices are tested. First welded connections are tested with tension and bend tests for robustness. Coated splices are then tested for insulative properties at both ambient and downhole temperatures and pressures. Coatings are investigated with Water Tests, Spark Tests, and Temperature-Pressure Well Tests.

#### 3.2.1 Testing Welded Connections:

**Tension Tests**

Welded connections undergo a tension, or "pull," test to determine the force they will fail at when put in tension at room temperature. Also, any unexpected break of the wire at elevated temperatures during the coating process is recorded.

**Bend Tests:**

Some bending can occur with handling of the splice during the welding and coating processes. Bend Tests investigated if bending the welds during would weaken the connection. If bending was found to cause adverse affects, special handling in manufacturing could be specified.

Welded connections are flexed in "Bend Tests." Each "flex" consists of taking a straight connection (at position 0 degrees), then bending it +90 degrees and -90 degrees from its original position. The bends center at the weakest part of the connection, where the smaller (26 AWG) of the two wires transitions into the weld. Each flex takes approximately 2 seconds to complete. After a given number of flexes (0, 1, 2, 3, or 4), connections undergo pull tests.

### 3.2.2 Testing Coated Splices

**Water Tests:**

"Water Tests" investigate the integrity of the insulative coatings in fluid at ambient temperatures and pressures, during the prototyping process. In a Water Test, the splice is submerged in a water bath (in a metal tub), while the loose ends of the wire are kept out of the water. A megohmmeter applies 500 Volts across one of the wire ends to the metal tub holding the water. Thus, a reading of "OL," or overload, implies that the resistance between the wire and the water is very high (greater than 4.9 GΩ). High resistance is desired and with the "OL" reading the splice passes the Water Test. If significantly lower resistance is detected, this means the coating is not properly insulating the conductor.

Water Tests are preliminary tests, performed before splices undergo a Temperature-Pressure Well Test. Water Tests are useful during the development phase of the coating process, but are not a testing option for final manufactured splices because the test requires the two wire-ends to be free, and in the actual tool the spliced wires will form a closed loop of wire.

**Spark Tests:**

"Spark Tests" also investigate the integrity of the insulative coating at ambient temperatures and pressures, only this time in air. The coated portion of the wire is passed through the metal bead chains of a spark-tester (Figure 26) with 2,000 Volts passing across them, for 1 minute. If any section of the insulation is too thin or absent all together, a hole will burn through the coating (or be enlarged) in that location. The spark-tester will indicate any such problem, and the hole will also be visually recognizable.

Spark Tests are useful both in the development phase of splices, as well as during manufacturing. Wires forming a closed loop of conductor, like those in the final downhole tool that splices are used in, can be tested with a spark-tester.

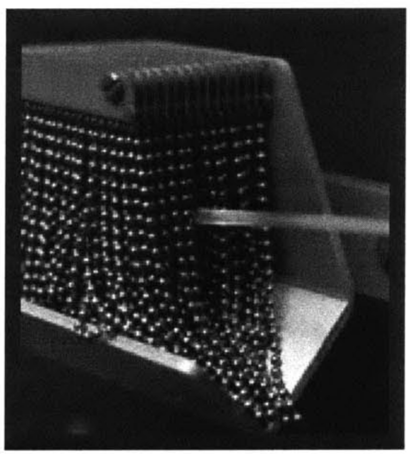


**Figure 26.** A spark-tester. The wire connection is passed through the metal beads of the spark-tester which detects any holes or particularly thin sections of insulation.

**Pressure-Temperature Well Tests:**

Pressure-Temperature Well Tests investigate the integrity of the insulative coating in an environment simulating an oil well, where a splice may be surrounded by fluid at high temperatures and pressures. This is the most demanding test a splice can undergo and is as harsh, or more so, than the actual environment in which the splice will be used. (Ideally fluid would not be able to flow through the potting material surrounding the splice when it is in the downhole tool, but such an occurrence is possible, and so is considered in this rigorous test.)

In a Pressure-Temperature Well Test, multiple splices are strung together, submerged in water (Figure 27), then cycled through various temperature and pressure settings (Figure

28). A test proceeds as follows: First the ambient temperature of 25°C (77°F) is held. Meanwhile the well-chamber, that the splices are in, is brought from the low pressure of 90 psi, to 10,000 psi, followed by 20,000 psi, then back down to a low pressure of 2,000 psi. Next, the temperature is raised to 150°C (302°F) and the pressure again steps up to 10,000 psi, followed by 20,000 psi, then back down to the ambient pressure of 14.7 psi. Throughout the course of the test, resistance measurements are taken while passing a 500 Volt charge across each loop's end and the water in the well. This determines whether the coating is insulating the conductor from the environment (in which case a very high resistance will be detected, over 4.9 $G\Omega$, and a reading of "OL," or overload, will be displayed on the meter), or if the fluid is able to reach the conductor and short the wire loop to the water (in which case a much lower resistance will be detected by the meter).

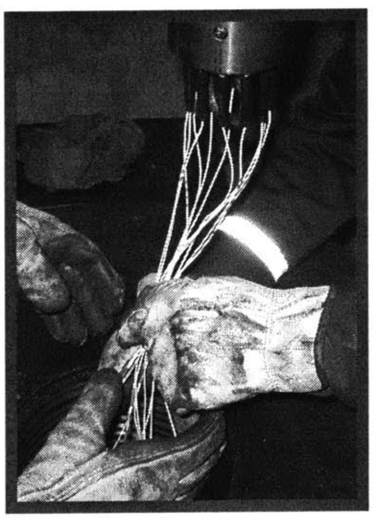


**Figure 27.** Preparing a Pressure-Temperature Well Test. Loops of wire, with multiple splices along them, are placed into the pressure-well to determine the integrity of the splices submerged in fluid at the high temperatures and pressures of an oil well.

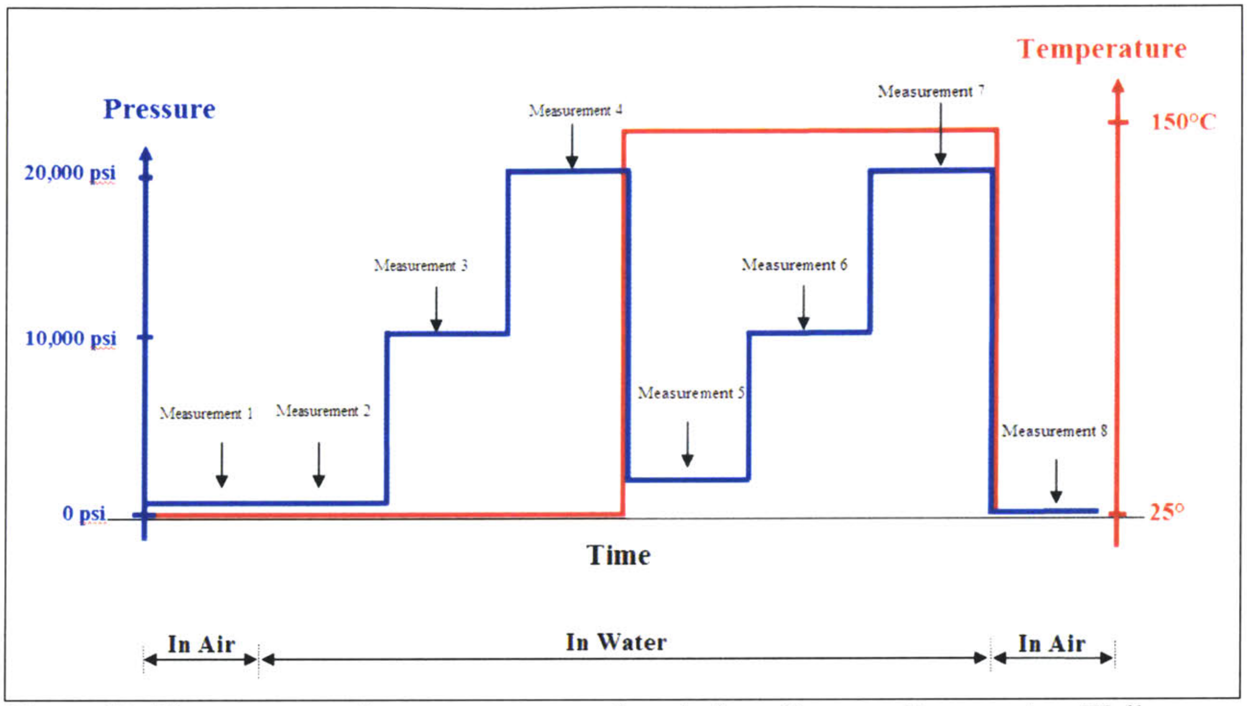



**Figure 28.** The pressure and temperature over time during a Pressure-Temperature Well Test. Resistance measurement are made after each environmental change (changes include air or water surrounding the splice, as well as pressure or temperature increases and decreases). The measurements determine if the Teflon coating continues to insulate the wire connection after each environmental change.

<u>**Chapter 4: Results**</u>

The following chapter contains a summary of the test results. Welded connections were tested for robustness with Tension Tests and Bend Tests. Observations on the coating process where made and coated splices were tested for their ability to insulate the welded connection with Water Tests, Spark Tests, and Pressure-Temperature Well Tests. (For more details on individual trials, refer to Appendix C.4.)

## 4.1 Testing Welded Connections

### Tension Tests:

At ambient temperature, the wire broke with approximately 9.0 lbs of weight applied (with a standard deviation of 0.4 lbs). This average is based on 50 tests[35]. Breakage occurred at the transition between the 26 AWG wire and the weld. The expected failure weight, given the manufacture's strength rating of the wire, is 7.88 lbs (see Appendix C.4 for the calculation).

| | average (lbs) | standard dev. (lbs) |
|---|---|---|
| Experimental breaking weight: | 9.0 | 0.4 |
| Expected breaking weight: | 7.88 | N/A |

Observations were made concerning the tension the wire can withstand at elevated temperatures. During the coating process, the wire broke in both cases where the actual temperature (not the set-temperature) exceeded 700°F. (This took place when 2 and 5 lbs were applied.) Given a chart of copper's strength vs. temperature (Figure 30), the wire is expected to fail at approximately 680°F.

### Bend Tests:

Bend Tests, as described in section 3.2.1, where performed by flexing wire connections 0, 1, 2, 3 or 4 times; then a tension test was done on each flexed wire connection

[35] As recorded at STAPLA Ultrasonics Corporation, 375 Ballardvale Street, Wilmington, MA 01887.

to see if bending had an affect on strength. Three trials where performed for each number of flexes.[36]

Breaking Weight for each group of Bend Tests:

| | average (lbs) | standard dev. (lbs) |
|---|---|---|
| 0 Flexes | 8.0 | 0.2 |
| 1 Flex | 8.0 | 0.7 |
| 2 Flexes | 8.9 | 0.4 |
| 3 Flexes | 10.1 | 2.1 |
| 4 Flexes | 8.7 | 0.4 |

## 4.2 Testing Coated Splices

**Observations on the Coating Process—Skill Sensitivity:**

When the one-page chart of directions (Figure 15) was given to an operator unfamiliar with the machine, splices were made that were visually comparable to those done by an operator familiar with the system.

**Water Tests (500 Volts):**

All connections passed. All meter readings were "overload", which means the resistance between the wire and water was very high, greater 4.9 GΩ which is greater than the meter can measure. (If any readings had shown lower resistance the integrity of the insulative coating, in water and at ambient temperature and pressure, would have been in question.)

**Spark Tests (2,000 Volts):**

All connections passed. No holes in the insulation or very thin areas of insulation were detected by the spark tester machine. (If any holes or thin areas had been present, the machine would have burned those areas into visually larger holes and would have indicated with an alarm.)

[36] As recorded at STAPLA Ultrasonics Corporation, 375 Ballardvale Street, Wilmington, MA 01887.

**Pressure-Temperature Well Tests (500 Volts):**

Resistance measurements where made in the Pressure-Temperature Well Tests after each environmental change (e.g. an increases or decreases in the temperature or pressure around the splices). A "pass" implies a resistance measurement of "overload," where the resistance is over 4.9 GΩ and higher than the meter can detect. Such a reading means that the splice's coating is properly insulating the wire connection from its environment. A "low" measurement means that the resistance between the conductor and its environment is lower than 4.9 GΩ and that the coating is not properly insulating the wire connection. A measurement of "both" signifies that the megohmmeter gave two different readings, and those two readings are listed in the table in parentheses. (Multiple readings at the same measurement point are not expected and may indicate flaws in test set-up, such as a loose connection on one end of the string of splices.)

The measurements from the first pressure-temperature well session were discarded because of a combination of megohmmeter malfunction and technician error. The second and third test session measurements were retained. In Test Session II, cable 2A did not pass at all measurement points in the test, but cables 2B, 2C, and 2D did. In Test Session II, none of the cables passed at all measurement points in the test. A variety of results were found at the initial low temperature, none of the cables passed at high temperature, but all cables passed at the final combination of low temperature and pressure.

Test Session II:

| | low temp. (69°F) | | | high temp. (302°F) | | | lower temp. (150°F) |
|---|---|---|---|---|---|---|---|
| | 14.7 psi | 10,000 psi | 20,000 psi | 2,000 psi | 10,000 psi | 20,000 psi | 14.7 psi |
| Cable 2A | pass | pass | BOTH (pass/300KΩ) | LOW (350KΩ) | LOW | LOW (150KΩ/pass) | pass |
| Cable 2B | pass | pass | pass | pass | pass | pass | pass |
| Cable 2C | pass | pass | pass | pass | pass | pass | pass |
| Cable 2D | pass | pass | pass | pass | pass | pass | pass |

Test Session III:

| | low temp. (69°F) | | | high temp. (302°F) | | | lower temp. (150°F) |
|---|---|---|---|---|---|---|---|
| | 14.7 psi | 10,000 psi | 20,000 psi | 2,000 psi | 10,000 psi | 20,000 psi | 14.7 psi |
| Cable 3A | Pass | LOW | pass | LOW | LOW | LOW | pass |
| Cable 3B | Pass | pass | pass | LOW | LOW | LOW | pass |
| Cable 3C | LOW | LOW | LOW | LOW | LOW | LOW | pass |

## Chapter 5: Discussion

### 5.1 Testing Welded Connections:

**Tension Tests**

Tension tests at room temperature showed better strength than predicted. On average, connections broke at 9.0 lbs in experiments rather than 7.9 lbs as predicted.

Breakage of the wire (Figure 29) during the development of the splicing process is attributed to high temperatures affecting the strength of the copper conductor. Of the two tests that exceeded 700°F, the wire broke in both cases. The results (strength at corresponding temperature) are directly supported by strength data available for copper from the American Society of Metals (see Figure 30). Copper loses over 30% of its tensile strength between room temperature and Teflon's melt temperature.

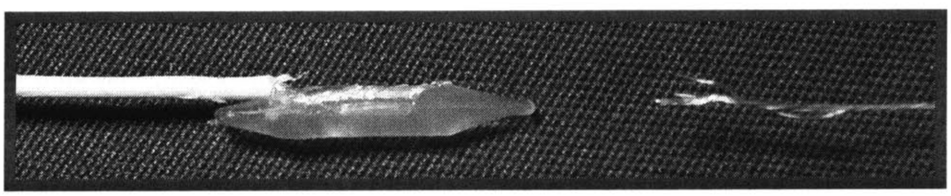


**Figure 29** High tension can cause the wire to break when brought to elevated temperatures.

**Bend Tests:**

The results of the Bend Tests showed no change or a slight increase in strength data as the number of flexes was increased. The increase in the strength data was not expected, but is welcomed. This increase is slight and most likely due to variation between individual wire connections and the small number of samples tested. The data is interpreted to show that no significant adverse change in strength is observed after flexing the edge of the wire connection. A decrease in strength would have signified that bending during handling and manufacturing could adversely affect the splice, but with no decrease in strength, bending during handling is dismissed as a manufacturing concern.

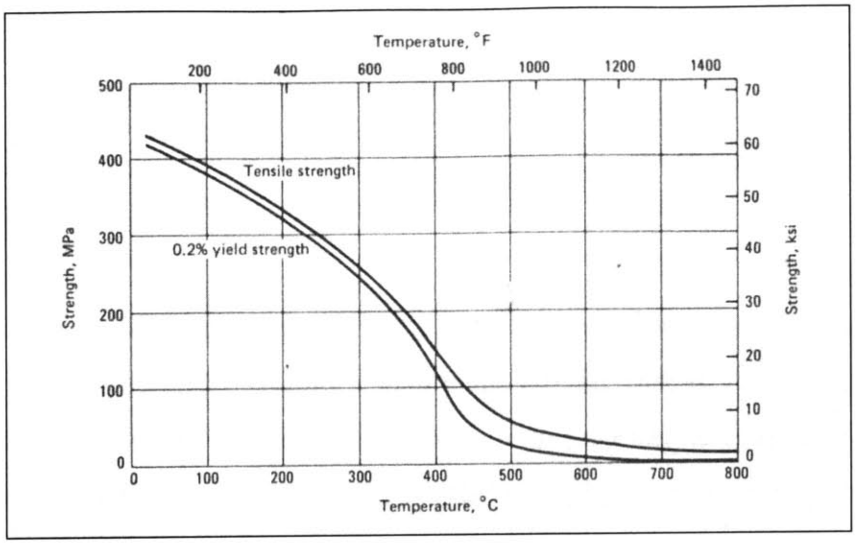



**Figure 30** [37]**.** Strength vs. Temperature data for copper [38]. This information closely corresponds with Tension Test results, at both ambient temperature and 700°F, and explains why wires broke when temperatures exceeded 700°F.

## 5.2 Testing Coated Splices

### Observations on the Coating Process—Skill Sensitivity:

When one-page directions for splicing were given to a person who had not used the molding system before, they could produce a splice comparable to those produced by a skilled operator. Ultimately however, the success of making the splicing process less skill sensitive is dependent upon verifying that the process produces splices that are hermetic in a downhole environment.

### Water Tests, Spark Tests and Temperature-Pressure Well Tests:

All splices passed the Water Test and Spark Test, but they did not all pass the Pressure-Temperature Well Test.

In Session II of the Pressure-Temperature Well Test, three of the four cables (chain of splices) passed the full test. This indicates that the coating method is capable of producing good splices (that can perform at up to 300°F and 20,000 psi as desired), but quality is not currently assured. The cable that did not pass at all measurement points in the test, passed at

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[37] American Society for Metals. Metals Handbook Ninth Edition: Properties and selection--nonferrous alloys and pure metals. Metals Park, Ohio: American Society for Metals, 1979. p 277.
[38] Data for: copper C10100 or C10200 rod, 1180 temper

low temperatures and pressures (up to 150°F at the ambient pressure of 14.7 psi). In addition to passing during the original ambient conditions, the cable also passed when it came back to the original temperature and pressure at the end of the testing cycle. Thus, its past history did not affect its later performance. Here, the cable's failure appears to be pressure related.

In session III of the Pressure-Temperature Well Test, the majority of the measurements at lower temperatures showed passing results; however, none of the cables performed properly at high temperature. This trend is most apparent with Cable 3B, where the cable's splices all worked at low temperatures (regardless of applied pressure), did not work at high temperature, but then did again work when brought back down to a low temperature. Cable 3A shows similar results, with the notable exception of the test at 10,000 psi not passing (thus pressure is not ruled out as a contributing cause of failure). Cable 3C results appear the most inconsistent of all cables tested, since the cable did not pass until after a full temperature-pressure cycle was completed.

Though not all measurements are fully understood, three of the seven cables passed at all measurement points in the test, and all splices tested passed in at least one measurement point during the test cycle. This is encouraging and thus the splicing method employing injection molding shows promise and is worthwhile developing further.

Possible causes of inconsistent results or failure that appeared include quality control issues concerning the coating process and also equipment malfunction. (As noted in Chapter 4, a combination of a megohmmeter malfunction and technician error during test setup was the reason Session I test results are not valid for analysis.) Additionally, Spark Tests may have induced problems since they were performed at 2,000 Volts, and the 26 AWG wire is only rated up to 600 Volts. Further testing should be done to establish more definitive trends and to rule out the possibility of test equipment problems. These investigations will enable the splices' most critical failure modes to be better understood so the splicing method can be further refined and evaluated.

# Chapter 6: Conclusions and Recommendations

## 6.1 Conclusions

### 6.1.1 Welding

Ultrasonic welding is an excellent method for connecting the wires for the given application. The process connects wires rapidly, reliably and with quality independent of the operators' skills. The connection is compact, predictable in shape as well as size, and does not weaken the wire (including its bending or pull strength). Although the welding machine incurs a significant expense when purchased, once acquired, numerous splices may be made at minimal additional cost. The primary maintenance consists of calibrating the machine (no more than monthly). The ultrasonic welder is ready to be implemented into the manufacturing process of the downhole tool currently being developed. Ultrasonic welding, and in particular the customized machine developed during this project, is recommended as the means for connecting wires in the downhole tool's splices.

### 6.1.2 Injection Molded Coating

**Performance of the Coating:**

The tests currently show that nearly all splices made with the current coating method are hermetic at ambient temperatures and pressures. Also, it is possible to produce a suitable coating, using injection molding techniques, which will remain hermetic up to the desired 300°F of temperature and 20,000 psi of pressure. Tests show that, though the current method will work, it is not yet reliable and must be further improved. Concerns with splice performance relate to both elevated temperatures and pressures, with more emphasis on pressure. More tests are needed to create a larger body of viable data.

**Coating Equipment:**

The current process requires less technical expertise than previous methods to produce a typical splice. The existing equipment is a prototype version of injection molding manufacturing equipment. The current system is useful to refine the process parameters of injecting (e.g. experiments with adjustments of the temperature profile are able to be performed) and as a base to build upon for a next generation prototype leading to a final manufacturing device.

**Testing Methods:**

Water Tests, Spark Tests, and Temperature-Pressure Well Tests all have their place in the development of the splicing method and quality assurance as well as quality control in manufacturing.

Spark Tests are useful for detecting thin coatings. Of all three tests, Spark Tests are the only test that can be performed directly on a manufactured splice, once it is integrated into the downhole tool.

Water Tests are simple and useful, particularly directly before a Temperature-Pressure Well Test. A Water Test simulates the first part of the Temperature-Pressure Well Test and can alert the investigator to a problem before proceeding to the more expensive and involved Temperature-Pressure Well Test. Fluid seepage along the length of the wire (under the insulative coating and through to the splice), during ambient conditions, may be detected with this test. Further investigation of this failure mode, along the length of the wire, and the extent to which a Water Test will detect problems should be pursued.

Temperature-Pressure Well Tests are the best way to test a splice for performance in the hostile environment of an oil well. This is the most expensive, time intensive, and involved process of the three types of testing. Temperature-Pressure Well Tests will be extremely useful for further investigation of why some splices made with the current method do not perform suitably in downhole conditions. This testing method can also assist in the further refinement of the coating process and to confirm if and when suitable splices are being reliably produced.

## 6.2 Recommendations

### 6.2.1 Welding

Though the welder is ready for manufacturing splices, a future investigation should examine why the alarm triggers so often on the "Splice 1" setting (see Appendix B.3). This setting has very tight tolerances, so investigating the alarm rate may lead to requiring less stringent tolerance settings. The cart is also ready for manufacturing use, but may be changed once manufacturing commences.

### 6.2.2 Coating

**The Coating Method:**

More extensive testing and further refinement of the process parameters will lead to better, more consistent splices. At that point, improvements to the injection molding system should focus on minimizing the time required for the process. Improvements to individual components of the injection system could include: the modification of the mold (so plastic is injected from above rather than from the side), the addition of an automatic pellet feed, the development of a more sophisticated method for removing the splice from the mold, automation of the control for the pressure and heating profiles (including feedback), and the employment of a force meter in the tension system. The use of Teflon in a powder form, as opposed to the pellet form used in this thesis, could also be investigated.

Additionally, an automated shrink-tube method should be compared to a plastic injection method before the final decision for the manufacturing method is made.

**Testing Methods:**

Spark Tests:

Small, portable spark-testers are available (see Appendix C.4). Also, the most appropriate voltage to apply to the 26 AWG wire should be investigated.

Water Tests:

Splices should continue to undergo a Water Test prior to the Temperature-Pressure Well Tests. This may detect problems early, so resources are not wasted on unnecessary Temperature-Pressure Well Tests.

Temperature–Pressure Well Tests:

Pressure and temperature testing must be performed to further investigate the integrity of splices and the possible failure modes, so splices can be properly produced and evaluated. Inconsistencies in the Temperature-Pressure Well Tests must be better understood. Additional tests may include coloring the water in the pressure well to investigate the bonding between the wires' insulation and the cavity coating.

If bonding problems are expected or found from such tests, the next step would be to proceed with modifying the coating process. This may begin with making small increases (such as in 5°F increments) to the maximum set-temperature of the injection molding heating profile.

Refer to Appendices B.5, B.6, C.2, and C.3 for further explanations and recommendations.

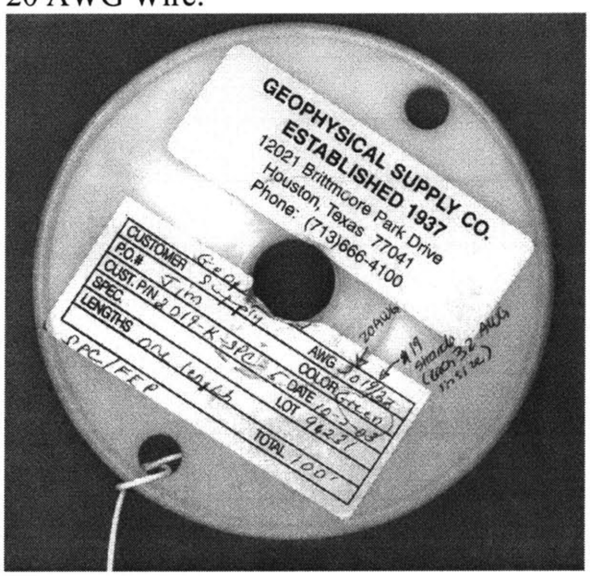
<u>**Appendices**</u>

## Appendix A: Materials

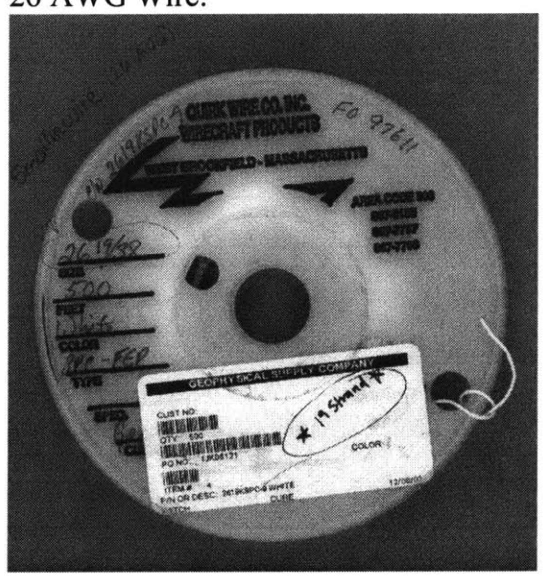
### A.1 Wires

Initially, the larger wire (20 AWG) was designated for this project. The smaller wire (26 AWG), consisting of 19 strands, was later chosen. Having 19 smaller strands, rather than 7 larger ones, is optimal in the welding process and electrically superior (for its use in the downhole tool).

20 AWG Wire:




26 AWG Wire:



## A.2 Wire and Cable Specification

**100054857- WCT-5135**

10/1

Quirk Wire Co. Inc

WIRECRAFT® PRODUCTS

Route 9, P.O. Box 1180
West Brookfield, MA 01585

(508) 867-3155
(508) 867-7767
(508) 867-7768

Fax (508) 867-5132

*Wire and Cable Specification*

COMMERCIAL SPEC: WCT-5135

GENERAL DESCRIPTION: 2 CONDUCTOR ELECTRONIC CABLE

INNER CONDUCTORS: 20 19/32 SILVER PLATED COPPER
40 MICRO INCHES SILVER PLATING MINIMUM

O.D. TOLERANCE: .037 - .040 — conductor O.D.

PRIMARY DIELECTRIC INSULATION: EXTRUDED FEP TEFLON

COLORS: WHITE, GREEN — white & Green (from WPP, steel covering)

O.D. TOLERANCE: .054 - .062 — insulator's OD

SECONDARY DIELECTRIC INSULATION: NOT REQUIRED

O.D. TOLERANCE: N/A

CABLING: TWIST 2 CONDUCTORS 1¼" LAY

JACKET DESCRIPTION: .010 WALL NOMINAL EXTRUDED FEP TEFLON
COLOR ORANGE

SHIELD DESCRIPTION: 36 AWG TYPE 304 STAINLESS STEEL, BRAIDED
85% - 90% COVERAGE

FINAL DIAMETER: .164 MAXIMUM

ADDITIONAL NOTES, IF ANY:
SPARK TEST INNERS - 4600 VAC, DIELECTRIC TEST 3000 VAC
CAPACITANCE 15.30 PF/FT @ .062, IMPEDANCE 96.22 OHMS
17.99 PF/FT @ .054, IMPEDANCE 81.33 OHMS

CEOWCT5135

ISO 9002
Certificate No. A1030

MANUFACTURERS OF HIGH TEMPERATURE WIRE & CABLE

### A.3 Teflon Pellets

The plastic pellets melt and mingle with the wires' insulation. Both the pellets and wire insulation are FEP fluoropolymer resins, but specifically the pellets are Teflon FEP 100-J (the J stands for the manufacturing location) and the insulation is FEP NP-101. They are similar, but not identical and are made by different manufactures. The Teflon FEPs were assumed to be similar enough to ensure compatibility between the two in bonding, but this can be further investigated.

## A.4 Teflon FEP 100: Technical Information

# TEFLON® FEP 100

Fluorocarbon Resin

## Technical Information

### Description

TEFLON® FEP 100 fluorocarbon resin is a melt-processible fluorocarbon resin suitable for extrusion as a primary coating onto most gauge wires (AWG #12 and smaller) for twisted-pair constructions and for limited jacketing applications.

As shown in **Table 1**, this resin provides the electrical and mechanical properties needed for low-voltage applications. TEFLON FEP 100 has a melt flow rate that is between TEFLON 3100 and TEFLON FEP 140. This permits a good combination of extrusion speed and stress crack resistance, making TEFLON FEP 100 the insulation of choice for most primary insulation that is more than 7 mils thick.

TEFLON FEP 100 possesses a balance of processing and performance properties which make it the preferred resin for many applications. Like all TEFLON fluorocarbon resins, TEFLON FEP 100 offers an excellent combination of properties: chemical inertness, exceptional dielectric properties, heat resistance, toughness, flexibility, low coefficient of friction, nonstick characteristics, negligible moisture absorption, low flammability, performance at temperature extremes, and weather resistance.

### Applications

TEFLON FEP 100 is used in many applications. One of the largest uses is in telecommunications/data cables where TEFLON FEP 100 not only provides excellent fire performance and physical properties but also superior electrical performance. In this role, it is ideal as an insulation for constructions meeting Article 725 and Article 800 of the National Electric Code (NEC) where TEFLON FEP 100 provides superior dielectric properties for rapid, clear signal transmission. Cables insulated with TEFLON FEP 100 have met the requirements of Underwriter's Laboratory UL 910 Steiner Tunnel Test for installation in plenums without metal conduits.

TEFLON FEP 100 is not normally recommended as a jacket material, but it can be used as jacketing for small plenum cables that do not have a braided wire shielding.

### Safe Handling

Use of an adequate ventilation system allows safe processing of TEFLON FEP in extruders at high temperatures. For further information, refer to the DuPont bulletin "TEFLON® Fluorocarbon Resin: Safety in Handling and Use," which can be obtained from your DuPont representative.

### Packaging

TEFLON FEP 100 is supplied as pellets and is available in 55-lb (24.9-kg) multilayer kraft bags with an integral polyethylene liner.

### U.S. Freight Classification

For rail shipments, TEFLON FEP 100 is classified as "Plastic, Synthetic, OTL, NOIBN;" for truck shipments as "Plastic Materials, Granules;" and for express shipments as "Plastics, Synthetic."

DuPont Materials for Wire & Cable

**TABLE 1**
**Typical Properties of TEFLON® FEP 100 Fluorocarbon Resin**

| Property | ASTM Method | Units | Value |
|---|---|---|---|
| **Electrical** | | | |
| Dielectric Constant | D-1531 | | |
| 100 kHz ($10^5$ Hz) | | – | 2.06 |
| 1 MHz ($10^6$ Hz) | | – | 2.06 |
| Dissipation Factor | D-1531 | | |
| 100 kHz ($10^5$ Hz) | | – | 0.0003 |
| 1 MHz ($10^6$ Hz) | | – | 0.0006 |
| Dielectric Strength | D-149 | | |
| 10 mil film | | V/mil | 2000 |
| 1/8 in Sheet | | V/mil | 510 |
| **Mechanical** | | | |
| Melt Flow Number | D-2116 | g/10 min | 6.6 |
| Specific Gravity | D-762 | – | 2.15 |
| Tensile Strength | D-1708 | psi | 4000 |
| | | MPa | 27 |
| Elongation | D-1708 | % | 340 |
| **Thermal** | | | |
| Melting Point | DTA-E168 | °C | 264 |
| | | °F | 507 |

## Processing Guidelines for Wire and Cable Use Extrusion Equipment

TEFLON® FEP 100 is fabricated using the same melt processing techniques as other thermoplastics. A brief description of the extrusion equipment used with TEFLON FEP 100 is given here; for more detailed processing information, consult the DuPont "Extrusion Guide for Melt Processible Fluoropolymers," which can be obtained from your DuPont representative.

Molten TEFLON resins are corrosive to many metals; therefore, special corrosion-resistant materials must be used for all parts of extrusion equipment that come into contact with the melt. Nickel-based alloys such as HASTELLOY®, INCONEL®, MONEL®, and XALOY® are the materials of choice. Hardened electroless nickel plate can be used, but even small holes, chips, or cracks in the plating can compromise its performance. Chrome-plated materials are not recommended. Additional information on materials of construction can be obtained from your DuPont representative. Corrosion is likely to occur if dead spots exist in the equipment, processing temperatures are too high or hold-up time is too long. In addition, resin degradation will accelerate corrosion.

A 1.5- to 2.5-inch (38- to 64-mm) extruder with a barrel length-to-diameter ratio of 20:1–30:1 is recommended for extruding TEFLON FEP 100. Extruder barrels should have three to five independently controlled heater zones with temperature controllers capable of accurate operation (±0.6°C/ ±1°F) in the temperature range of 316°C to 425°C (600°F to 800°F). Heaters should be made of cast bronze or aluminum. Controllers with proportional-integral-derivative (PID) action are recommended.

A 3:1 compression ratio screw consisting of a relatively long feed zone, a 1- to 3-turn transition and a metering section that comprises approximately 1/4 of the length of the screw is recommended. The addition of a mixing section at the end of the screw can improve processibility. Contact your DuPont representative for more information.

A melt thermocouple and melt pressure probe should be installed in the adapter section of the extruder. To obtain an accurate measurement, the thermocouple should extend to the center line of the flow channel.

Degradation of the resin during processing greatly reduces the performance of TEFLON® FEP 100 in stringent applications. Degradation is caused by excessively high melt temperatures, long residence time in the extruder, and/or excessive shear from the screw. In general, increases in the melt flow number (MFN) greater than 10% during extrusion should be avoided. This 10% rise in MFN will occur after only five minutes at 393°C (740°F) or approximately 45 minutes at 382°C (720°F), but it increases to only 5% after 60 minutes at 360°C (680°F). This indicates the importance of maintaining resin flow through the extruder while at operating temperature and shows why temperatures should be decreased if the extruder is down for even a short period of time.

Other processing conditions that can reduce the resin's performance include melt fracture, very low or uneven melt temperatures, and the presence of hydrocarbon or silicone oils which act as stress crack promoters.

### Wire-Coating Techniques

TEFLON FEP 100 is typically applied as a wire insulation using tubing techniques. Draw-down ratios (DDR) generally ranging from 50:1 to 200:1 are common, with higher DDRs usually allowing greater line speed. A draw-ratio balance (DRB) ranging from 0.9 to 1.1 is recommended. A complete discussion of DDR and DRB can be found in the DuPont "Extrusion Guide for Melt Processible Fluoropolymers," which can be obtained from your DuPont representative.

A controlled vacuum is required at the rear of the crosshead to adjust the melt cone to the desired length. A melt cone that is too long results in excessive caliper variations while a melt cone that is too short results in excessive spark failures and cone breaks. Laboratory experience has shown that a cone length of 2.5 in to 3.0 in (64 mm to 76 mm) yields satisfactory results with a DDR of 156:1 and a DRB of 1.00. Control can be achieved at a shorter cone length if a higher DRB is used.

An electronic wire preheater located as close to the crosshead as possible is recommended for preheating the wire. Although the amount of preheat will depend upon the application, the preheater should be capable of heating the wire to 149°C to 204°C (300°F to 400°F) while operating at a typical line speed of 500 ft/min (152 m/min).

Stationary pulleys should be located on both sides of the crosshead to reduce wire flutter. The wire should pass through the crosshead, without touching the crosshead or the extrusion tip. Sponges should not be used to reduce flutter downstream of the crosshead because they can produce insulation faults.

The coated wire should pass through a 1- to 5-ft (0.3- to 1.5-m) air gap followed by a warm-water quench at 38°C to 66°C (100°F to 150°F) to allow uniform cooling and prevent the formation of shrinkage voids in the insulation. The cooling is highly dependent on the thickness of the insulation.

Processing conditions depend on the equipment size and line speed. **Tables 2** and **3** list the actual processing conditions for a 10-mil wall of TEFLON FEP 100 on a 24 AWG copper wire. Adjustments may be necessary for other equipment.

### Color Concentrates

TEFLON FEP based color concentrates are commercially available from several manufacturers. Only inorganic pigments should be used due to the high temperatures used to process TEFLON FEP. Concentrate loading information is available from the manufacturer, and it will normally depend on the compositions of concentrate, wire size, insulation thickness, and intensity of color desired. Your DuPont representative can provide additional information on suppliers.

### Band Marking

Band marking inks for TEFLON FEP are commercially available from several manufacturers. In-line band marking of TEFLON FEP can be accomplished by positioning the band marking unit as close to the crosshead as possible and by using inks with high-boiling solvents. Your DuPont representative can provide additional information on suppliers.

**TABLE 2**
**Typical Temperature Profile for Extruding TEFLON® FEP 100 on AWG #24 Solid Copper Wire[1]**

| Zone | °C | °F |
|---|---|---|
| Rear Zone[2] | 366 | 690 |
| Rear Center[2] | 382 | 720 |
| Center | 388 | 730 |
| Front Center | 393 | 740 |
| Front | 396 | 745 |
| Clamp | 396 | 745 |
| Adapter | 396 | 745 |
| Crosshead | 396 | 745 |
| Die Holder | 416 | 780 |
| Melt | 393 | 740 |

[1]Based on a 60-mm extruder with a 30:1 L/D; adjustments may be necessary for other equipment.

[2]For a smaller machine, it will be necessary to raise the temperature to ensure that the resin is completely melted before entry into the extruder's transition zone. A surging output at the die could be caused by incomplete melting.

**TABLE 3**
**Typical Operating Conditions for Extruding TEFLON® FEP 100 on AWG #24 Solid Copper Wire[1]**

| | | |
|---|---|---|
| Extruder Speed | rpm | 8 |
| Line Speed | ft/min<br>m/min | 500<br>335 |
| Wire Preheat | °C<br>°F | 152<br>240 |
| Pressure | MPa<br>psig | 4.6<br>670 |
| Die | in<br>mm | 0.500<br>12.70 |
| Tip | in<br>mm | 0.250<br>6.35 |
| DDR | – | 156:1 |
| DRB | – | 1.00 |

[1]Based on a 60-mm extruder with a 30:1 L/D; adjustments may be necessary for other equipment.



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DUPONT®

## A.5 Teflon FEP 100-J: Product Information

**Product Information**

DUPONT

# TEFLON® FEP 100-J

Fluoropolymer resin

## Extrusion and Molding Resin

### Brand

Teflon® is a registered trademark of DuPont for its brand of fluoropolymer resins, which can only be licensed by DuPont for use in approved applications. Customers who wish to use the Teflon® trademark in connection with DuPont FEP products under license from DuPont should contact your local DuPont office. Without a license, customers may not identify their product as containing Teflon®, but may refer to the resin as FEP 100-J.

### Description

Teflon® FEP 100-J is a general-purpose resin available in translucent, 2.5mm pellets. Compared with Teflon® FEP 140-J and FEP 160, it has higher flow rate and provides the best balance between end-product performance and ease of processing.

Teflon® FEP 100-J and other Teflon® FEP (fluorinated ethylene propylene) copolymer resins combine the processing ease of conventional thermoplastics with properties similar to those of polytetrafluoroethylene (PTFE). They have high melt strength and stability at recommended processing temperatures.

Teflon® FEP 100-J is preferred for products that are not exposed to severe environmental stress in service. It is often selected for products made by injection molding because it offers the higher available flow rate.

Properly processed products made from neat Teflon® FEP 100-J resin provide the superior properties typical of the fluoropolymer resins: retention of properties after service at 200°C, useful properties at –240°C, and chemical inertness to nearly all industrial chemicals and solvents. Dielectric properties are excellent. Molded products have moderate stiffness and high ultimate elongation.

In a flame, products made of Teflon® FEP 100-J resist ignition and do not themselves promote flame spread.

When ignited by flame from other sources, their contribution of heat is very small and is added at a slow rate with very little smoke.

### Typical End Products

Teflon® FEP 100-J is ideal for many end products, including: extruded tubing, heat shrinkable sleeving, and other profiles for electrical insulation or fluid handling; film and products made from film; labware, and injection-and blow-molded articles requiring superior chemical inertness, electrical properties, and purity.

### Processing

Teflon® FEP 100-J can be processed by conventional melt extrusion and by injection, compression, and transfer and blow molding processes. High melt strength permits the use of relatively large die openings and high temperature draw-down techniques that increase production rates. Reciprocating screw injection molding machines are preferred. Corrosion-resistant metals should be used in contact with molten resin. Extruder barrels should be long relative to diameter, to provide residence time for heating the resin to approximately 400°C.

### Safety Precautions

**Warning!**

**VAPOURS CAN BE LIBERATED THAT MAY BE HAZARDOUS IF INHALED**

Before using Teflon®, read the Material Safety Data Sheet and the detailed information in the "Guide to the Safe Handling of Fluoropolymer Resins, Latest Edition" published by the Fluoropolymers Division of The Society of the Plastics Industry – available from DuPont.

Open and use containers only in well-ventilated areas using local exhaust ventilation (LEV). Vapors and fumes liberated during hot processing, or from smoking tobacco or cigarettes contaminated with resin dust, may cause flu-like symptoms (chills, fever, sore throat) that may not occur until several hours after exposure and typically pass within 36 to 48 hr. Vapors and fumes liberated during hot processing should be exhausted completely from the work area; contamination of tobacco with polymers should be avoided. Mixtures with some finely divided metals, such as magnesium or aluminum, can be flammable or explosive under some conditions.

## Storage and Handling

The properties of Teflon® FEP resin are not affected by storage time. Ambient storage conditions should be designed to avoid airborne contamination and the formation of water condensation on the resin when it is removed from containers.

## Packaging

Teflon® FEP 100-J is supplied as pellets and is available in 25kg multilayer kraft bags with an integral polyethylene liner.

**Table 1 Typical Property Data for Teflon® FEP 100-J**

| Property | ASTM Test Method | Unit | Nominal Value |
|---|---|---|---|
| **Thermal** | | | |
| Nominal Melting Point | D3418 | °C | 255 – 265 |
| Upper Service Temperature | UL 746 | °C | 200 |
| Flow Rate | D2116 | g/10min. | 7 |
| **Mechanical** | | | |
| Tensile Strength, 23°C | D2116 | MPa | 27 |
| Specific Gravity | D792 | - | 2.13 – 2.17 |
| Ultimate Elongation, 23°C | D2116 | % | 380 |
| Flexural Modulus, 23°C | D790 | MPa | 586 |
| Impact Strength, 23°C | D256 | J/m | No Break |
| Hardness Durometer | D2240 | ShoreD | 56 |
| Compressive Strength | D695 | MPa | 21 |
| Linear Coefficient of Expansion, 0 – 100°C | E831 | mm/mm/°C | $13.5 \times 10^{-5}$ |
| **Electrical** | | | |
| Dielectric Strength, 0.25mm | D149 | kV/mm | 80 |
| Dielectric Constant, 1MHz, 23°C | D1531 | - | 2.02 |
| Dissipation Factor, 1MHz, 23°C | D1531 | - | 0.0007 |
| Volume Resistivity | D257 | T ohm-cm | $>10^{16}$ |
| Arc Resistance | D495 | sec | No Track |
| **General** | | | |
| Water Absorption, 24hr | D570 | % | 0.004 |
| Weather and Chemical Resistance | - | - | Outstanding |
| Limiting Oxygen Index | D2863 | % | 95 |

**Note**: Typical properties are not suitable for specification purposes. Statements, or data, regarding behavior in a flame situation are not intended to reflect hazards presented by this or any other material when under actual fire conditions. Properly processed products (sintered at high temperatures common to the industry) made from Teflon® FEP resins can qualify for use in contact with food in compliance with FDA regulation 21 CFR 177.1550.
Teflon® FEP 100-J is ASTM D2116, Type I.

## For more information :

DuPont - Mitsui Fluorochemicals Co., Ltd.
Chiyoda Honsha Building
1-5-18 Sarugaku-cho
Chiyoda-ku, Tokyo 101-0064 Japan
Tel. 81-3-5281-5872



12/99 MDF

## Appendix B: Equipment

### B.1 Welder Quote and Specifications

**STAPLA Ultrasonics Corporation**

STAPLA Ultrasonics Corporation
375 Ballardvale Street
Wilmington, MA 01887
Telephone: (978) 658 9400
Telefax: (978) 658 6550
info@staplausa.com
www.staplaultrasonics.com

**STAPLA Ultrasonics Quotation No.:** **A2211-104** Date: January 20, 2004

Based on our attached sales and delivery terms we are pleased to submit our quotation on the **ALFA Servo** for your special welding application. This price will include the modifications of the tooling and the fixture for positioning the wires.

**Price and Specifications**

| Part No. | Qty. | Description | Unit Price | Total |
|---|---|---|---|---|
| **c402-560-011** | 1 | **CONTROLLER USC1** | $ 26,500.00 | $26,500.00 |
| **c257-900-571** | 1 | **ALFA SERVO Weld Head with:** | | |
| 257-900-514 | 1 | Height Sensor | | |
| 832-570-013 | 1 | Booster | | |
| 112-560-743 | 1 | HF Cable | | |
| 256-901-764 | 1 | Foot Switch w/E-stop | | |
| | 1 | Special Tooling (12mm Wave) | | |
| 802-310-823 | 1 | Converter | | |
| 100-000-113 | 1 | Tool Kit | | |
| 050-A01-012 | 1 | Air Service Unit | | |
| | 1 | Fixture for wire replacement | | |
| | | | | |
| | | Special Rolling Cart (optional) | $1,850.00 | |
| | 1 | Barcode w/Software | | |
| | | | | |
| **Total for the ALFA Servo System including specified Tooling: This equipment will meet the requirements included in the Schlumberger's guideline attached.** | | | | **$26,500.00** |

C_pp66-71_from p76-81 Thesis 6.02 aka 2c-Welder Quote-modified.doc

schunk Group

## Terms and Conditions

| | |
|---|---|
| **Equipment** | 1/3 down with written purchase order.<br>Balance net 30 days. |
| **Tooling-only Orders** | 50% down with written purchase order.<br>Balance net 30 days. |
| **Spare Part Orders** | Net 30 days. |
| **Delivery:** | 4 – 6 weeks after receipt of written purchase order, a sufficient amount of good production parts and down payment, as well as clarification of all technical details. STAPLA Ultrasonics reserves the right to adjust delivery time depending on production scheduling at the time of purchase. |
| **Documentation/ Specifications:** | Quoted prices include documentation and equipment made to STAPLA Ultrasonics' standards. |
| **Acceptance/Training and Service:** | Acceptance of equipment in operation and training of operators can be provided at STAPLA Ultrasonics, Wilmington, MA, at no charge.<br><br>The quoted prices do also include up to one (1) to two (2) 8-hour days of on-site installation support and operator training, excluding travel expenses. |
| **Prices:** | Our technicians are available for non-warranty service on STAPLA Ultrasonics equipment at your company for a rate of $1,250.00 per day based on an 8- hour working time plus all travel related expenses from Wilmington, MA. After the initial 8 hour daily rate for working time, additional hours will be charged at $140.00 per hour. Weekend rates will be $155.00 per hour for Saturday and $175.00 per hour for Sunday, F.O.B. Wilmington, MA, excluding any sales tax, packing, shipping and insurance charges. Our quotes are without obligation and subject to our written order confirmation. Massachusetts' law requires that we have a copy of your tax-exempt certificate on file. Failure to provide this document will result in the assessment of 5% Massachusetts Sales Tax. The prices and deliveries of this quotation are based on information, parts, and drawings provided to STAPLA Ultrasonics at the time of quoting. Any final tooling changes or additions due to deviations in customer's parts from original samples and drawings provided are the responsibility of the customer. |
| **Warranty:** | When used in accordance with the instructions and under normal operating conditions, STAPLA equipment is warranted to be free from defects in material and workmanship for a period of one (1) year from the date of original delivery by STAPLA. Any component, which proves to be defective during the stated period, will be repaired or replaced free of charge at the sole discretion of STAPLA, F.O.B. Wilmington, Massachusetts. In case an on-site repair is required, STAPLA will charge for travel expenses and any applicable In-Plant Service Fees (see section "Acceptance/Training and Service").<br>Customers must obtain a RMA (Return Merchandise Authorization) number from STAPLA for any item being returned to STAPLA for warranty purposes. We request that you ship the part to STAPLA in the original condition and packaging, |

prepaid and insured. RMA numbers are valid only for a period of 30 days from date of issue.

All parts or equipment sent to STAPLA, for any reason, will be accepted only if they are shipped F.O.B. STAPLA, Wilmington, MA. STAPLA is not responsible for any equipment damage incurred during shipment, including damage due to improperly packed goods.

If STAPLA determines that failure of the part or system was not a result of a defect in STAPLA's products or assembly, STAPLA reserves the right to charge the customer for repairs and inspection.

This warranty does not apply to any equipment, which has been repaired or altered in any way, by anyone outside the STAPLA organization.

**Exclusive Remedy:** STAPLA's liability, whether based on warranty, negligence of any kind, strict liability, tort, or other cause arising out of and/or incidental through the sale, use or operation of the equipment, or any part thereof, shall not, in any case, exceed the cost of repair or replacement of the defective equipment or at STAPLA's discretion, of refunding the purchase price of such equipment. Such repair, replacement, or refund shall be the exclusive remedy of the purchaser. In no case shall STAPLA be responsible for any and/or consequential, incidental, direct, or special damages, including damages arising out of commercial losses.

**Validity:** This quotation is valid for 90 days from date of quotation.

**Sample Part Returns:** STAPLA Ultrasonics shipping policy for returning sample parts is UPS Ground.

**Samples/Equipment** If the customer requires samples/equipment to be returned more quickly, customer must provide STAPLA Ultrasonics with either a shipping account number or purchase order for the applicable shipping charges.

Sincerely,
**STAPLA Ultrasonics Corporation**

Saeed Mogadam
President

SM:idi

Cc: Javier Tenreiro

### Detailed System Description

**STAPLA SPLICER MODEL ALFA Servo Ultrasonic Splice Welder**
**Welds Cu-wires of cross-sectional areas of up to 24 $mm^2$**

**1. Welding unit**

The ALFA Servo is designed offer user-friendly characters and simple set-up. Modular components and a few moving parts add to the simplicity and highly reliable performance of this splice welder. Compact size and low weight allows ALFA Servo to be used at a table or harness assembly board. This welder and its advanced Controller will provide an easy method of set-up and operation with full quality control capability.

Maintenance of the welder is simple due to its design nature. The Transducer Assembly (Horn, Booster, and Converter) is modular and can be removed and set-up in less than five (5) minutes. Displacement-sensored safety guards accomplish the ALFA series.

**STAPLA Tooling**

The SPLICER ALFA Servo tooling is designed for efficient welding and long life. An exclusive STAPLA designed "Nodal Support" Transducer Assembly, which is modular and includes a special Booster, will allow welding capability of splices up to a total cross sectional area of 24 $mm^2$ at a high production rate.

The following are some of the other features of the system:

- The tooling is universal and operated pneumatically. The gathering block allows wide-open space for ease of handling wires and prevents any loose strands.
- A direct and perpendicular actuation of the anvil holder shaft assures consistent welding force and thus, reliable quality weld.
- Exclusive designed "Nodal Support" Transducer Assembly allows generating larger splices and makes the welder more robust. Therefore, the system is capable of supporting a tougher production environment, and longer tool life.
- The Transducer Assembly is completely modular, and self supported with minimum horn deflection and easier set-up and changeover. A self-aligned design feature allows the horn set up square automatically.
- The Converter has a cooling fan for efficient performance and longer life.
- The tool size, adjustment in increments of 0.1mm, is done automatically by the DC-Servo motor controlled by the multifunction button.
- Vertical Anvil retracts pneumatically and allows large space for loading wires and yet small for safety.
- All pneumatic and electrical wiring is packed underneath the welder, away from the tooling and welding components.

## 2. STAPLA Controller and Power Supply

The STAPLA Controller, USC1, with 3 kW high performance power supply is utilized for the Model 20-ALFA Servo. The USC1is designed to be user-friendly and simple to operate. The following are some of the standard features in the USC1:

(a) Housing

Standard 19" / 3 height units box

b) Controls

- High intensity & large area fluorescence display for optimum readability even under adverse lighting conditions.
- Multi-function buttons.
  Functions shown on display for the 8 buttons located on the panel.
- Selectable user's language within the same software (English, French, German, and Spanish). Other languages are available on request.
- Lock key switch for different functions and to prevent tampering with the unit.

  The keys are for following functions:

  - System set-up by maintenance during the machine installation. Functions included are for calibration, methods of welding, test, and other features.
  - Teaching mode. This will allow the controller to display the settings. QC personnel may use this key.
  - Normal operation. Used for operator to display the counter, splice number, and the splice cross sectional area. The QC variables may be displayed in this mode by simply pressing the "Monitor" button.

(c) Interfaces

- RS232 and RS485 ports for local PC and remote communications.
- Multi-pin signal connector to control additional systems / machinery.
- Printer Port.
- Service port for calibrations and internal adjustments.

The controller USC1is designed to provide the ultimate capabilities in ultrasonic metal welding. The following are some of the features utilized for the wire splicing process:

(a) Calibration procedures supported by menu.

The calibrations are for pressure, amplitude, energy, weld height tool width for ALFA Automatic and other functions and mechanical motions. The pressure and weld height is done during set-up. Amplitude and energy calibration is done for yearly maintenance.

(b) Weld methods are selectable by pushing a button in the menu screen

- Weld to Energy
- Weld to Time
- Weld to compaction

(c) Triple quality controls / selectable

Controller checks for three of the following different QC variables:

- Correct Weld Time for variation of the wires.
- Correct Weld Energy for variation of the wires.
- Height before is measured to assure correct insertion of the wires.
- Final height is measured for indication of the weld strength.

The nominal QC variables are automatically determined by averaging the results of three (3) samples made by the operator. All variables have control limits established automatically or adjusted by the user. If the measured value is outside the control limit, an alarm will sound and the welder will not work until it is reset.

d) Automatic weld settings recommendation

All data can be stored in the system for up to 1000 different wire combinations / splices.

Recall of stored data is done by finding the splice number and pressing the recall button. Different parameters are pre-programmed for different splice sizes. Set-up for a new splice is easy. The controller will have reference settings for all cross-sectional sizes of different splices. By locating the correct cross-section size, you press recall and test the new splice with the given settings. If the results are acceptable, you can save these settings under a new number by pressing the save button (optional).

e) Software:
STAPLA offers full service in providing specially designed software for specific applications as well as "SPC" programs for QC analytical reports.

f) Sequential Welding:

Automatic tool size adjustment makes sequential welding fully automatic and possible. Special software will allow up to 250 different sequence programs.

**Installation:**

| | |
|---|---|
| Voltage: | 220 Volt or any other desired voltage |
| Fuse: | 16 Ampere |
| Air pressure: | Approximately 6 bar, the machine is equipped with a pneumatic service unit |

## B.2 Ultrasonic Welding Machine System Guidelines

(1) Main application of the ultrasonic welding system consists of welding 20 gage to 26 gage stranded and silver-plated copper conductors. The selected system should lend itself to the welding of any combination of wires in the 20-26 gage range for future needs.

(2) Welding system should be portable such that it can be moved to the components being welded on the manufacturing floor. Space and wire length restrictions for our first application are shown in Figure 2. Welding system to be setup on a movable cart with adjustable height feature. Due to space issues on the production floor, operator may be standing at the back of the welding head (and reaching over the device) to do the operation.

(3) Welding system and parameters (Amplitude, welding time, etc.,) for welding 20 to 26 gage wires to be optimized by STAPLA.

(4) Welding system to be sensitive enough to identify a loss of 2 strand or more on the 20 gage (19 strands of 32 gage) and 3 strands or more of the 26 gage (19 strands of 38 gage) wires prior to the weld cycle.

(5) Fine diamond knurl to be used on the horn surface.

(6) Weld section to meet geometry per figure 1. Wire placement for welding to be independent of operator skills. Wires to be located and welded with proper fixturing so that consistent weld quality and geometry can be achieved during manufacturing.

(7) Weld shape to be square (aspect ratio of 1.0) in cross-section.

(8) Welded section to be straight within 3 degrees (kinks exceeding 3 degree from being straight are not allowed at the weld point)

(9) No broken strands are allowed at the weld transition. Welding forces may be reduced in the transition area with proper profiling of the horn.

(10) 20 to 26 gage weld to meet pull strength of above 7 lbs. STAPLA to help optimize this value.

(11) Weld section to with -stand 4 full cycles of +90 to –90 degree bending (1 cycle consists of bending the welded section from the straight 0 degree initial position to + 90 degree to –90 degree and back to 0 degree) without breaking any strands at the weld transition.

(12) No loose strand-ends are allowed at the weld transition as it can position itself radially and cause subsequent process problems.

(13) STAPLA to setup new equipment and train key personnel during the installation phase.

(14) STAPLA to recommend techniques/guidelines to evaluate the quality of welds during manufacturing runs.

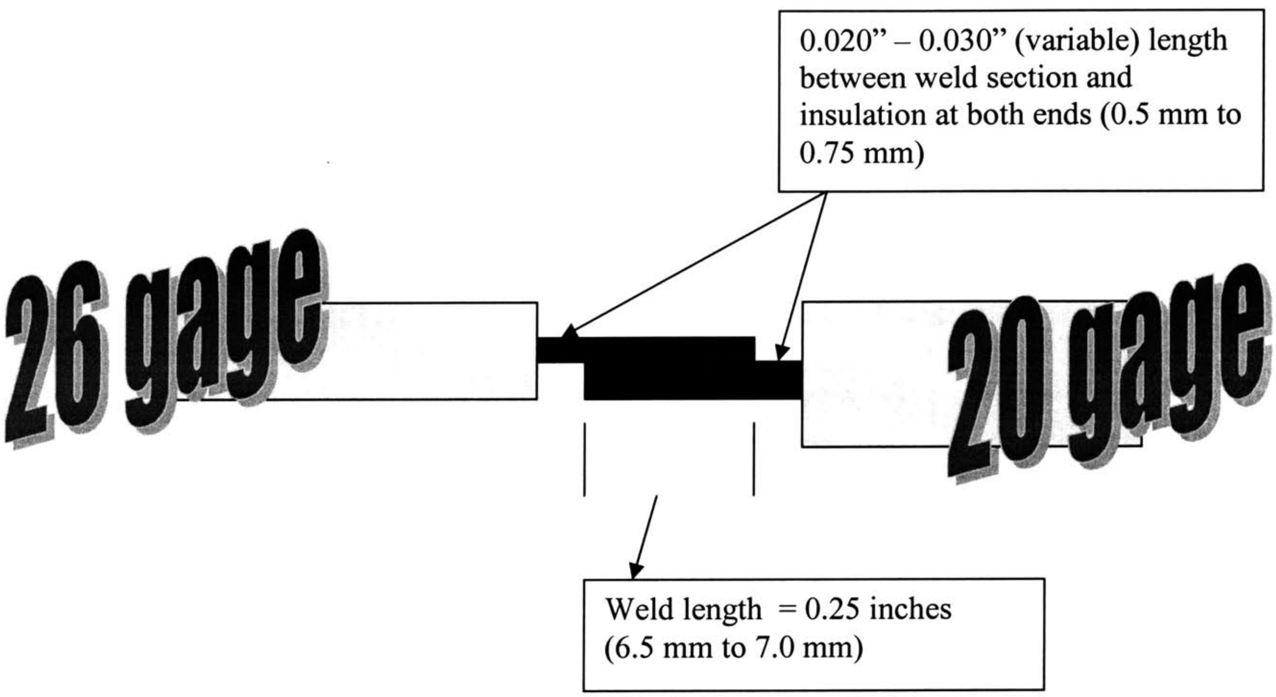



Figure 1: Weld section geometry between a 20 gage wire (with 19 strands of 32 gage conductors) and a 26 gage wire (with 19 strands of 38 gage conductors). The outer diameter of 20 gage wire is 0.054-0.062" and that of 26 gage wire is 0.035"-0.043". The 0.020" to 0.0.030" space shown between the weld and the insulation may be changed to obtain optimum weld section characteristics.

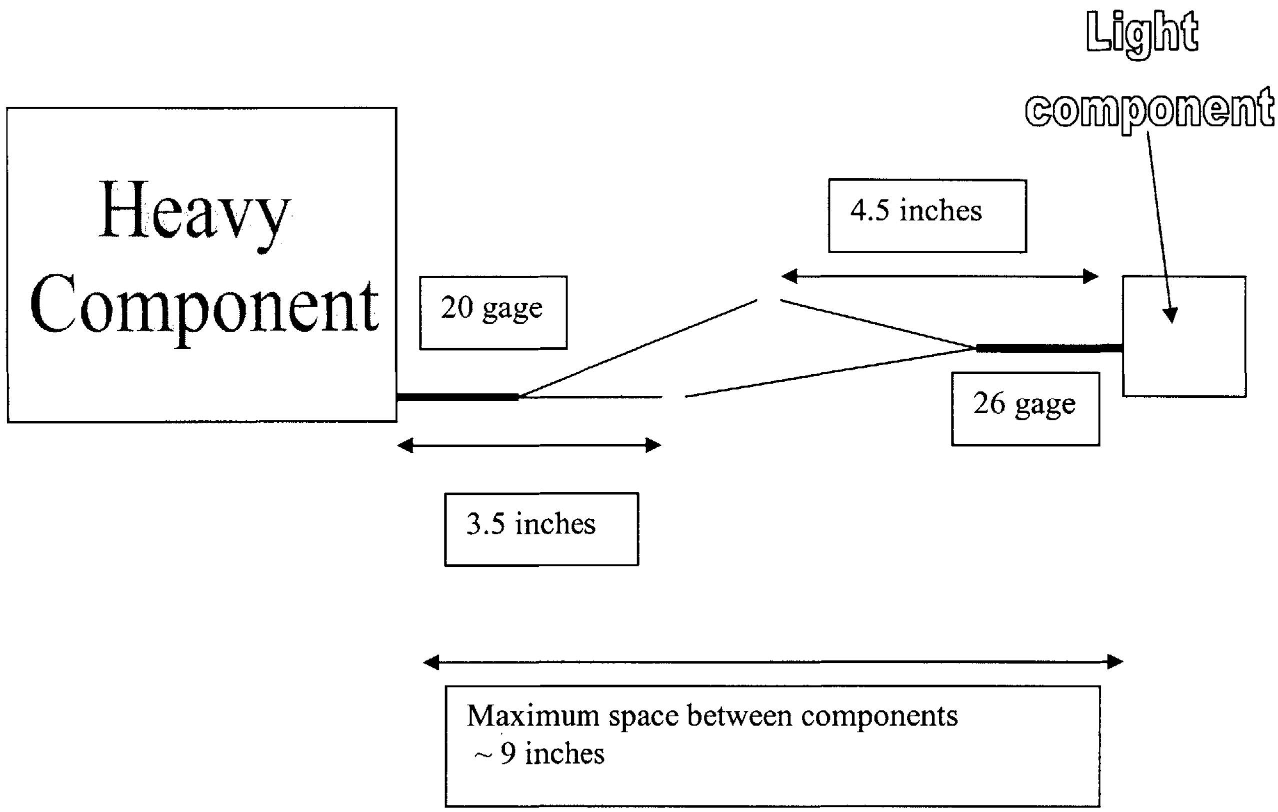



Figure 2: Shows space restriction for welding 20 to 26 gage wires. The wires exit the components in a twisted pair configuration. The light component may be located on top of the weld head during the welding process.

### B.3 Method to Recalibrate the Ultrasonic Welder

1. Turn Key 3 to "setup"
2. Select "calibrate" then "height"
3. The machine will prompt the operator to insert the 2mm pin (this is the smallest of the three pins provided). Insert the pin and press the foot pedal. At the next prompt follow the instructions by inserting the 4mm pin (the largest pin) and pressing the pedal.
4. The calibration is now complete, press the "CL" button to clear the menu, or simply turn the key to the "operate" mode and begin welding wires.

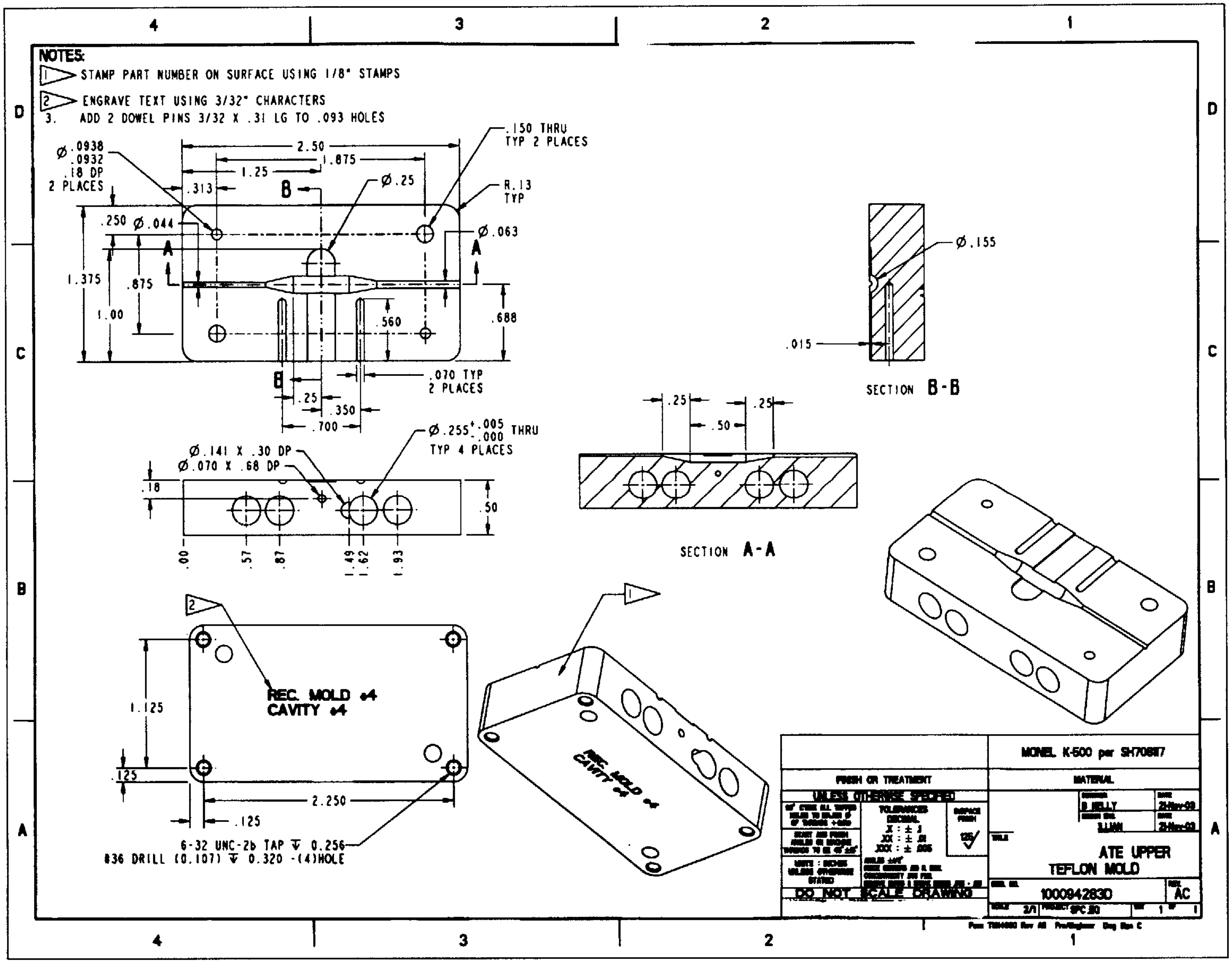
Note: Recalibration should not be needed often, but may be useful to approximately monthly.

## B.4 Project's Parts List and Drawings

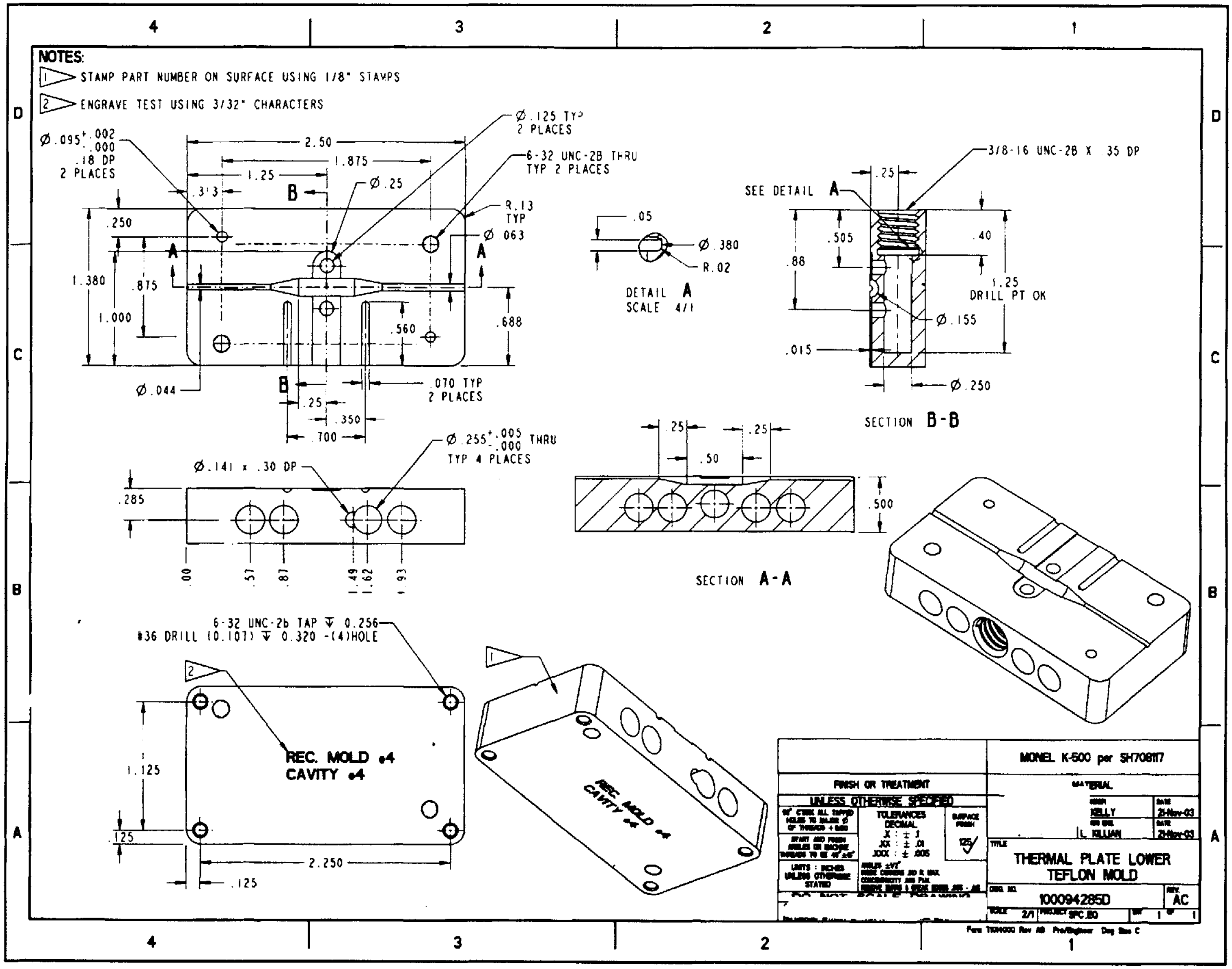
| Final Parts: | Drawing Number: |
|---|---|
| Monel Mold (top) | # 100094283D |
| Monel Mold (bottom) | # 100094285D |
| Monel Tube | # 100096503D |
| Monel Plunger | # 100100619D |
| Cylinder Platform | # 100099526 |
| Block Supports | # 100099519 |
| Insulator Support | # 100099518 (Insulator's part #: S-298553) |
| Controller | P.O. #: 1HG01394 |
| Cable Heater | P.O. #: 1HG006006 |
| Cartridge Heaters (4 on 1 plug) | P.O. #: 1HG06009 |
| Thermocouples ("rod tipped") | P.O. #: 1HG06001 (TS0108) |
| Thermocouples ("wire tipped") | P.O. #: 1HG06001 (AD6506) |
| Double-Acting Pneumatic Cylinder | P.O. # not available* |

| Experimental Parts: | Drawing Number: |
|---|---|
| Mold Insert #1 | # 100113062 |
| Mold Insert #2 | # 100068348 |
| Mold Insert #3 | # 100068349 |
| Mold Insert #4 | # 100068364 |
| 1st Rectangular Mold | # 100075749D and 100075746D |
| 2nd Rectangular Mold | # 100082443D and 100082444D |
| 3rd Rectangular Mold | # 100090387D and 100090388D |
| Original Stainless Steel Injecting Tube | # 100078568D |
| Later Stainless Steel Injecting Tube | # 100078568D |
| Original Brass Plunger | # 100078554D |

*Note: P.O. # not available for this part; Information available: purchased through Doug McCorquodale (281) 242-1596, received 3/4/04, Manufacturing information: "Speedaire, Mod: 6W102, Mft. For: Daton Electric Mfg. Co., Niles, IL 60714"

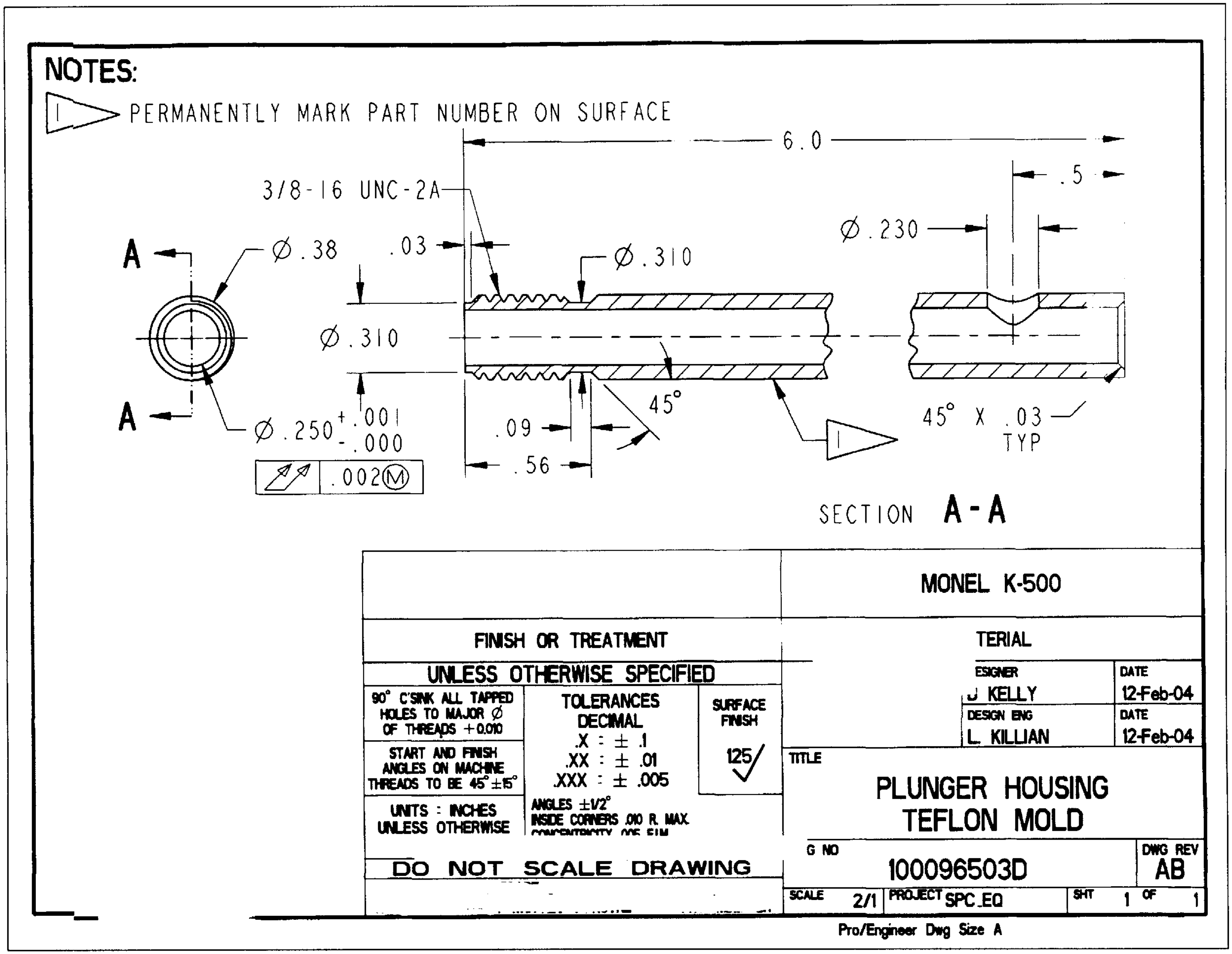


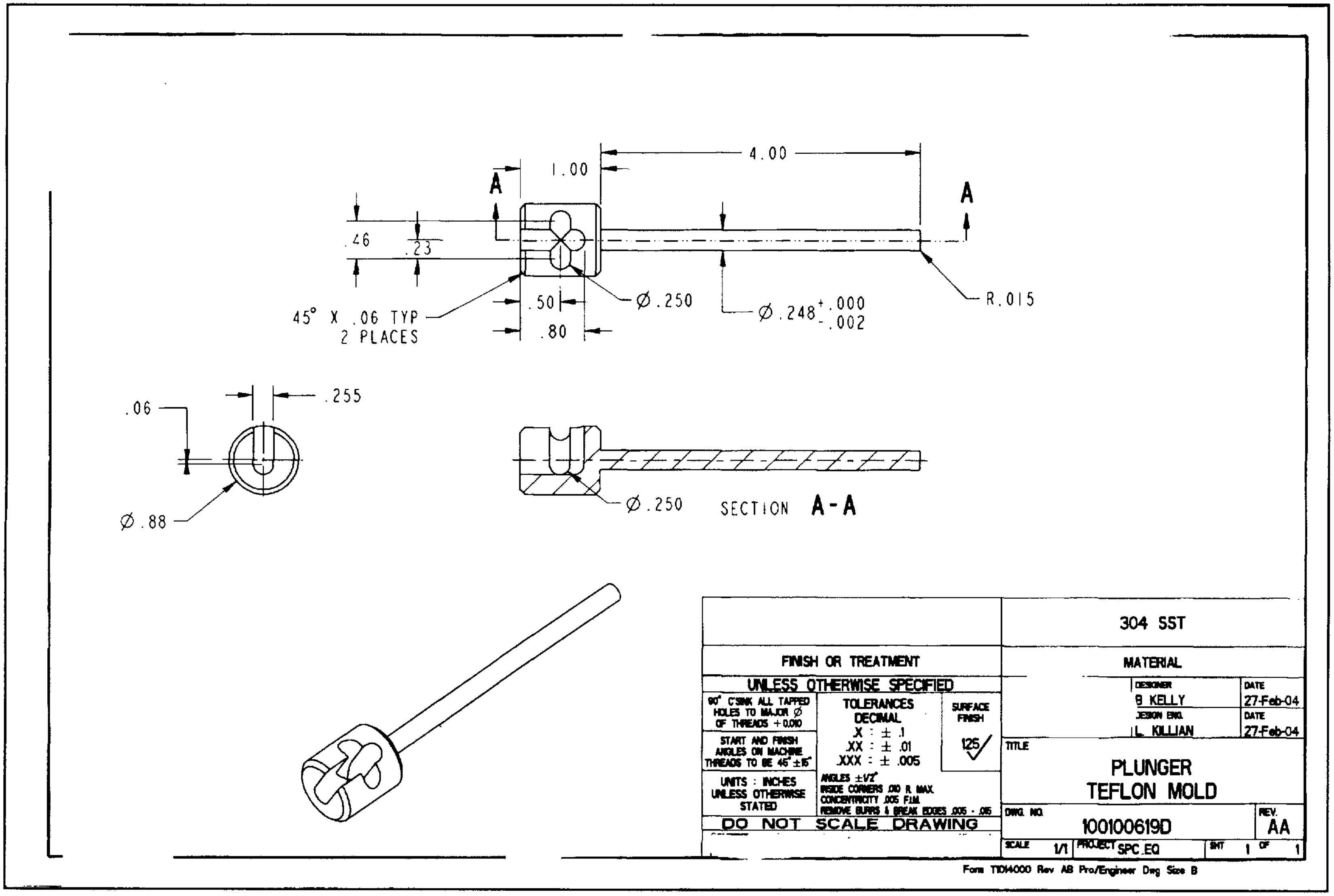

Monel Mold (top): # 100094283D



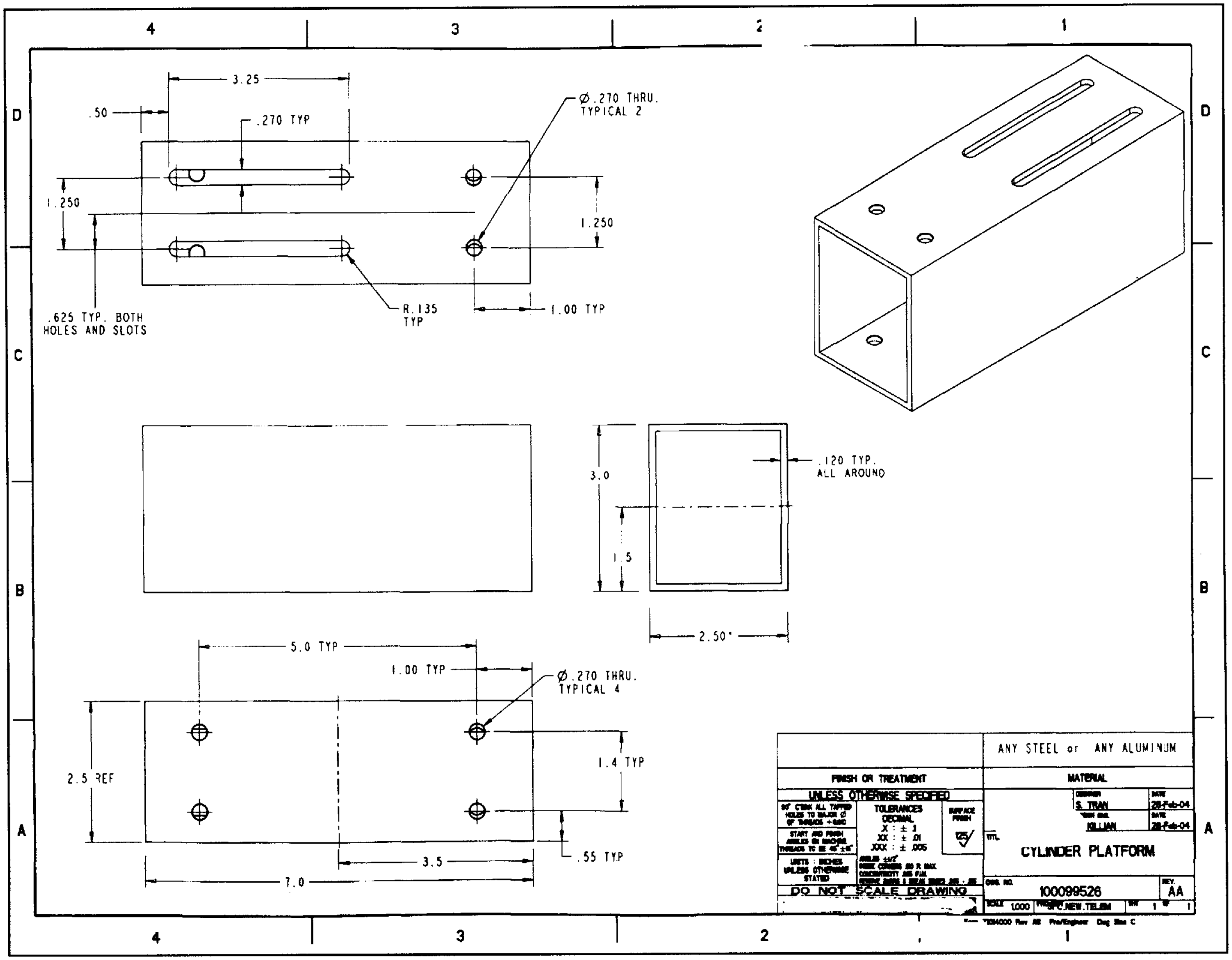

Monel Mold (bottom): # 100094285D

Monel Tube: # 100096503D



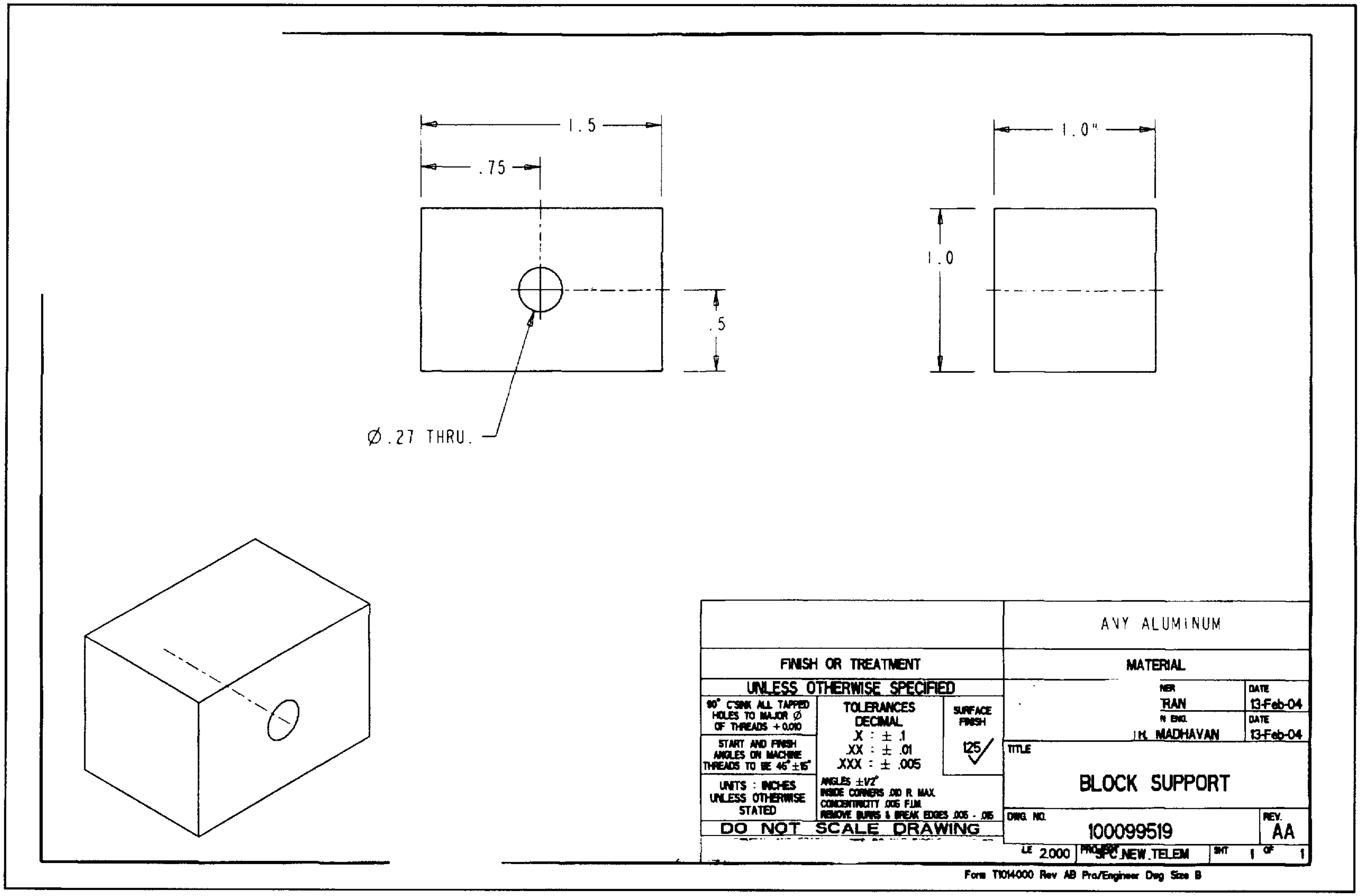


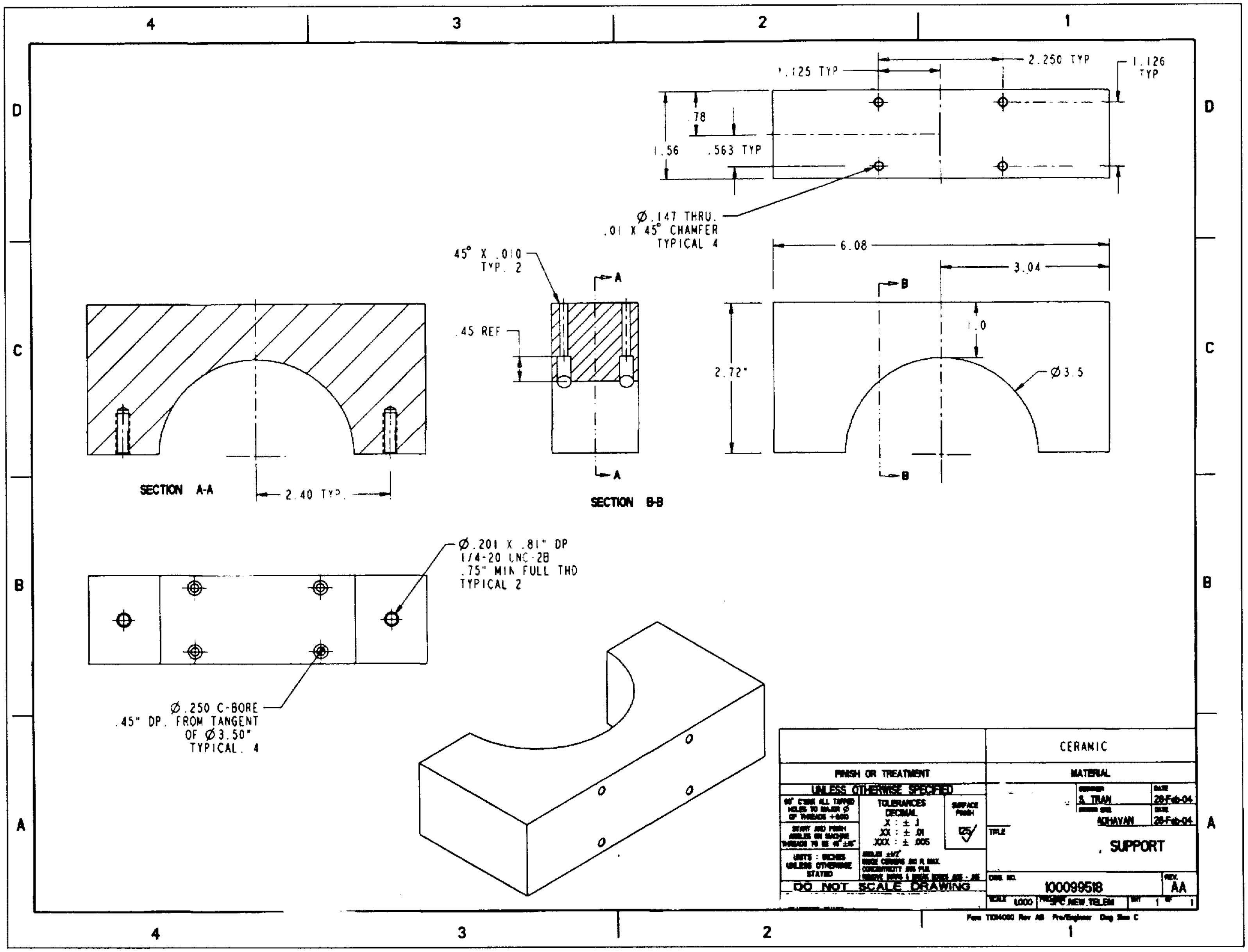

Monel Plunger: # 100100619D




Cylinder Platform: # 100099526

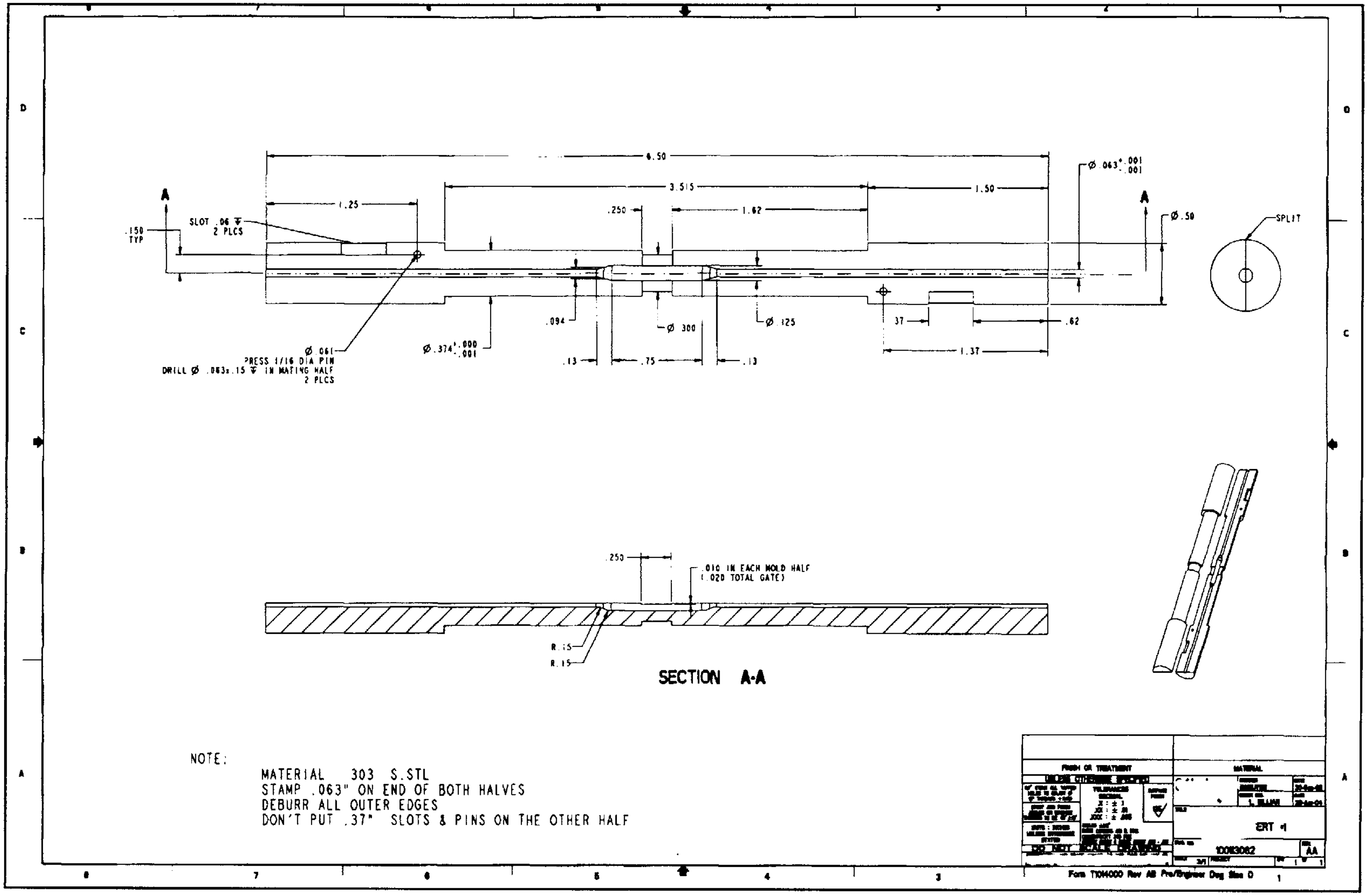
Block Supports: # 100099519



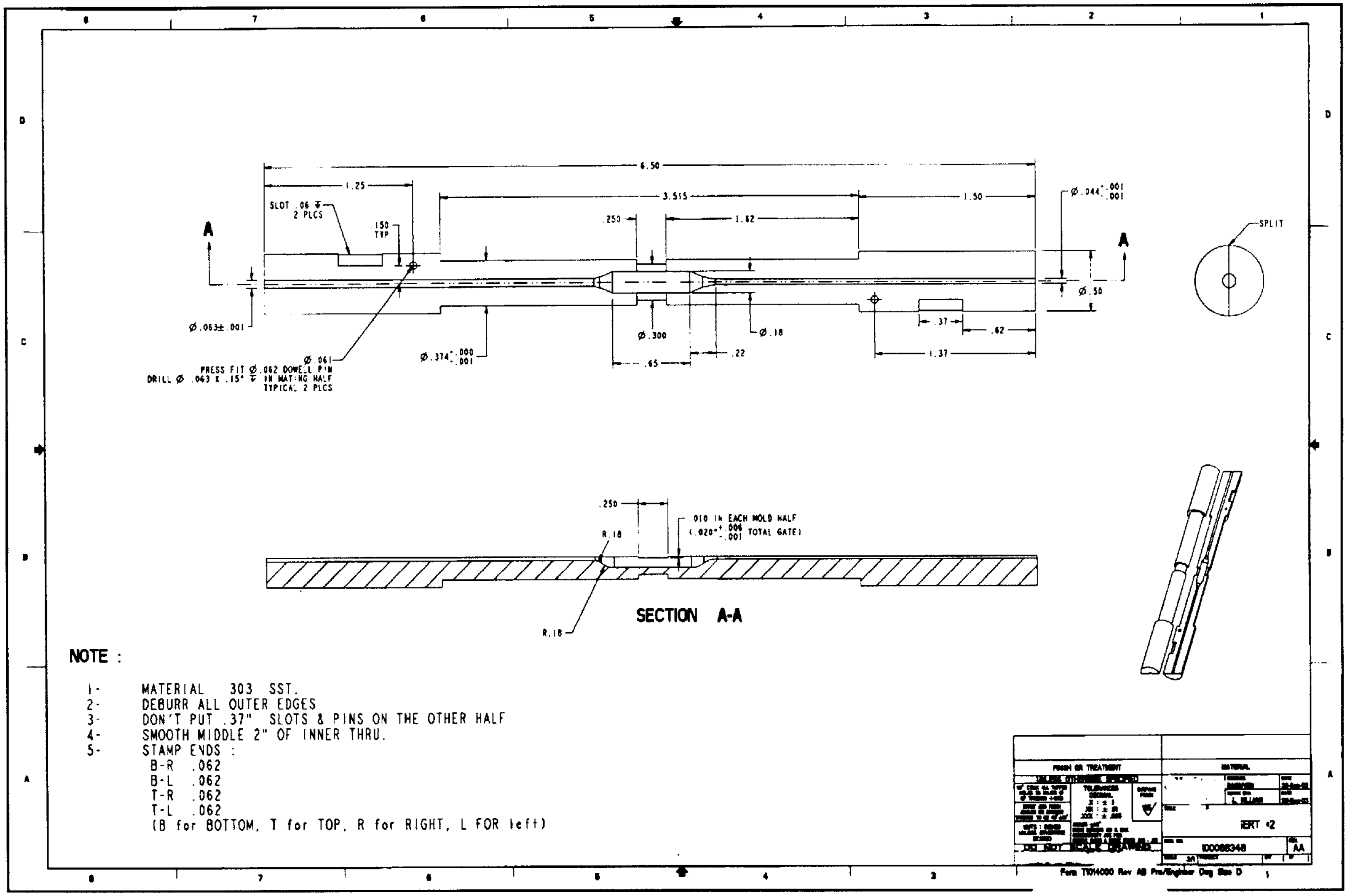



Insulator Support: # 100099518 (Insulator's part #: S-298553)

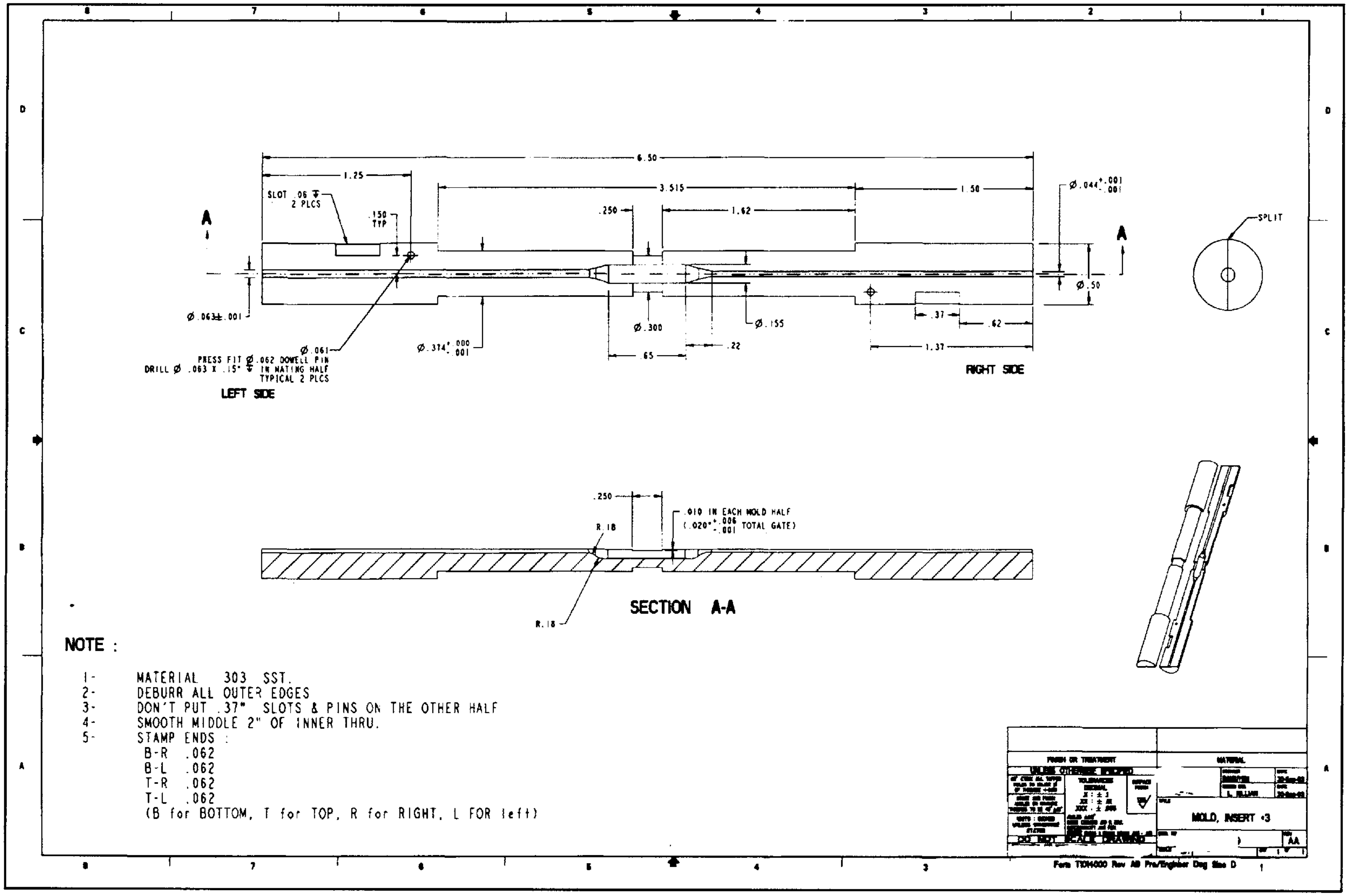
Mold Insert #1: # 10013062

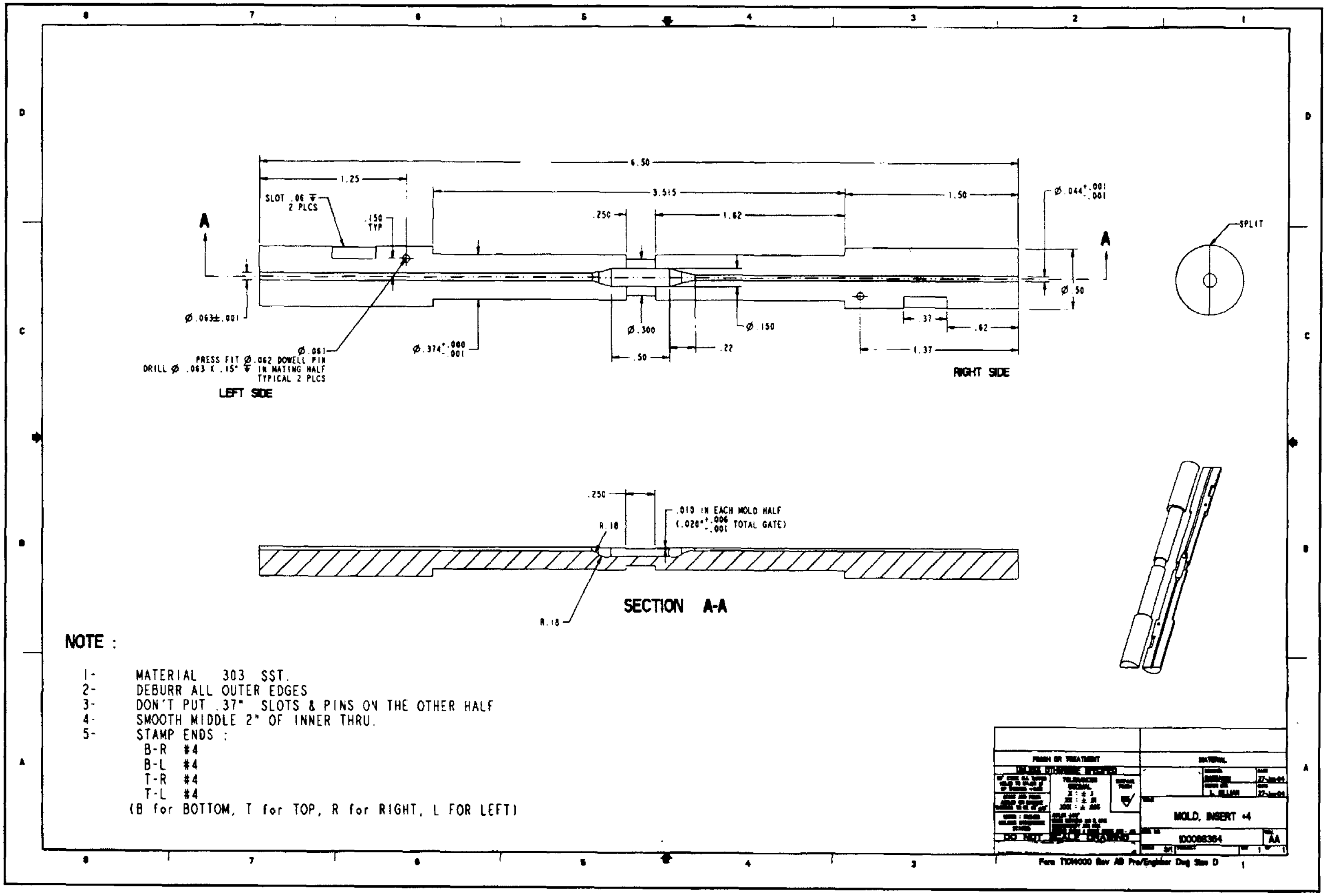


Mold Insert #2: # 100068348

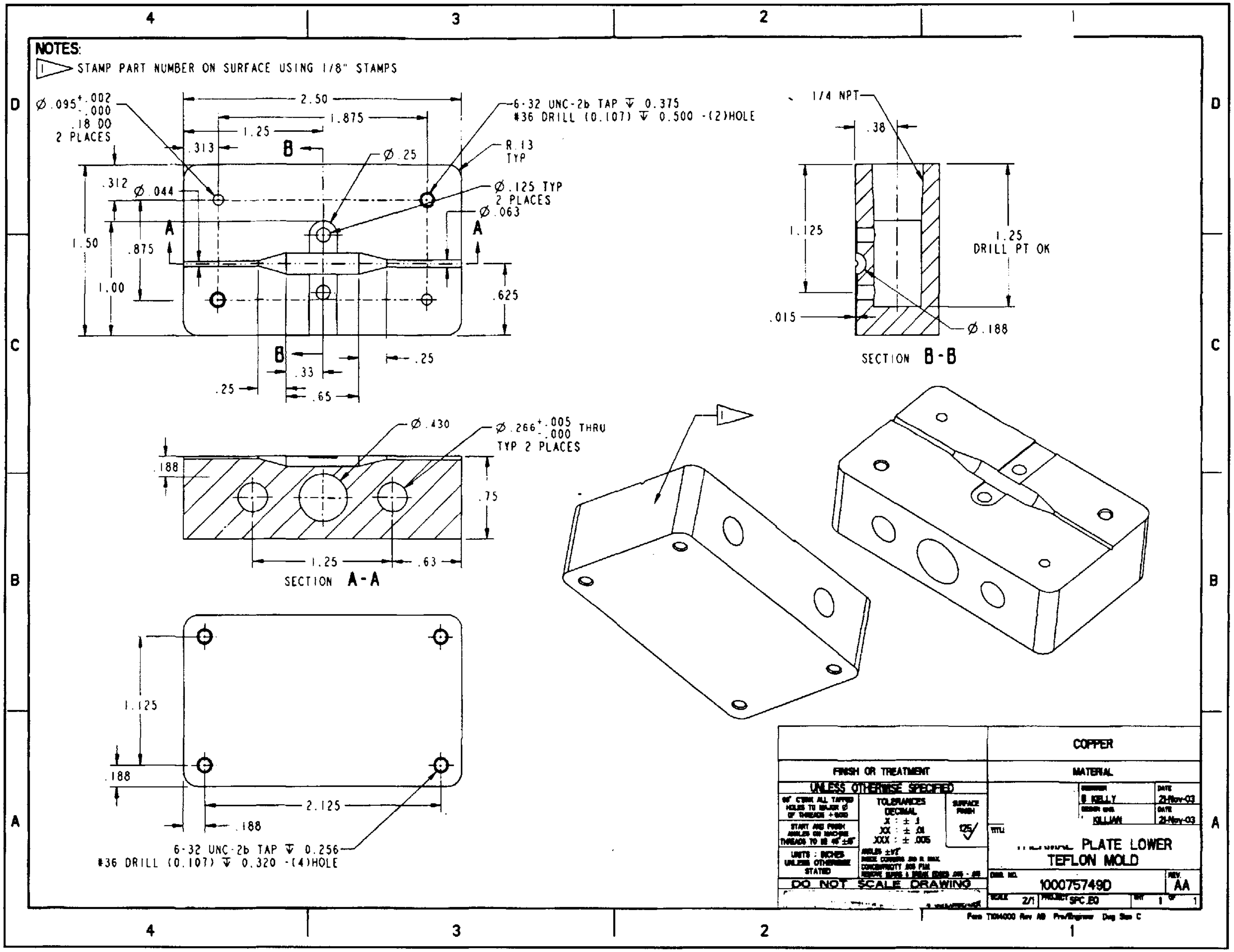


Mold Insert #3: # 100068349

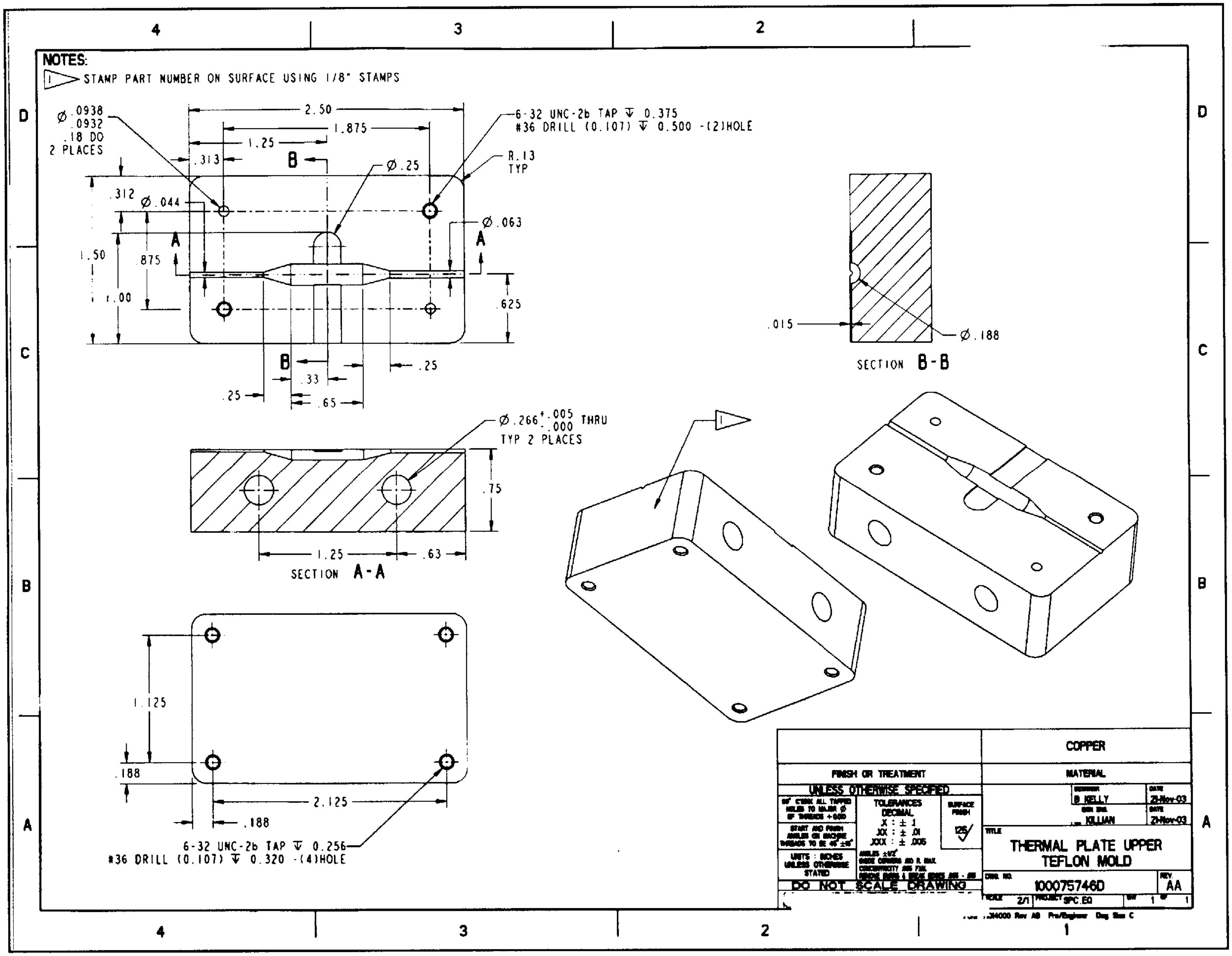




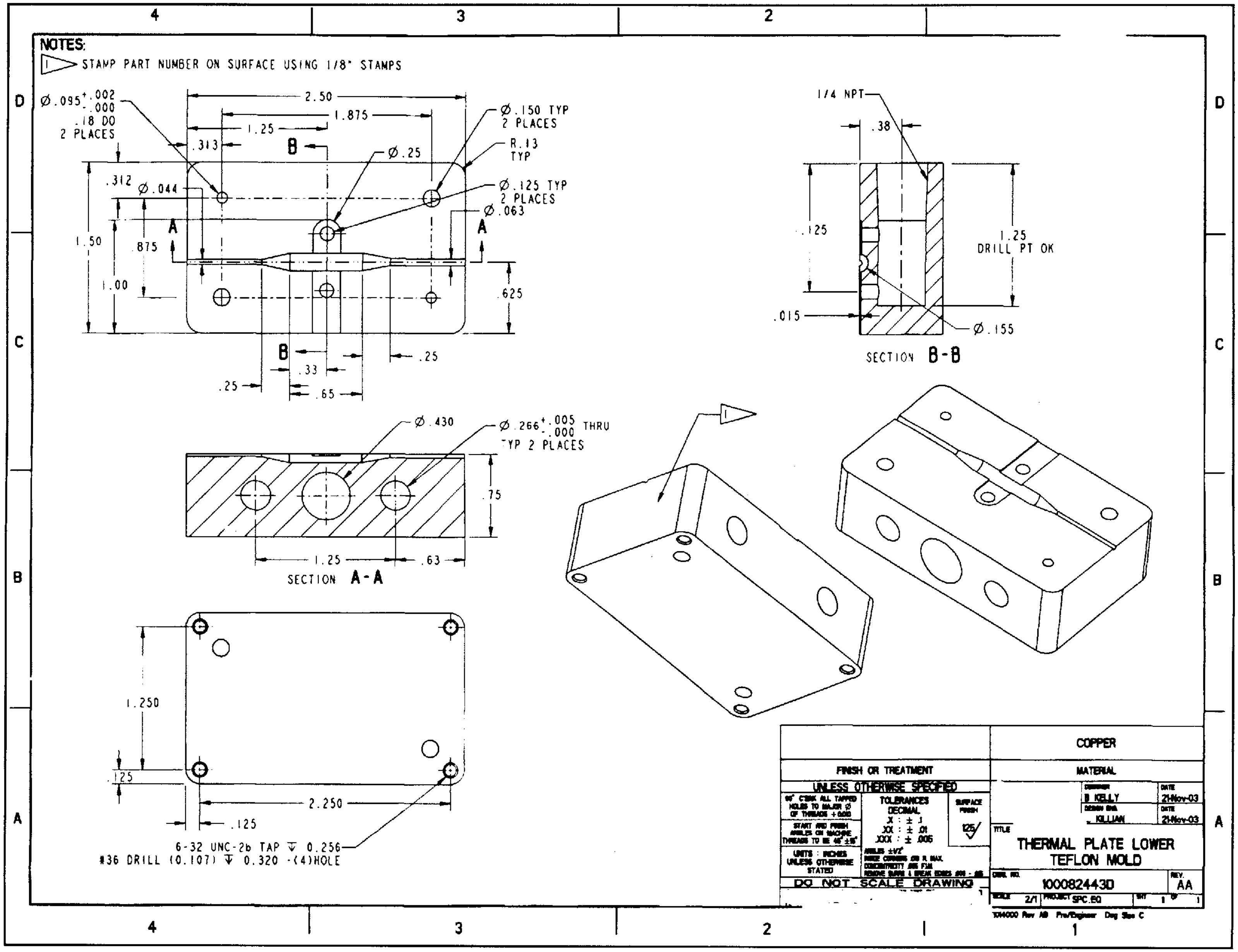

Mold Insert #4: # 10068364

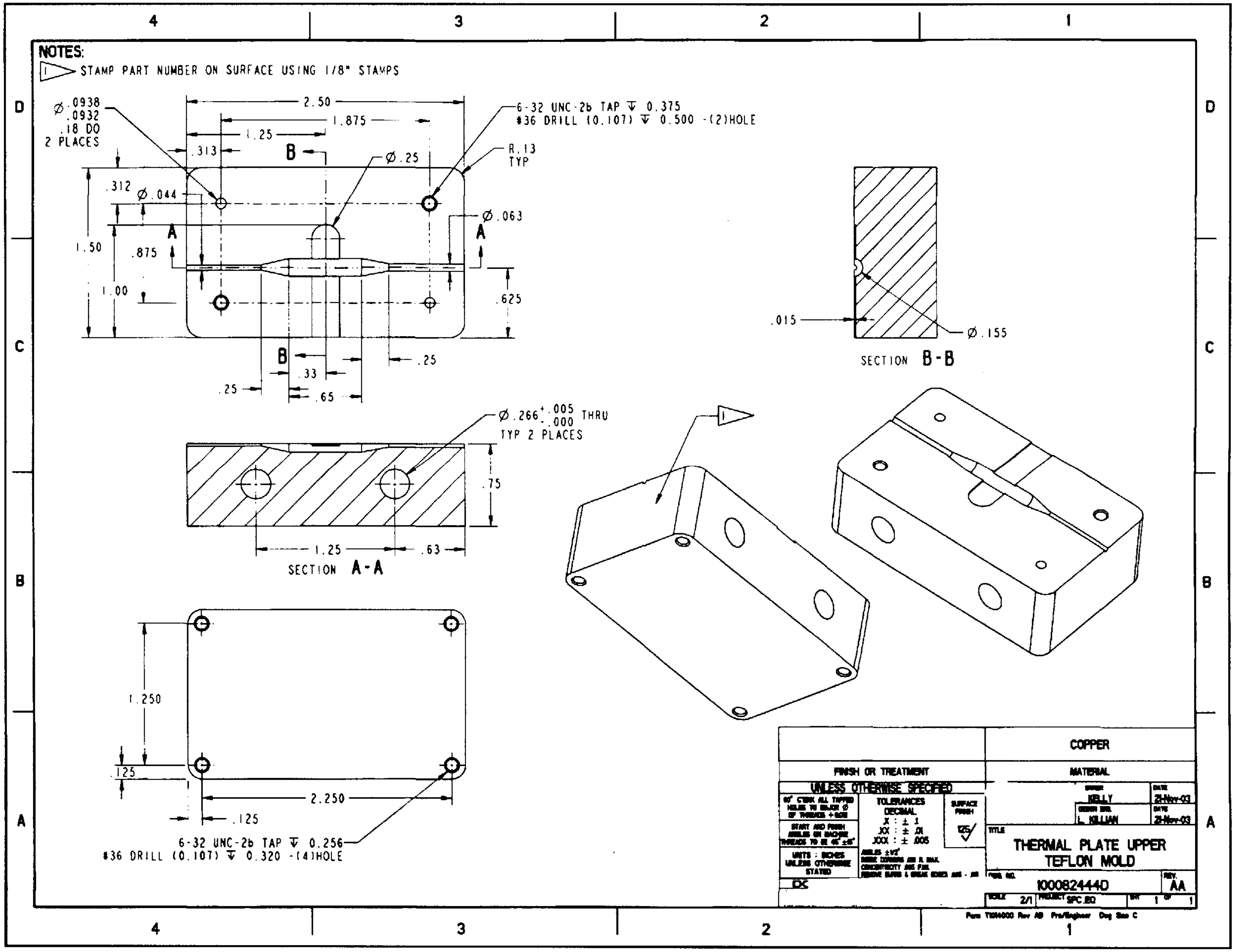



1st Rectangular Mold: # 10007549D and 10007546D


NOTES:
1 STAMP PART NUMBER ON SURFACE USING 1/8" STAMPS
Ø.0938 .0932 .18 DO 2 PLACES
2.50
1.875
1.25
.313
B
Ø.25
6-32 UNC-2b TAP ↧ 0.375
#36 DRILL (0.107) ↧ 0.500 -(2)HOLE
R.13 TYP
.312
Ø.044
Ø.063
A
1.50
.875
1.00
.625
.25
.33
.65
.015
Ø.188
SECTION B-B
Ø.266 +.005 -.000 THRU
TYP 2 PLACES
.75
1.25
.63
SECTION A-A
1.125
.188
2.125
6-32 UNC-2b TAP ↧ 0.256
#36 DRILL (0.107) ↧ 0.320 -(4)HOLE
COPPER
FINISH OR TREATMENT
MATERIAL
UNLESS OTHERWISE SPECIFIED
TOLERANCES DECIMAL
.X : ± .1
.XX : ± .01
.XXX : ± .005
125
UNITS : INCHES UNLESS OTHERWISE STATED
B KELLY
21-Nov-03
KILLIAN
21-Nov-03
THERMAL PLATE UPPER TEFLON MOLD
100075746D
AA
DO NOT SCALE DRAWING
2/1
SPC EQ

2nd Rectangular Mold: # 100082443D and 100082444D




NOTES:
1 STAMP PART NUMBER ON SURFACE USING 1/8" STAMPS
Ø .0938 .0932 .18 DO 2 PLACES
2.50
1.875
1.25
.313
B
Ø .25
6-32 UNC-2b TAP ↧ 0.375
#36 DRILL (0.107) ↧ 0.500 -(2)HOLE
R.13 TYP
.312
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Ø .063
A
A
1.50
.875
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B
.25
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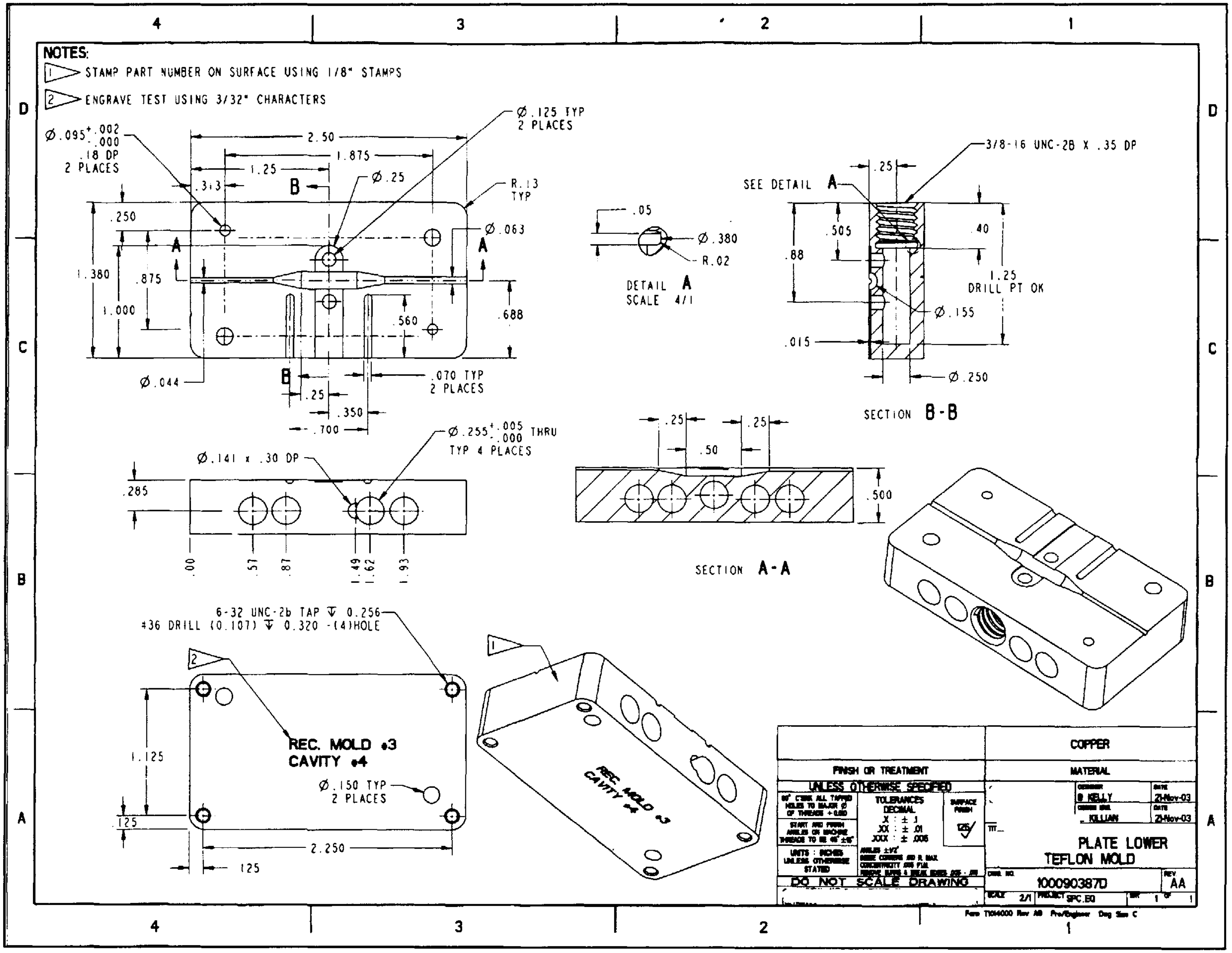
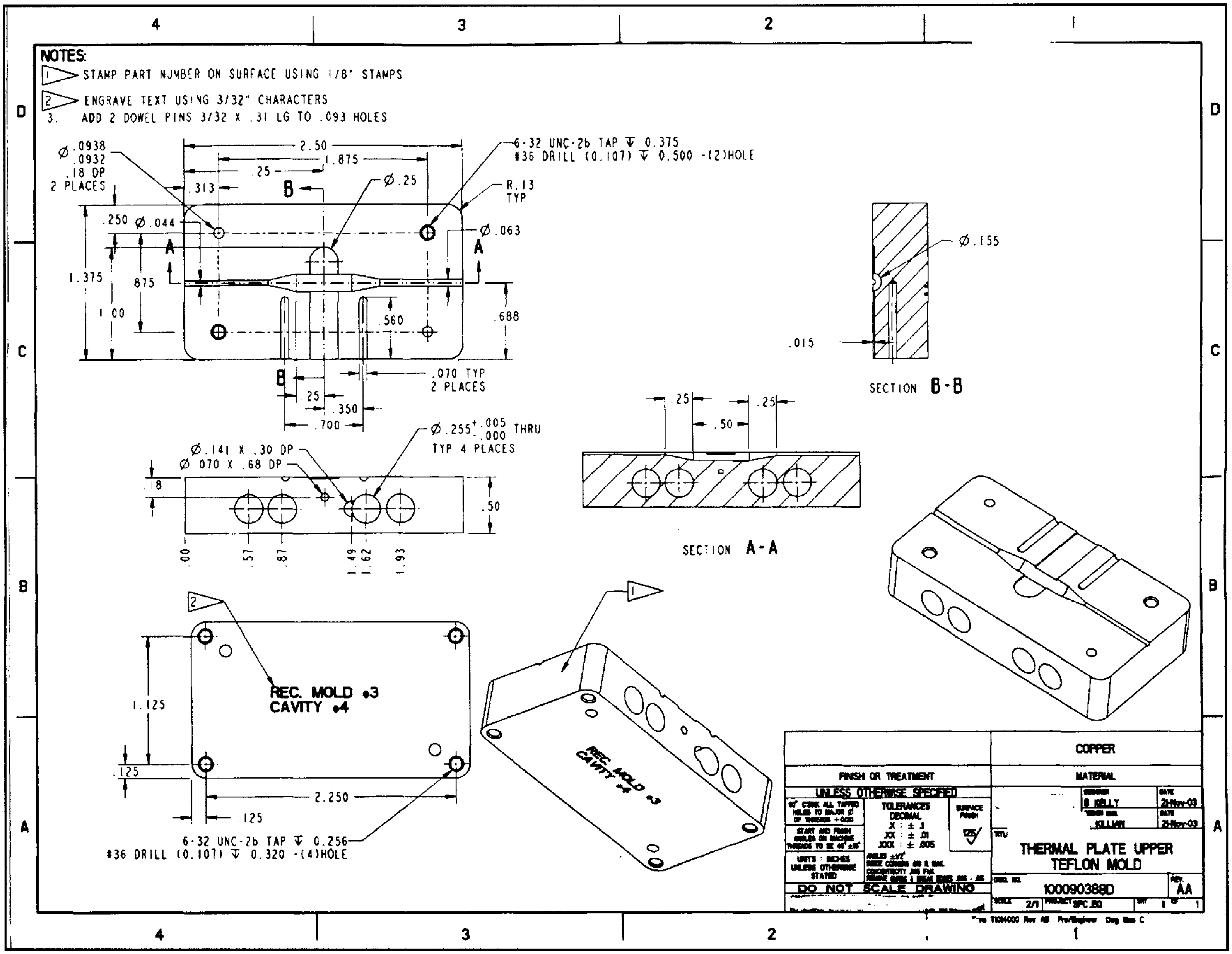
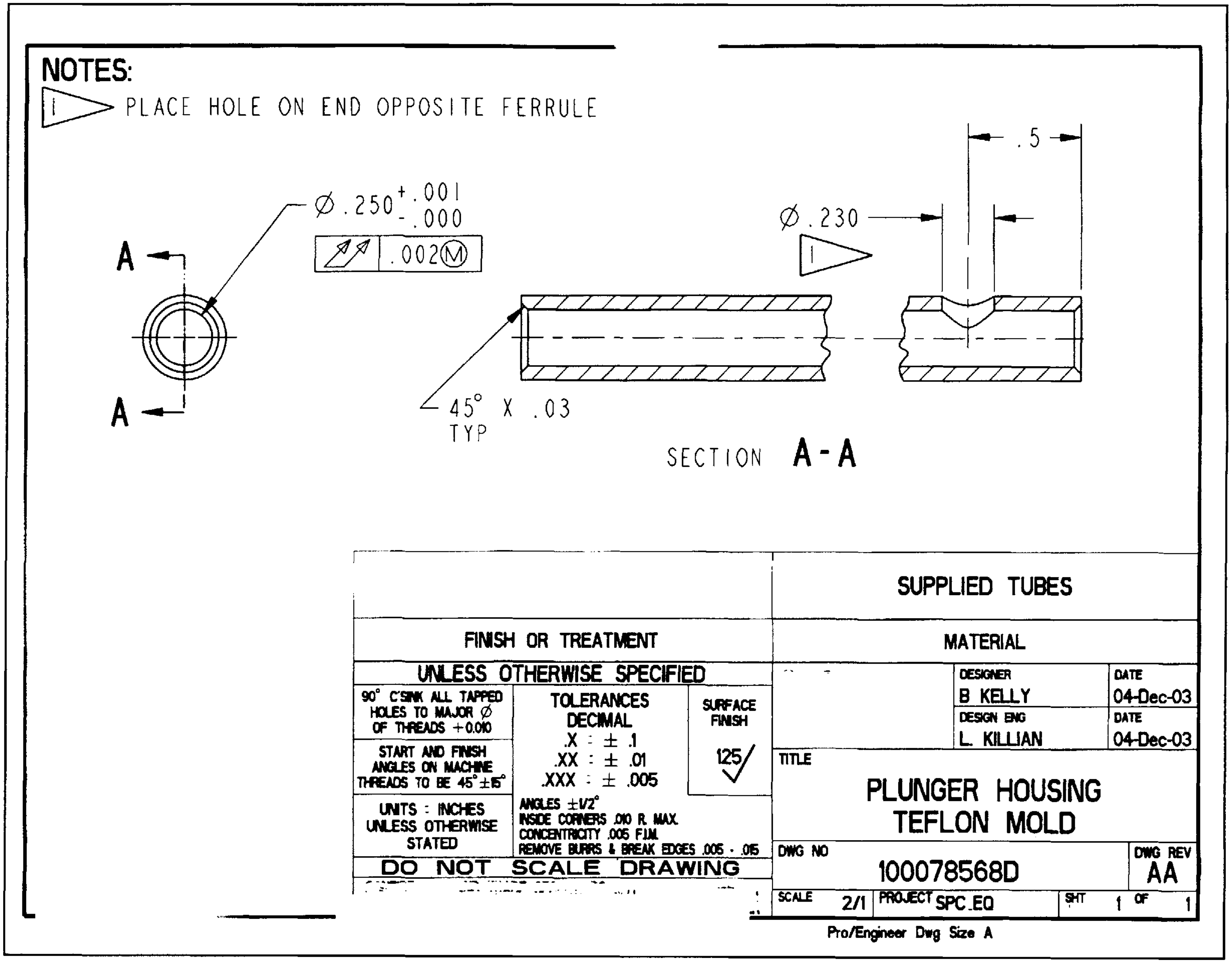
.65
.25
SECTION B-B
.015
Ø .155
Ø .266 +.005 -.000 THRU
TYP 2 PLACES
.75
1.25
.63
SECTION A-A
1
1.250
.125
2.250
.125
6-32 UNC-2b TAP ↧ 0.256
#36 DRILL (0.107) ↧ 0.320 -(4)HOLE
COPPER
FINISH OR TREATMENT
MATERIAL
UNLESS OTHERWISE SPECIFIED
TOLERANCES
DECIMAL
.X : ± .1
.XX : ± .01
.XXX : ± .005
SURFACE FINISH
125
UNITS : INCHES UNLESS OTHERWISE STATED
KELLY
21-Nov-03
L. KILLIAN
21-Nov-03
TITLE
THERMAL PLATE UPPER
TEFLON MOLD
1000824440
REV. AA
SCALE 2/1
PROJECT SPC.EQ
SH 1 OF 1
Form T004000 Rev AB Pro/Engineer Dwg Size C

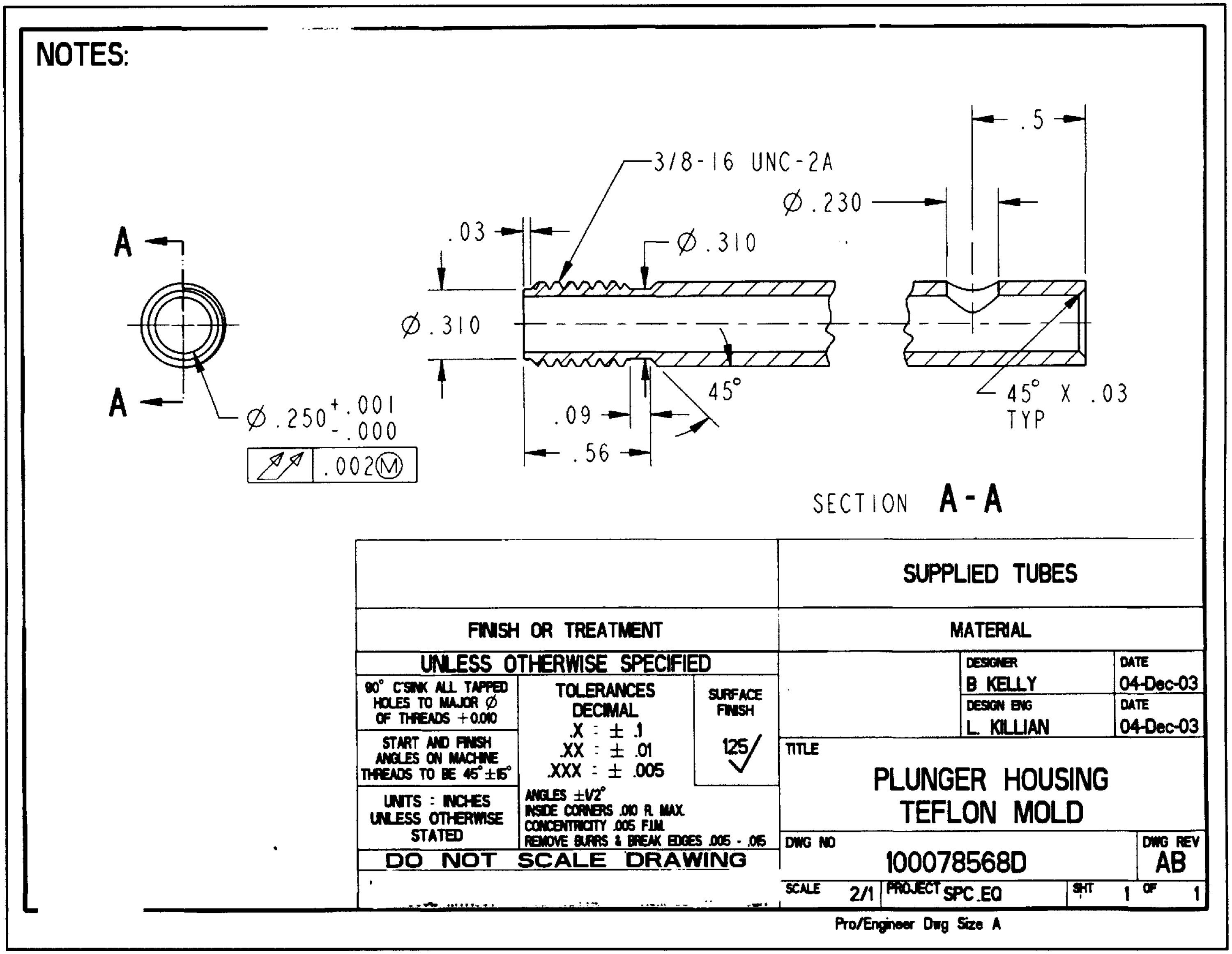



3rd Rectangular Mold: # 100090387D and 100090388D


NOTES:
1 STAMP PART NUMBER ON SURFACE USING 1/8" STAMPS
2 ENGRAVE TEXT USING 3/32" CHARACTERS
3. ADD 2 DOWEL PINS 3/32 X .31 LG TO .093 HOLES
Ø .0938 .0932 .18 DP 2 PLACES
6-32 UNC-2b TAP ↧ 0.375 #36 DRILL (0.107) ↧ 0.500 -(2)HOLE
R.13 TYP
Ø .25
Ø .044
Ø .063
Ø .155
.070 TYP 2 PLACES
Ø .141 X .30 DP
Ø .070 X .68 DP
Ø .255 +.005 -.000 THRU TYP 4 PLACES
SECTION B-B
SECTION A-A
REC. MOLD #3 CAVITY #4
6-32 UNC-2b TAP ↧ 0.256 #36 DRILL (0.107) ↧ 0.320 -(4)HOLE
COPPER
MATERIAL
FINISH OR TREATMENT
UNLESS OTHERWISE SPECIFIED
TOLERANCES DECIMAL .X ± .1 .XX ± .01 .XXX ± .005
UNITS : INCHES UNLESS OTHERWISE STATED
DO NOT SCALE DRAWING
B KELLY 21-Nov-03
KILLIAN 21-Nov-03
THERMAL PLATE UPPER TEFLON MOLD
100090388D
AA
2/1

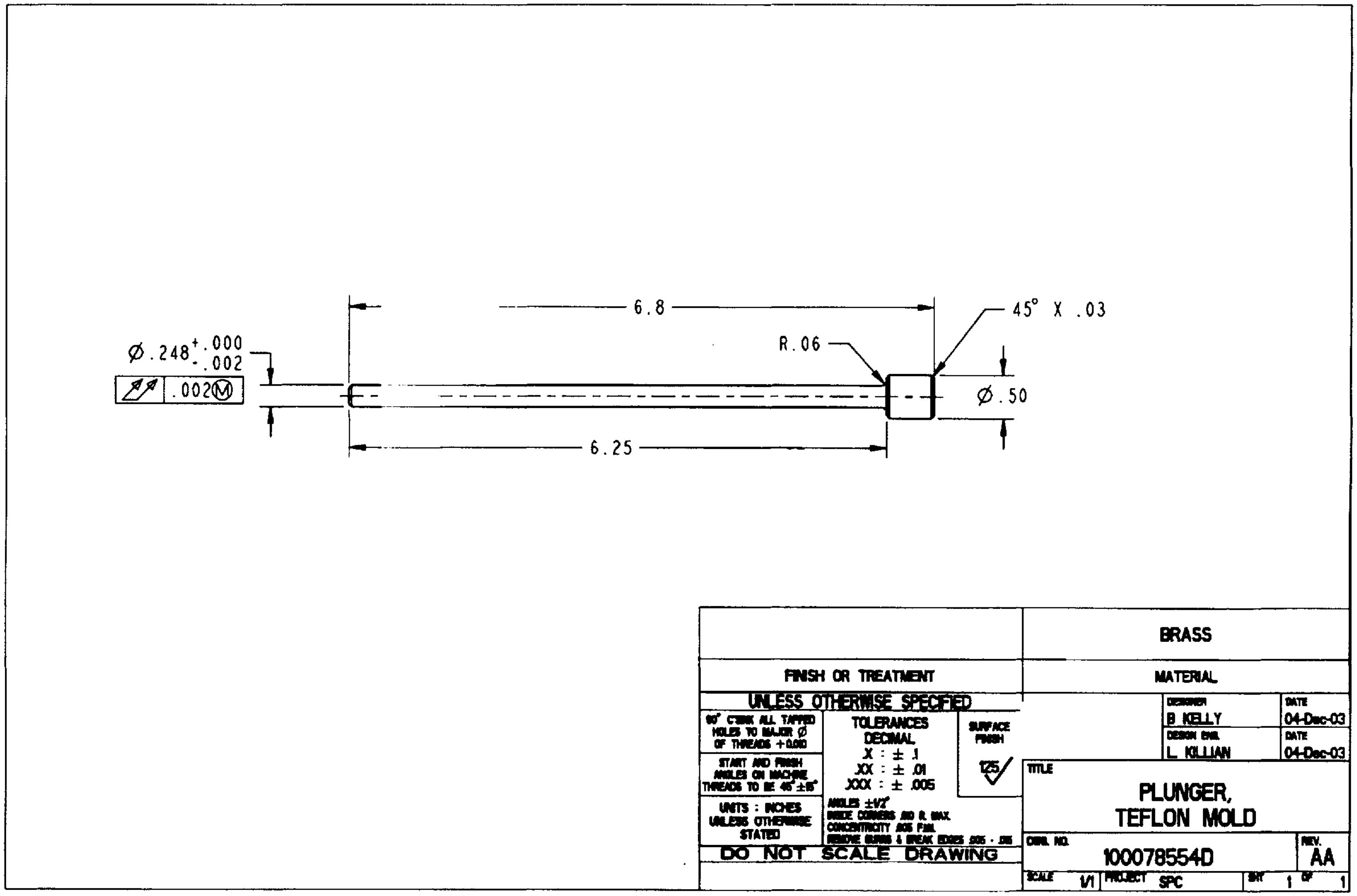



Original Stainless Steel Injecting Tube: # 100078568D




Later Stainless Steel Injecting Tube: # 100078568D

Original Brass Plunger: # 100078554D



### B.5 The Mold

**Shape:**

Plastic is injected into the rear, bottom-half of the mold (see part drawing GeMS# 100094285D). The melt then splits as it turns upward (at a 90-degree angle), turns another 90-degrees inward, and finally enters the cavity from either side of the wire-connection. It is an important characteristic of the mold that the plastic enters from two sides (through the two gates). This is designed to help center the connection. The gates are structured so the coated splice can be easily cut out of the mold and removed, followed by excess plastic being cut out when there is no longer a risk of damaging the splice.

Though the direction of initial injection (from the side and into the bottom half of the mold) has several positive aspects, a change should be considered. The current design provides the simplicity of cutting the coated splice from the more accessible bottom-mold, as well as having no other moving part other than the unencumbered top-mold. Additionally, the current design of injection from the side (rather than above) was pursued for ease of prototyping and because of concerns with melted plastic leaking from above onto the top of the mold. However, these two issues are no longer concerns so the next generation design should consider injecting from above. Reasons for injecting straight into the mold, without the initial 90-degree turn, include the simplified cleaning of the flow path (which is particularly important if cleaning becomes an issue over time).

The mold's cavity shape has been optimized using the "SCD Machine" (a wire-insulation-repairing machine). Two dimensions of primary consideration are the length and diameter of the cavity. Cavities that are too long or that have diameters that are too large are likely to have the melt push the wire off-center. Cavities that are too short or have diameters that are too small, risk the protrusion of the bent wire-connection to the edge of the cavity. Insufficient insulation coverage can then occur. Another important dimension is the height of the gates (the two paths of rectangular cross section that Teflon flows through in order to enter the cavity from two sides). When the gates are too high, insufficiently heated plastic is allowed to enter the cavity and air is likely to become trapped before it can escape the melt. Concerning the important dimensions of the mold, machine shops may have particular difficulty cutting the curved cavity correctly.

Other characteristics of the mold include the mold pieces being clamped together by tightening two screws going through the mold. In the future, it is recommended to supply clamping force with a hydraulic clamp, in order to supply a high clamping force as well as a quick release.

**Material:**

The mold, like the plunger and injection tube, is made of Monel K-500. This material was chosen because of its corrosion-resistant properties. It is more difficult to procure, more expensive, and harder to machine than other materials investigated, but it has significant advantages because of the reduced cleaning required. Monel has been working well, but if an even more corrosion-resistant alloy is desired, Hastelloy should be considered (such as Hastelloy C-276 or MP 35). Note however, that since Hastelloy has a lower thermal conductivity, is more expensive, and less readily available than Monel it is not recommended unless an unacceptable corrosion problem develops.

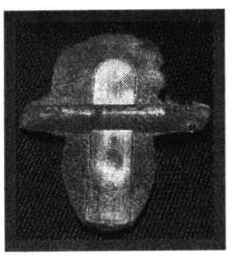


**Figure 31.** Material selection is important because using a material that corrodes easily will lead to contamination problems in the coating. In this example, the Teflon coating (usually clear) has turned yellow from contact with a copper mold. Changing to a mold made of Monel, during the design-phase, addressed this issue.

**Thermal Characteristics**:

To assist in heating the mold, holes for heaters and thermocouples exist. Also, the volume of the mold's material should continue to be minimized for faster heating and cooling. In the future, an active cooling system could be added. The procedure on the following pages can be used in designing additional molds and approximating their cooling characteristics.

## B.6 Design of Heated Molds[39] (including energy calculations)

# Introduction:

This application guide, devoted to the application of electric heating elements in various environments, is organized according to a step-by-step method that is modified to handle specific application problems.

First, the method is defined, then each step in the method is described. Later in this section there are solved example problems to demonstrate solution techniques.

The approach uses a static heat transfer analysis in an effort to clearly state the application solution. First level approximations have been used throughout, and then supplemented with safety factors. We encourage the use of more detailed thermal analysis if the system warrants a more exact solution.

The physical properties of most commonly used materials are included in the General Engineering Data Section of this Application Guide.

**Steady State Approach**

Because of the complex nature of transient heat flow calculations, we are utilizing a steady state approach. Transient cases will be handled with a simplified technique that defines the starting and finishing points, but doesn't allow for analysis of points in between.

**Energy And Power**

Throughout this section heater ratings are established in units of **Power** (watts). However, the **Energy** (watt hr) needs are first established and then converted to **Power** (watts). Energy is a basic physical unit usually expressed in British Thermal Units (BTU) or watt hr. Power defines the **Rate** at which energy is being used (BTU/hr or watts). Power and energy are related by:

$$\text{Power (watts or BTU/hr)} = \frac{\text{Energy (watt} \cdot \text{hr or BTU)}}{\text{Time (Hours)}}$$

This concept is extremely important. A heater has a **Power** rating of 1000 watts regardless of time; however, the **Energy** rating of this same 1000 watt heater is:

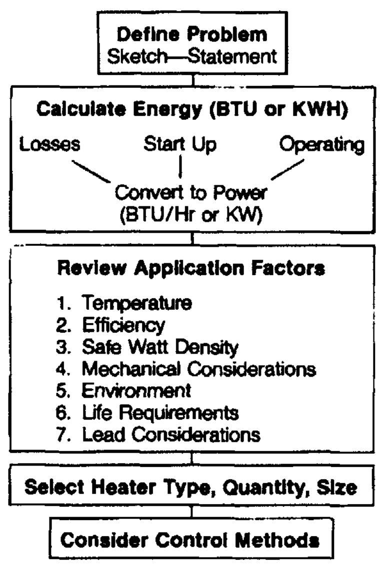
1,000 watt · hr (1 KWH) for 1 hour usage
10,000 watt · hr (10 KWH) for 10 hour usage

# Method—Determining Requirements

Most electrical heating problems can be readily solved by determining the heat required to do the job. The heat requirement must be converted to electrical power and the most practical heater then selected for the job. Whether the problem is heating gases, liquids or solids, the approach to determining the power requirement is the same. All heating problems involve the following steps to their solution:

1. Definition of the problem. A brief statement and sketch of the known requirements and parameters concerning the problem.
2. Calculation of heat energy required (KWH or BTU).
   A. Losses—System Losses Under Operating Conditions
      1. Conduction
      2. Convection
      3. Radiation
   B. Heat Required for Process Start-Up.
   C. Heat Required to Maintain Process.
   D. Convert to Power.
3. Review application factors to evaluate the operating environment, life requirements, mechanical considerations, and operating costs.
4. Selection of the type, size, and number of heaters, while considering factors such as efficiency and total system cost.
5. Consideration of the temperature control method.

All of the examples mentioned in this section use this approach to their solution. The solved problems at the end of the section illustrate this method.




[39] Watlow. "Watlow Electric Heating Technology" electric heaters catalog. pp. 332-336, 379-380. (As distributed by Thermal Solutions, Controls & Indicators; 24310 Tomball, TX 77375, (281) 351-4328.)

# Defining the Problem

The heating problem must be clearly stated, specifically defining the operating parameters:
—Minimum Start and Maximum Finish Temperatures Expected.
—Maximum Flow Rate of Heated Material(s).
—Required Start Heat-Up Time, and Process Cycle Times.
—Weights and Dimensions of Both Heated Media and Containing Vessels.
—Effects of Insulation and Its Thermal Properties.
—Electrical Requirements Such as Voltage, Control Methods and Electrical Limitations.
—Other Requirements:
1. Safety Considerations
2. Heater Life Requirements
3. Efficiency and Cost Factors

With these items in mind, an assessment must be made as to whether enough information is available for problem solution. Supporting information from the available body of reference material will be required. As a minimum, the thermal properties of both the process materials and the containing vessel will be required.

# Energy Calculations

## Calculation of Heat Energy Required

The total heat energy (KWH or BTU) required to satisfy the system needs will be either of the two values shown below depending on which calculated result is larger.

a. Heat Required for Start-Up.
b. Heat Required to Maintain the Desired Temperature.

The power required (KW) will be the heat energy value (KWH) divided by the required start-up or working cycle time. The KW rating of the heater will be the greater of these values plus a safety factor.

The calculation of start-up and operating requirements consist of several distinct parts that are best handled separately. However, a short method can also be used for a quick estimate of heat energy required. Both methods are defined below and then evaluated using the following formulas and methods:

## Short Method

Start-up watts = A + C + ⅔L + Safety Factor
Operating watts = B + D + L + Safety Factor
Safety Factor is normally 10% to 35% based on application.

A = Watts required to raise the temperature of material and equipment to the operating point, within the time desired.
B = Watts required to raise temperature of the material during the working cycle.

**Equation for A and B (Absorbed watts—raising temperature)**

$$\frac{\text{Lbs. of material (lbs)} \times \text{Specific heat of material (BTU/lb} \cdot {}^\circ\text{F)} \times \text{Temperature rise (}^\circ\text{F)}}{\text{Start-up or cycle time (hrs)} \times 3.412}$$

C = Watts required to melt or vaporize material during start-up period.
D = Watts required to melt or vaporize material during working cycle.

**Equation for C and D (Absorbed watts—melting or vaporizing)**

$$\frac{\text{Lbs. of material (lbs)} \times \text{heat of fusion or vaporization (BTU/lb)}}{\text{Start-up or cycle time (hrs)} \times 3.412}$$

L = Watts lost from surfaces by:
1. Radiation—use heat loss curves.
2. Convection—use heat loss curves.
3. Conduction—use equation below.

**Equation for L (Lost conducted watts)**

$$\frac{\text{Thermal conductivity of material or insulation (BTU} \cdot \text{in/ft}^2 \cdot {}^\circ\text{F} \cdot \text{hr)} \times \text{Surface area (ft}^2\text{)} \times \text{Temp. differential to ambient (}^\circ\text{F)}}{\text{Thickness of material or insulation (ins)} \times 3.412}$$

## Detailed Method

**Equation 1—Absorbed Energy, Heat Required to Raise the Temperature of a Material**
Because substances all heat differently, different amounts of heat are required in making a temperature change. The specific heat capacity of a substance is the quantity of heat needed to raise the temperature of a unit quantity of the substance by 1 degree. Calling the amount of heat added Q, which will cause a change in temperature ΔT to a weight of substance W, then $Q = W \cdot Cp \cdot \Delta T$.

**Example:** How much heat energy in BTU's is needed to change the temperature of 50 lbs. of copper from 10°F to 70°F?
$Q = W \cdot Cp \cdot \Delta T$ or
$Q = (50 \text{ lbs.}) \cdot (.10 \text{ BTU's per lb./}^\circ\text{F}) \cdot (60^\circ\text{F}) = 300$ BTU's

Since all calculations are in watts, an additional conversion of 3.412 BTU = 1 Watt. Hr is introduced yielding:

**Equation 1—Absorbed Energy, Heat Required to Raise the Temperature of a Material**

$$Q_1 \text{ (BTU)} = W \cdot Cp \cdot \Delta T$$

$$Q_1 \text{ (WH)} = \frac{W \cdot Cp \cdot \Delta T}{3.412}$$

$Q_1$ = Heat Required to Raise Temperature
W = Pounds of Material
$C_p$ = Specific Heat of Material (BTU/lb. · °F)
ΔT = Temperature Rise of Material ($T_{Final} - T_{Initial}$) °F

This equation should be applied to all materials absorbing heat in the application. Heated media, work being processed, containers, racks, belts, and ventilation air should be included.

**Equation 2—Heat Required to Melt or Vaporize a Material**
In considering adding heat to a substance, it is also necessary to anticipate changes in state that might occur during this heating such as melting and freezing. The heat needed to melt a unit quantity of material is known as the latent **heat of fusion** and represented by $H_f$ in the relationship $Q = W \text{ (weight)} \times H_f$. Another state change is involved in vaporization and condensation. The latent **heat of vaporization** $H_v$ of the substance is the energy required to change a unit quantity of the substance from a liquid to a vapor. This same amount of energy is released as the vapor condenses back to a liquid. The energy required is given by the relationship $Q = W \text{ (weight)} \times H_v$. It is important to keep in mind that in both vaporizing and melting, the heat of the system must be increased to make the change.

**Example:** How much energy is required to melt 50 lbs. of lead?
$Q_2 = W \cdot H_f$ or
$Q_2 = (50 \text{ lbs.}) \cdot (11.3 \text{ BTU/lb.}) = 565$ BTU's

**Equation 2—Heat Required to Melt or Vaporize a Material**

$$Q_2\ (BTU) = W \cdot H_f \text{ or } W \cdot H_v$$

$$Q_2\ (WH) = \frac{W \cdot H_f}{3.412} \text{ or } \frac{W \cdot H_v}{3.412}$$

$Q_2$ = Heat Required to Melt/Vaporize
W = Pounds of Material
$H_f$ = Latent Heat of Fusion (BTU/lb.)
OR
$H_v$ = Latent Heat of Vaporization (BTU/lb.)

This is a constant temperature process than can change the specific heat value of the material. Separate heat absorbed calculations are then required using Equation 1 for the material below and above the phase change temperature which is used as the reference point.

**Equation 3—Losses**

Losses occur in systems in three ways: conduction, convection, and radiation. These values will be individually calculated and then summed for total losses.

**Conduction**

Heat transfer by conduction is the contact exchange of heat from one body at a higher temperature to another body at a lower temperature, or between portions of the same body at different temperatures. The transfer of energy takes place from the higher temperature body to the lower temperature body.

As a rule, heat transfer by conduction is faster in solids because of the more tightly packed molecules, and by the same reasoning somewhat slower in liquids, and slower still in gases on account of their relative densities.

Problems involving the addition or subtraction of heat from a system wherein conduction is the heat transfer mechanism can be solved by using a derivation of Fourier's Law for steady state conduction:

**Equation 3A—Conduction Losses**

$$Q_{L1}\ (BTU) = \frac{K \cdot A \cdot \Delta T \cdot t_e}{L}$$

$$Q_{L1}\ (WH) = \frac{K \cdot A \cdot \Delta T \cdot t_e}{3.412 \cdot L}$$

$Q_{L1}$ = Conduction Heat Losses
K = Thermal Conductivity
BTU·In./Ft$^2$·°F·Hour
A = Heat Transfer Surface Area (Sq. Ft.)
L = Thickness of Material (Inches)
T = Temperature Difference Across Material ($T_2-T_1$) °F
$t_e$ = Exposure Time (Hours)

This expression can be used to calculate losses through insulated walls of containers or other plane surfaces where the temperature of both surfaces can be determined or estimated. It is also useful in determining losses in situations where a surface loss factor $F_{SL}$ in Equation 3B is not known. Tabulated values of thermal conductivity are included in this section.

**Convection**

Convection is a special case of conduction. Convection is defined as the transfer of heat from a high temperature region in a gas or liquid as a result of movement of the masses of the fluid. Calculation of this factor is a difficult fluid dynamics problem that is approximated by using empirically derived graphical data. Care must be taken to recognize whether natural or forced convection is occurring, and the appropriate curves utilized.

**Equation 3B—Convection Losses**

$$Q_{L2}\ (BTU) = 3.412 \cdot A \cdot F_{SL} \cdot C_F \cdot t_e$$
$$Q_{L2}\ (WH) = A \cdot F_{SL} \cdot C_F \cdot t_e$$

$Q_{L2}$ = Surface Heat Losses
A = Surface Area (In$^2$)
$F_{SL}$ = Vertical Surface Convection Loss Factor (Watts/In$^2$) Evaluated at Surface Temperature (See Fig. 1)
$C_F$ = Surface Orientation Factor

| | |
|---|---|
| Horizontal Top | = 1.29 |
| Vertical | = 1.00 |
| Horizontal Bottom | = 0.63 |

$t_e$ = Exposure Time (Hours)

**Radiation**

For the purposes of this section, graphs are utilized to estimate radiation losses and watts/in.$^2$ vs. temperature. Charts give emissivity values. The radiation loss graph shows losses from a perfect blackbody and are not dependent on orientation of the surface. Emissivity is used to convert the blackbody curve values for various materials. Emissivity (e) has a range of 0 to 1.0.

**Example:**

At 500°F, blackbody losses are 2.5 watts/in$^2$. Polished aluminum (e=.09) losses are 2.5 watts/in$^2$×e= .22 watts/in$^2$.

**Equation 3C—Radiation Losses**

$$Q_{L3}\ (BTU) = 3.412 \cdot A \cdot F_{SL} \cdot e \cdot t_e$$
$$Q_{L3}\ (WH) = A \cdot F_{SL} \cdot e \cdot t_e$$

$Q_{L3}$ = Radiation Heat Losses
A = Surface Area (In$^2$)
$F_{SL}$ = Blackbody Radiation Loss Factor (Watts/In$^2$) Evaluated at Surface Temperature
e = Emissivity Correction Factor of Actual Material
$t_e$ = Exposure Time (Hours)

**Combined Convection and Radiation**

Most curves combine both radiation and convection losses. If only the convection component is required, then the radiation component must be determined separately and subtracted from the combined curve.

**Equation 3D—Combined Convection and Radiation Surface Losses:**

$$Q_{L4}\ (BTU) = 3.412 \cdot A \cdot F_{SL} \cdot t_e$$
$$Q_{L4}\ (WH) = A \cdot F_{SL} \cdot t_e$$

$Q_{L4}$ = Surface Heat Losses Combined Convection and Radiation
$A$ = Surface Area ($In^2$)
$F_{SL}$ = Surface Loss Factor (Watts/$In^2$) Evaluated Combined at Surface Temperature
$t_e$ = Exposure Time (Hours)

This equation assumes a constant surface temperature and the loss factor is to be evaluated at that point. Graphs of heat losses from various surfaces are included in this section. Their use is illustrated by the example problems. Both convective and radiant losses are normally taken into account by this method.

**Total Surface Losses**

The total conduction, convection and radiation losses are summed together to allow for all losses in the power equations. Depending on the application, some of these components may be very small and assumed negligible. In the case of surfaces where combined curves are used, the $Q_L$ total is calculated in the second equation as shown below:

**Equation 3E—Total Losses**

| | |
|---|---|
| $Q_L = Q_{L1} + Q_{L2} + Q_{L3}$ | If convection and radiation losses are calculated separately. (Surfaces are not uniformly insulated and losses must be calculated separately.) |
| OR | |
| $Q_L = Q_{L1} + Q_{L4}$ | If combined radiation and convection losses are used. (Pipes, ducts, uniformly insulated bodies.) |

During start-up of a system the losses are zero, and rise to 100% at process temperature. A good approximation of actual losses will be obtained by applying Equation 3E at the process temperatures, and then multiplying the result by ⅔.

**Equations 4 and 5—Start-Up and Operating Power Required**

Both of these equations estimate required energy and convert it to power. Since power (watts) specifies an energy rate, we can use power to select electric heater requirements. Both the start up power and the operating power must be analyzed before heater selection can take place.

**Equation 4—Start Up Power (Watts)**

$$P_S = \left[\frac{Q_A + Q_C}{t_s} + \frac{2}{3}\left(\frac{Q_L}{t_e}\right)\right] \cdot (1 + S.F.)$$

where:
$Q_A$ = Heat Absorbed by Materials During Heat-Up
$Q_C$ = Latent Heat Absorbed During Heat-Up
$Q_L$ = Conduction, Convection, Radiation Losses
S.F. = Safety Factor
$t_s$ = Start-Up Time Required (Hours)
$t_e$ = Exposure Time (Hours)

**Equation 5—Operating Power (Watts)**

$$P_O = \left[\frac{Q_B + Q_D}{t_c} + \frac{Q_L}{t_e}\right] \cdot (1 + S.F.)$$

where:
$Q_B$ = Heat Absorbed by Processed Materials in Working Cycle (WH)
$Q_D$ = Latent Heat Absorbed by Materials Heated in Working Cycle (WH)
$Q_L$ = Conduction, Convection, Radiation Losses
S.F. = Safety Factor
$t_c$ = Cycle Time Required (Hours)
$t_e$ = Exposure Time (Hours)

# Safety Factor

A safety factor of varying size is always added to allow for unknown or unexpected conditions. The size of the safety factor is dependent on the accuracy of the wattage calculation. Heaters should always be sized for a higher value than the calculated figure. A factor of 10% is adequate for small systems that are closely calculated; 20% additional wattage is more common. Values of 20% to 35% should be considered for large systems with doors opening or large radiant applications.

## Verification of Radiation Heat Transfer Problems

Where the primary mode of heat transfer is radiation, the problem solution must be verified using the Stefan-Boltzman equation.

This equation is used to calculate the net radiant heat transfer between two bodies.

Thermal radiation is electromagnetic radiation emitted by a body proportional to its temperature. Radiation heat transfer occurs when electromagnetic waves carry energy from hot objects to cool ones. The following derivation of Stefan-Boltzman Law expresses these relationships:

$$Q(\text{BTU}) = S \cdot A \cdot (T_1^4 - T_2^4) \cdot \left( \frac{1}{\frac{1}{e_1} + \frac{1}{e_2} - 1} \right) \cdot F$$

For our purposes this expression is typically utilized as watts/in.$^2$ where the process is assumed to be continuous and time equals one hour.

**Equation 6 — Radiation Heat Transfer Between Infinite Size Parallel Surfaces**

$$\frac{P_R \text{ (watts)}}{A \text{ (in}^2)} = \frac{S \cdot (T_1^4 - T_2^4) \cdot \left( \frac{1}{\frac{1}{e_1} + \frac{1}{e_2} - 1} \right) \cdot F}{(144 \text{ in}^2/\text{ft}^2) \cdot (3.412 \text{ BTU/watt} \cdot \text{hr})}$$

where:

$P_R$ = Watts Absorbed by the Load
$A$ = Area of Heater (in$^2$)
$S$ = Stephan Boltzman Constant
= $.1714 \times 10^{-8}$ (BTU/Hr. Sq. Ft. °R$^4$)
$T_1$(°R) = Emitter Temperature (°F + 460)
$T_2$(°R) = Load Temperature (°F + 460)
$e_1$ = Emissivity of Emitter (0 to 1.0)
$e_2$ = Emissivity of Load (0 to 1.0)
$F$ = Shape Factor (0 to 1.0)

Both emissivity and shape factor are measures of efficiency that must be utilized in radiant heating applications. They are used to compensate for different material emissivity characteristics and for side and end losses due to radiation scattering. The shape factors most used are for parallel planes facing each other separated by a working distance. See graphs in this section for values of F.

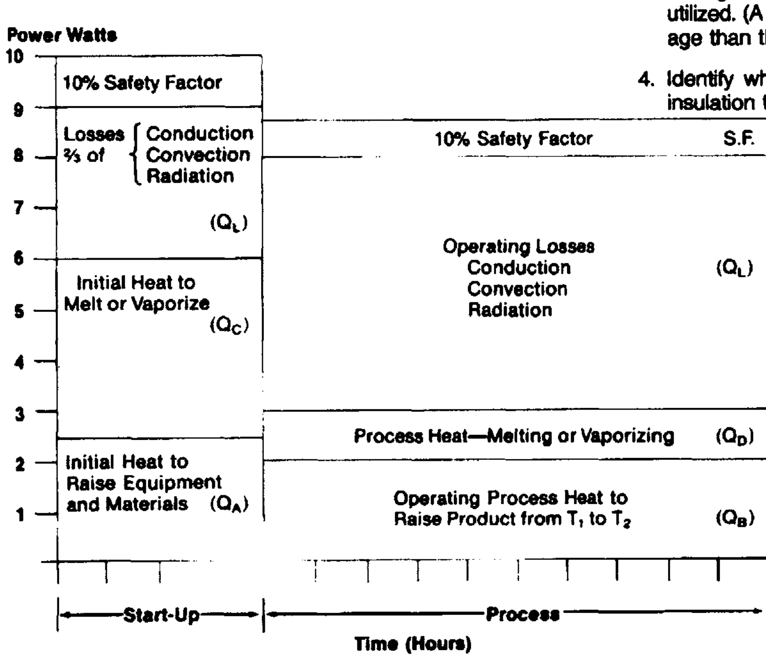
## Power Evaluation

After calculating the start-up and operating power requirements, a comparison must be made and various options evaluated.

Shown below are the start-up and operating watts displayed in a graphic format to allow visualization of the various component parts.

With this graphic aid in mind, the following evaluations are possible:

1. Compare start-up watts to operating watts.
2. Evaluate effects of lengthening start up time such that start up watts equals operating watts (use timer to start system before shift).
3. Recognize that more production capacity exists than is being utilized. (A short start-up time requirement needs more wattage than the processing wattage.)
4. Identify where most energy is going and redesign or add insulation to reduce wattage requirements.




Having considered the entire system, a re-evaluation of start-up time, production capacity, and insulating methods should be made. The selection of heaters will then be made utilizing the most efficient system.

# General Engineering Data

## Heat Loss Graphs

### Heat Losses at 70°F Ambient

**How to use the graph for more accurate calculations**

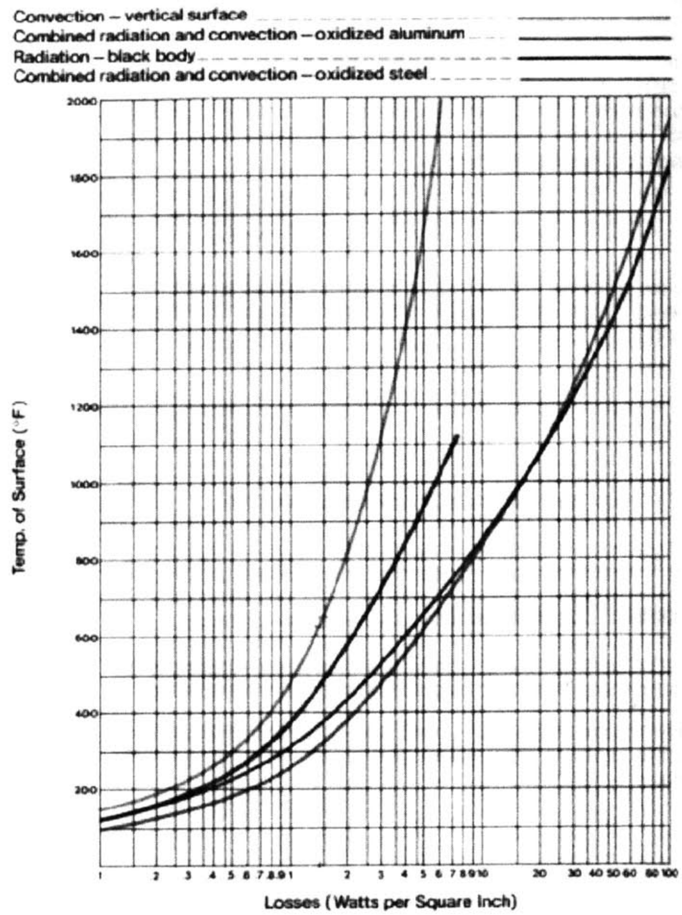
**Table 1- Convection curve correction factors:**

| | |
|---|---|
| For losses from top surfaces or from horizontal pipes | Multiply convection curve value by 1.29 |
| For side surfaces and vertical pipes | Use convection curve directly |
| For bottom surfaces | Multiply convection curve value by .63 |

**Radiation curve correction factors:**
The radiation curve shows losses from a perfect blackbody and are not dependent upon position. Commonly used block materials lose less heat by radiation than a blackbody, so correction factors are applied. These corrections are the emissivity (e) values listed below:

**Total Heat Losses =**
Radiation losses (curve value times e) + Convection losses (top) + Convection losses (sides) + Convection losses (bottom) + Conduction losses (where applicable)

### Figure 1- Heat Losses From Uninsulated Surfaces




### Some Material Emissivities — Table 2

| Material | Specific Heat BTU/lb. °F | Emissivity: Polished Surface | Emissivity: Med. Oxide | Emissivity: Heavy Oxide |
|---|---|---|---|---|
| Blackbody | | | | 1.00 |
| Aluminum | .24 | .09 | .11 | .22 |
| Brass | .10 | .04 | .35 | .60 |
| Copper | .10 | .04 | .03 | .65 |
| Incoloy 800 | .12 | .20 | .60 | .92 |
| Inconel 600 | .11 | .20 | .60 | .92 |
| Iron, cast | .12 | — | .80 | .85 |
| Lead, solid | .03 | — | .28 | — |
| Magnesium | .23 | — | — | — |
| Nickel 200 | .11 | — | — | — |
| Nichrome, 80-20 | .11 | — | — | — |
| Solder, 50-50 | .04 | — | — | — |
| Steel | | | | |
| mild | .12 | .10 | .75 | .85 |
| stainless 304 | .11 | .17 | .57 | .85 |
| stainless 430 | .11 | .17 | .57 | .85 |
| Tin | .056 | — | — | — |
| Zinc | .10 | — | .25 | — |

**To estimate losses (watts) from uninsulated surfaces:**
.67 watts x surface area (ft²) x temperature rise (°F) over ambient (70°F) = losses (watts)

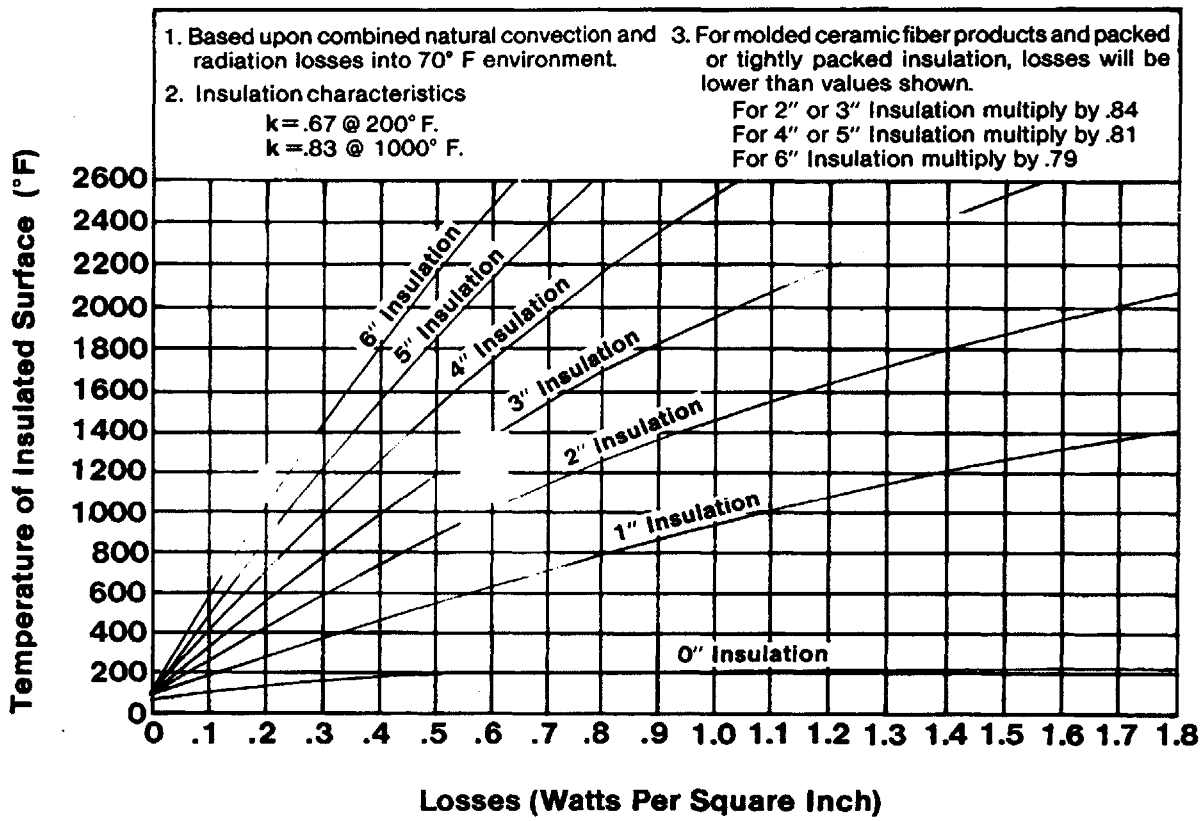
**To estimate losses (watts) from insulated surfaces:**
.16 watts x surface area (ft²) x temperature rise (°F) over ambient (70°F) = losses (watts)

| Material | Specific Heat BTU/lb. °F | Emissivity |
|---|---|---|
| Asbestos | .25 | Most non-metals: .90 |
| Asphalt | .40 | |
| Brickwork | .22 | |
| Carbon | .20 | |
| Glass | .20 | |
| Paper | .45 | |
| Plastic | .2-.5 | |
| Rubber | .40 | |
| Silicon Carbide | .20-.23 | |
| Textiles | — | |
| Wood, oak | .57 | |

Additional information on emissivities is available from Watlow.

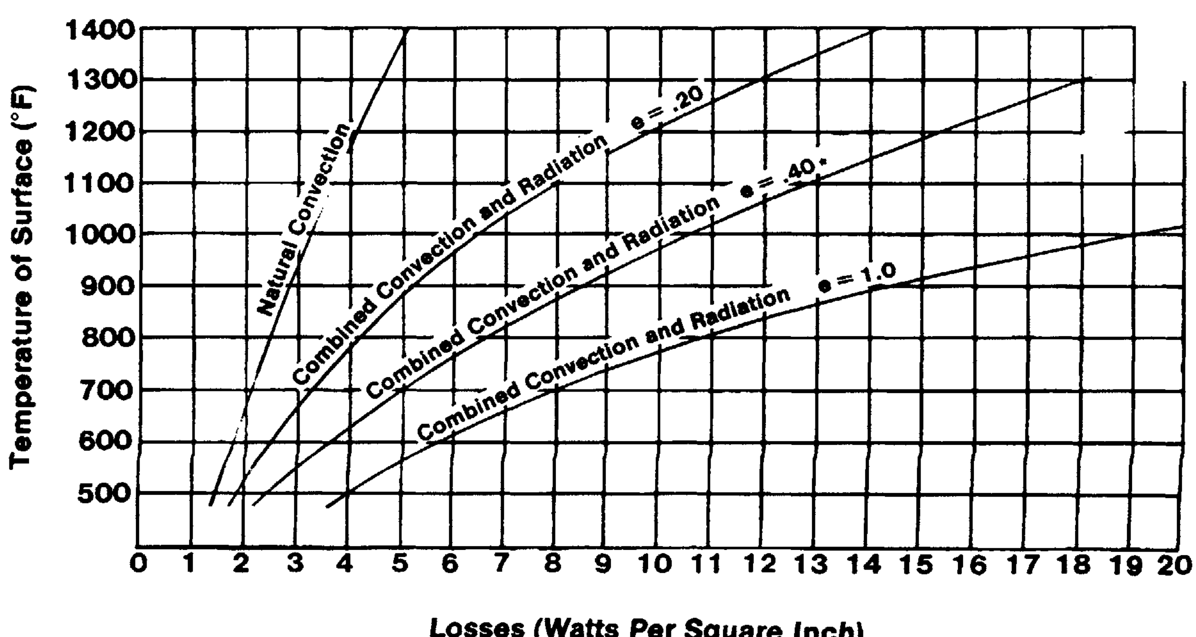
## Heat Losses From Vertical Insulated Surfaces

Figure 2-




## Losses From Horizontal Metal Surfaces

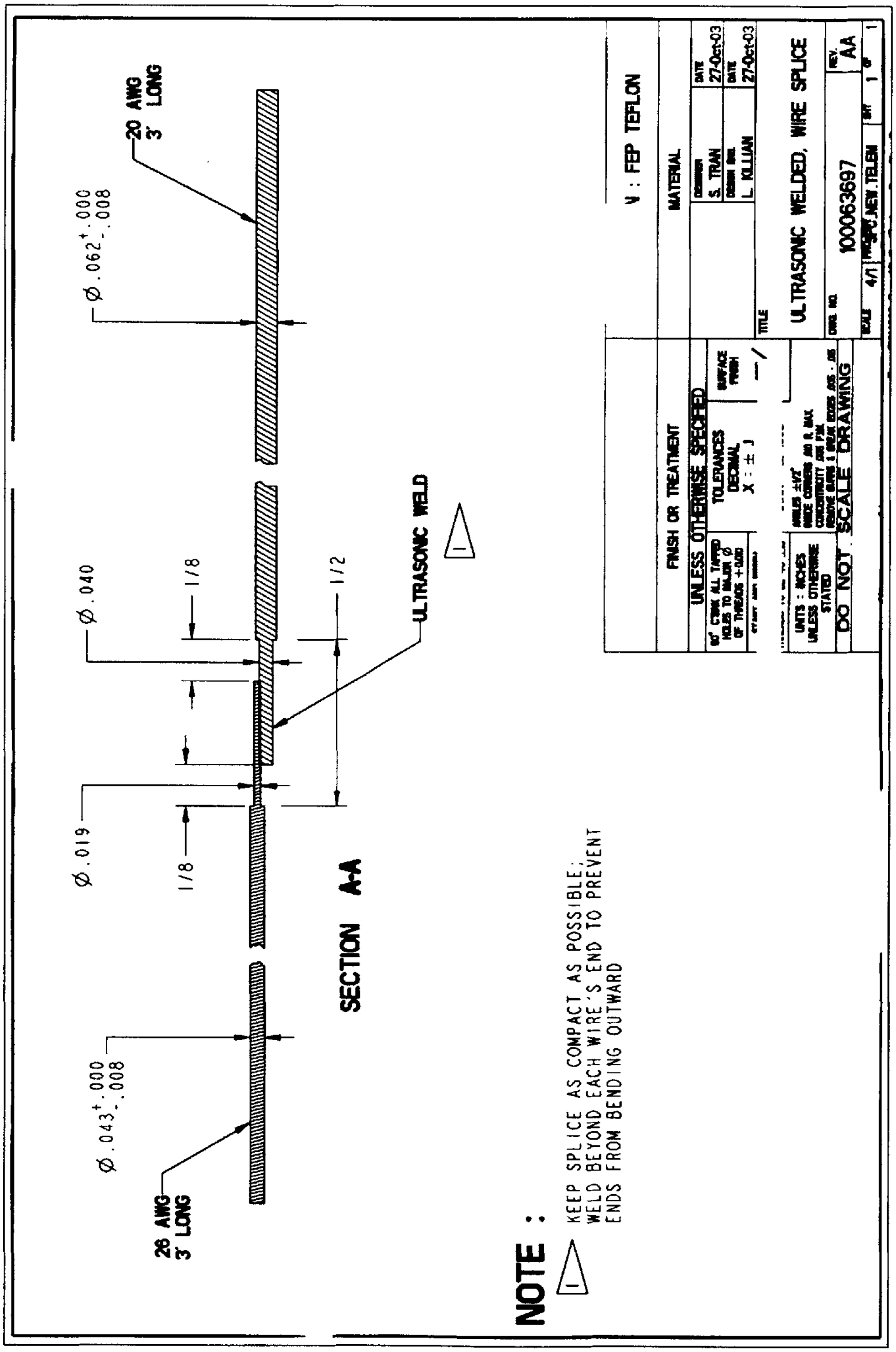
Figure 3-

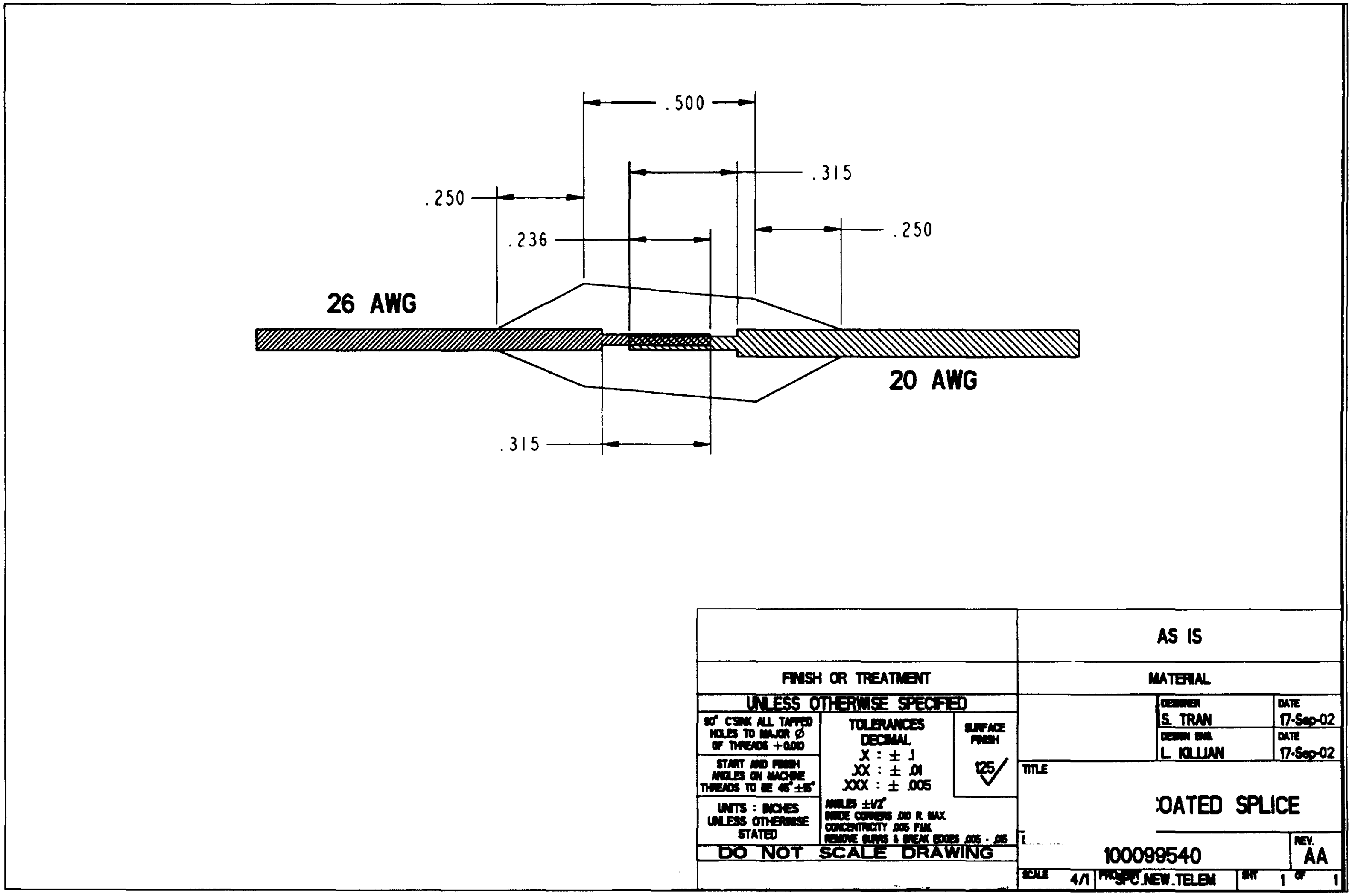



* For losses of molten metal surfaces, use the curve e = .40.

## Appendix C: Splices

### C.1 Splice Drawings (a wire connection and coated splice)




.500
.315
.250
.236
.250
26 AWG
20 AWG
.315
AS IS
FINISH OR TREATMENT
MATERIAL
UNLESS OTHERWISE SPECIFIED
90° C'SINK ALL TAPPED HOLES TO MAJOR Ø OF THREADS +0.00
START AND FINISH ANGLES ON MACHINE THREADS TO BE 45°±15°
UNITS : INCHES UNLESS OTHERWISE STATED
TOLERANCES DECIMAL
.X : ± .1
.XX : ± .01
.XXX : ± .005
SURFACE FINISH
125
DESIGNER
S. TRAN
DATE
17-Sep-02
DESIGN ENG.
L. KILLIAN
DATE
17-Sep-02
TITLE
OATED SPLICE
REV.
AA
100099540
DO NOT SCALE DRAWING
SCALE 4/1
SPC.NEW.TELEM
SHT 1 OF 1

## C.2 Coating the Connection

### Heating and Applying Pressure:

Resources for developing Heating and Pressure Profiles:

Heating and pressure profiles were developed via theory and experimentation. Useful resources include: DuPont's "Injection Molding Guide for Teflon FEP, Teflon PFA and Tefzel" (included on the following pages), books on injection molding, and DuPont's technical support (http://teflonindustrial.custhelp.com). Input from previous users of the "SCD Machine" (the wire-insulation-repair machine), in addition to experimenting with the SCD Machine and the current injection molding machine, were helpful in gaining information and understanding as well as troubleshooting during profile development. The new injection system, designed for this project, is ideal for further experimentation, including fine-tuning of the profiles preparatory to the design of the final manufacturing equipment and processes.

Equipment:

Heating is accomplished with one cable heater (120V/240W, 0.062" diameter, unwound length of 24", wound length of 2" around a 3/8" tube), 8 cartridge heaters (each 120V/150W, 0.25" diameter, length of 1.25"; 4 heaters per plug), and thermocouples (K-type, sheath length of 0.75"). The operator currently uses the control consol (3 zones, ramping controller, capable of 4 recipes with 8 steps each) to manually regulate the temperature.

Pressure is applied using standard shop air.

Optimization:

Further optimization of the heating process would focus on automating it and minimizing the time required to complete the process. The controller can be programmed to automatically run heating profiles. For the current injecting machine, designing a longer heating coil and tube would reduce the preparation time between each heating cycle by making pellet-feeding less frequently required. Automating the procedure with a more sophisticated pellet-feeding system, such as one involving cold-feeding Teflon pellets or powder with a screw mechanism, would be desirable in the manufacturing version of the injection machine. Adding fans, fins, or heat sinks would also improve the process by reducing cooling time.

Further optimization of the injecting components should consider a way to sense pressure drops (particularly during cooling) and regulate them. Valves for adjusting the pressure of the system should be automated in response to measured temperatures and include feedback.

**Applying Tension:**

In future optimizations, the use of a force meter in conjunction with wheels (Figure 32) should be investigated for applying tension to the wire. Quick release clamps should also be investigated. (A suggested supplier for such force gauges is Stroud Systems, a Chatillon distributor: www.chatillon.com/tx.html.)

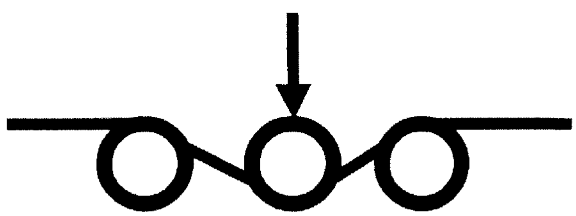


**Figure 32.** Applying tension using a force meter and wheels

## C.3 Injection Molding Guide for Teflon FEP, Teflon PFA, and Tefzel

# INJECTION MOLDING GUIDE FOR

# TEFLON FEP

# TEFLON PFA

# TEFZEL

FLUOROPOLYMER RESINS

FLUOROPOLYMERS
INDUSTRIAL

DU PONT

# CONTENTS

# Melt Processible Fluoropolymers

## A Family of Resins With Unique Properties

Du Pont produces a family of fluoropolymer resins to meet a wide range of demanding end-use requirements. They have gained widespread recognition for their unique properties and design versatility which are helping to solve some of industry's toughest materials problems. Common to all Du Pont fluoropolymers are:

- Outstanding chemical resistance
- High-temperature resistance
- Anti-stick characteristics
- Excellent dielectric properties
- Outstanding resistance to weather and aging

A summary of the physical properties of TEFLON® fluorocarbon resin and TEFZEL® fluoropolymer resin is shown in Table 1 on page 4.

## The Melt Processible Resins

The melt processible fluoropolymer resins extend the product line by providing the desirable properties of TEFLON® PTFE fluorocarbon resins in products that can be processed by conventional thermoplastic techniques, such as injection molding and extrusion.

Applications encompass those where designers and end users require a thermoplastic with excellent chemical stability, dielectric properties, anti-stick characteristics and mechanical strength for use in extreme high- and low-temperature environments.

This versatile family of melt processible fluoropolymer resins is available from Du Pont to meet specific end-use requirements and processing needs:

- TEFLON® FEP fluorocarbon resin—TEFLON® FEP is rated for service to 400°F/204°C and retains the chemical resistance and dielectric strength of TEFLON® PTFE fluorocarbon resin.
- TEFLON® PFA fluorocarbon resin—TEFLON® PFA is a premium performance resin with good melt processing characteristics and unique thermal stability. It offers high-temperature strength and stiffness; excellent stress-crack resistance; high flex life and excellent electrical properties. Its high temperature service rating is 500°F/260°C and it resists virtually all chemicals.
- TEFZEL® fluoropolymer—TEFZEL® is a strong, tough material with chemical resistance, electrical properties and aging resistance approaching those of TEFLON® fluorocarbon resins. Rated for use to 302°F/150°C, TEFZEL® has excellent processing properties using conventional thermoplastic techniques.

Fluoropolymer resins are different from most other thermoplastics since they have higher melting points and higher melt viscosities. Accordingly, TEFLON® and TEFZEL® require relatively high processing temperatures and slow injection rates. Special consideration for mold design is needed because of the molding characteristics of these resins, also, process equipment needs to be constructed of corrosion-resistant materials.

## Thermal Stability

The flow rate, defined as the number of grams of molten polymer that flows through the orifice of a rheometer in ten minutes, is inversely proportional to the viscosity of the molten polymer. Use of a heated, insulated, and thermostatically controlled laboratory melt indexer (comprising a cylinder and a weighted piston capable of forcing molten resin through an orifice at the bottom of the cylinder) permits accurate measurement of flow rates for TEFLON® and TEFZEL® resins. (See Table 2 and Figure 1).

Since thermal degradation of polymeric materials is a time-temperature dependent phenomenon, careful measurement of the increase in the flow rate of a polymer during processing provides an excellent technique for monitoring thermal degradation of injection molded parts during the manufacturing process.

The effect of temperature and hold-up time upon the flow rate of TEFLON® and TEFZEL® resins is shown in Figures 2, 3 and 4 on page 6. With TEFLON® FEP, data show little significant change in properties if the change in flow rate, due to thermal degradation, is less than 10%. With TEFLON® PFA, a change of up to 20% may be tolerated without a significant effect on end-use properties. For TEFZEL® fluoropolymers, the flow rate may increase by as much as 50% without significant change in tensile or elongation properties of the resin. Such changes can be measured before any serious losses in important end-product properties occur. This provides sufficient time for corrective action to be taken by a technician so that the proper process variables may be altered to prevent serious damage to production.

Although discoloration or small bubble formation normally indicates resin degradation, dark color can occur in the resin melt from equipment corrosion products or from trace amounts of less thermally stable resins. Continued operation at conditions causing thermal degradation of the resin can result in black specks or streaks of contamina-

**Table 1 Properties of Fluoropolymers for Injection Molding**

| Property | ASTM Standards | Units | TEFLON® FEP 100 | TEFLON® PFA 340 | TEFZEL® 210 | TEFZEL® 200 | TEFZEL® 280 | TEFZEL® HT-2004 |
|---|---|---|---|---|---|---|---|---|
| Specific Gravity | D792 | | 2.15 | 2.15 | 1.70 | 1.70 | 1.70 | 1.86 |
| Melting Point | DTA-E168 | °F | 500 | 582 | 512 | 512 | 512 | — |
| | | °C | 260 | 305 | 267 | 267 | 267 | — |
| Tensile Strength, 73°F | D638 | psi | 3,400 | 3,600 | 5,800 | 6,500 | 6,700 | 12,000 |
| 23°C | | MPa | 23 | 25 | 40 | 45 | 47 | 82.7 |
| Elongation, 73°F/23°C | D638 | % | 325 | 300 | 300 | 300 | 300 | 8 |
| Flex Modulus, 73°F | D790 | psi | 90,000 | 90,000 | 170,000 | 170,000 | 170,000 | 950,000 |
| 23°C | | MPa | 586 | 586 | 1,200 | 1,200 | 1,200 | 6,550 |
| Hardness Durometer | D2240 | | D56 | D60 | D67 | D63 | D72 | — |
| Dielectric Constant, 1MHz | D150 | | 2.02 | 2.1 | 2.6 | 2.6 | 2.6 | 3.38 |
| Dielectric Strength, short time, 10 mil | D149 | V/mil | 2,000 | >2,000 | 1,800 | 1,800 | 1,800 | 425 |
| 0.25 mm | | kV/mm | 80 | 80 | 70 | 70 | 70 | 16.7 |
| Dissipation Factor, 1MHz | D150 | | 0.0007 | 0.0001 | 0.0054 | 0.0031 | 0.0072 | 0.0035 |
| Volume Resistivity | D257 | ohm-cm | 10[illegible] | 10[illegible] | 10[illegible] | 10[illegible] | 10[illegible] | — |
| Water Absorption, 24 hr | D570 | % | 0.004 | <0.03 | 0.007 | 0.007 | 0.007 | 0.025 |
| Weather Resistance | Florida Exposure | Years Unaffected | 20 | 10 | — | 5 | — | — |
| Limiting Oxygen Index | D2863 | % | 93 | 95 | 30 | 30 | 30 | — |
| Flame Rating* | UL94 | | VO | VO | VO | VO | VO | VO |
| Impact Strength, 73°F | D256 | ft-lb/in | no break | no break | no break | no break | no break | no break |
| 23°C | | J/m | | | | | | |
| -65°F | | ft-lb/in | 2.9 | 1.2*** | 2.5 | 3.5 | 2.0 | — |
| -54°C | | J/m | 154.8 | 64 | 133.5 | 186.8 | 106.8 | — |
| Chemical Resistance** | | | Excellent in Chemical Service | | | | | |

*This numerical flame-spread rating is not intended to reflect hazards presented by this or any other material under actual fire conditions.
**Refer to "Chemical Use Temperature Guide—TEFZEL® Fluoropolymer" and "TEFLON® Fluorocarbon Resins—in Chemical Service".
***At -320°F (-196°C)

tion. Since the injection molding temperatures required for TEFLON® and TEFZEL® will decompose many other thermoplastics, it is absolutely necessary that the molding equipment be thoroughly cleaned of such materials before molding TEFLON® fluorocarbon and TEFZEL® fluoropolymer resins. Should contamination occur, it is imperative that molding cease until the cause for the contamination is discovered. The equipment should then either be thoroughly purged or disassembled and scrupulously cleaned before restarting the molding process.

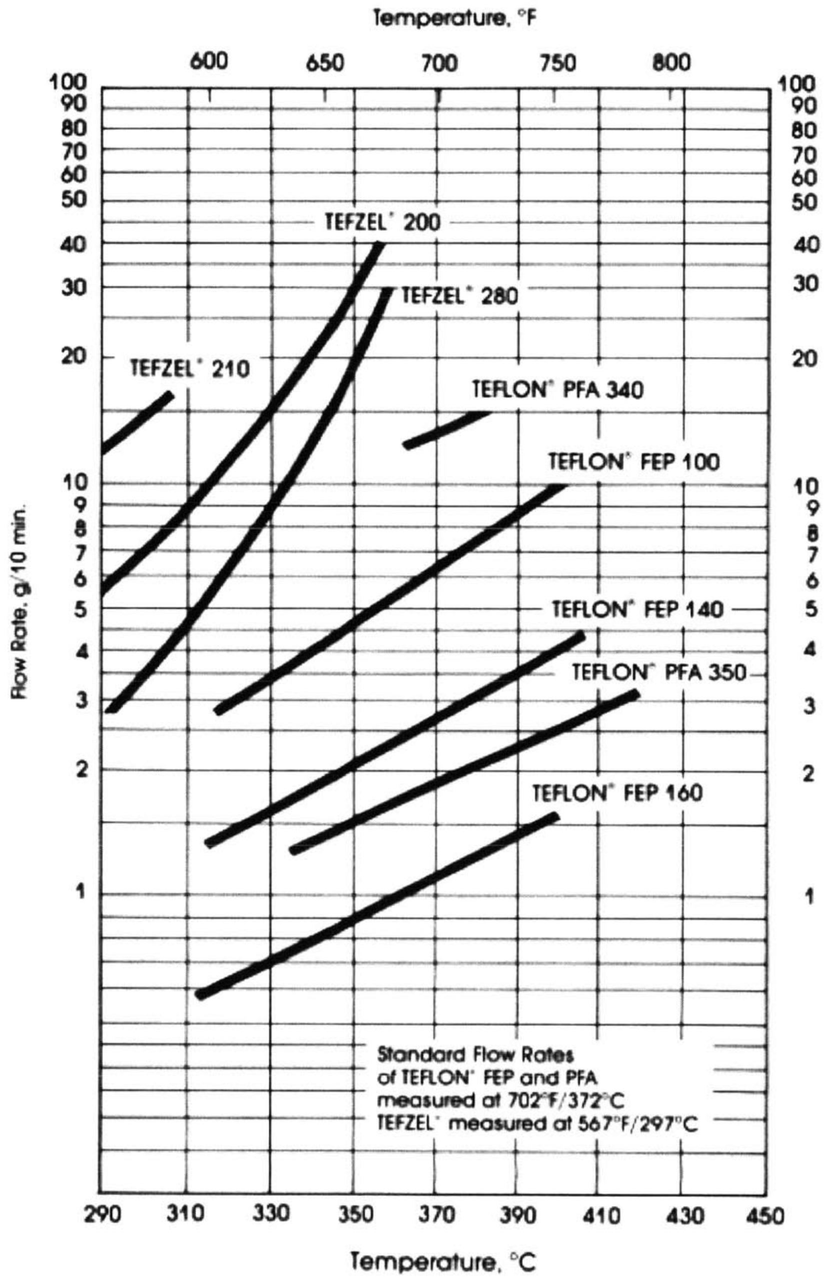
**Table 2. Typical Flow Rates (FR) for Fluoropolymers**

| Resin | Grade | Average FR, grams per 10 minutes |
|---|---|---|
| TEFLON® FEP | 100 | 7 |
| Measured at 702°F/372°C | 140 | 3 |
| ASTM Method D2116 | 160 | 1.2 |
| TEFLON® PFA | 340 | 14 |
| Measured at 702°F/372°C | 350 | 2 |
| ASTM Method D3307 | | |
| TEFZEL® | 210 | 23 |
| Measured at 567°F/297°C | 200 | 7 |
| ASTM Method D3159 | 280 | 4 |

## Resin Flow Properties

Melt fracture in molten polymer occurs when the velocity of the flowing resin exceeds the critical velocity (the point where the internal flow stresses in the molten

Figure 1
Flow Rates of TEFLON® FEP and PFA and TEFZEL® vs. Temperature at Constant Shear Stress—Typical Values




5

resin exceed the melt strength of the resin). Although melt fracture can occur with any thermoplastic material, the critical velocity at which it occurs with TEFLON* and TEFZEL* is much lower than most thermoplastic materials. A part molded under melt fracture conditions may have a cloudy or frosty surface, or, in the case of TEFLON* FEP and PFA, it may be internally fractured or delaminated with a normally appearing smooth and shiny surface.

There are three possible techniques for eliminating melt fracture:

1. Reduce the resin velocity by enlarging the runners, gates, or cavities, and/or using a slower ram speed.
2. Increase the critical flow rate by increasing the melt temperature or the mold temperature.
3. Reduce heat losses by shortening the distance through which the resin must flow to fill the cavity (e.g. multiple gates).

The three preventive possibilities are limited as remedies, however, since too slow an injection rate may cause the resin to solidify before the mold cavity is filled. Also, there are limits as to how much the mold area may be enlarged without adversely affecting the design. Maximum mold temperature is limited since it directly affects product parameters like ejectability, surface finish, warpage, shrinkage, and cracking, while maximum melt temperature is limited by resin degradation.

Figure 2
Percent Increase in Flow Rate of TEFLON* FEP 100 with Thermal Exposure

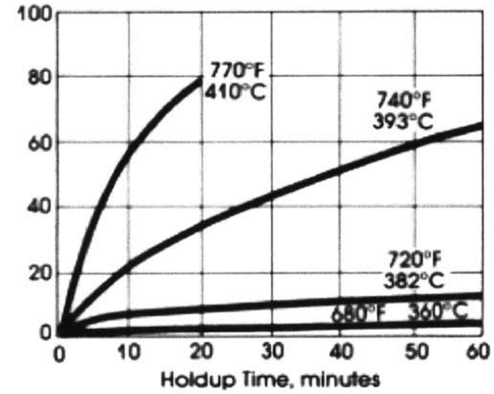



Figure 3
Percent Increase in Flow Rate of TEFLON* PFA 340 with Thermal Exposure

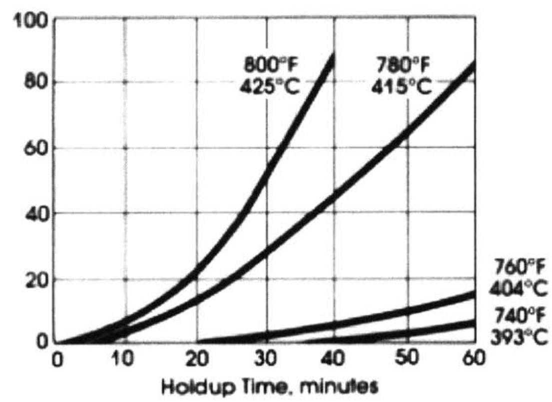
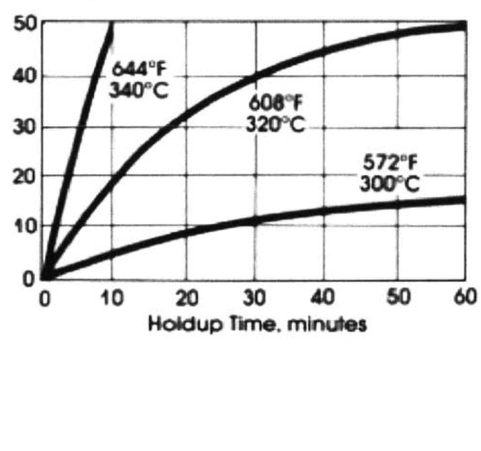



Figure 4
Percent Increase in Flow Rate of TEFZEL* 200 with Thermal Exposure



# Equipment for Injection Molding

Although it is possible to injection mold TEFLON* and TEFZEL* in ram type equipment, the reciprocating screw machine is recommended because the screw produces a thoroughly plasticated, uniform melt and provides a much more efficient transmission of pressure to the molten resin flowing into the mold.

Additional inherent advantages for the reciprocating screw machine over the ram type unit are:

1. Fewer sites for possible resin stagnation.
2. Better dispersion of fillers or pigments in the melt.
3. Less resin hold-up time.
4. Higher possible melt temperatures, with less thermal degradation.

## Materials of Construction

Since molten TEFLON* fluorocarbon and TEFZEL* fluoropolymer resins are corrosive to most metals, it is most important that corrosion-resistant metals be used for all parts in continuous contact with the molten resin. The only exception to this rule is for short, prototype runs. Traces of corrosion products that accumulate on the metal surfaces can break away, contaminating the finished product, and possibly adversely affecting physical properties. It is suggested that "Hastelloy" C[1], "Hastelloy" C-276[1], "Duranickel"[2], or "Monel" be used for the screw, adapter, and nozzle. For the cylinder lining the use of "Xaloy" 309[3], "Brux"[4], "Reiloy"[5] or "Bernex"[6] is suggested.

Since high operating temperatures are the rule, it is recommended that a high temperature resistant thread lubricant such as "Never Seez" be used to facilitate ease of machine part disassembly.

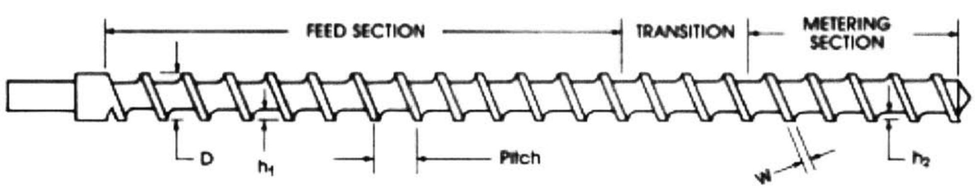
Because the mold is maintained at temperatures below the melting point of the resin, the corrosion rate of the mold surfaces will be less than for other parts of the machine. Except for long production runs, unplated molds of hardened tool steel, hardened stainless steel, or high quality chrome or nickel plated material may be satisfactory. For long runs, more corrosion-resistant materials of construction might be desirable.

## Screw Design

Figure 5 is a schematic diagram depicting a recommended screw design for molding TEFLON* and TEFZEL* resins. It is a metering type screw with a metering section which occupies 25% of the total length. The screw should have a constant pitch and a flight depth ratio from the feed section to the metering section of 3:1. For TEFZEL*

[1]Stellite Division, Cabot Corporation, 1020 W. Park Avenue, Kokomo, IN 46901.
[2]International Nickel Company, P.O. Box 1958, Huntington, WV 25720.
[3]Xaloy, Inc., 3 Terminal Road, New Brunswick, NJ 08903.
[4]Brookes (Oldbury) Ltd. 1 Oldbury, Warley, Worcestershire, B69 2DL England.
[5]Reiloy Metal GmbH (Reifenhäuser) Germany 521 Troisdorf Bezirk Köln, Post Box 1345.
[6]Berna AG, Olten, CH-4600 Olten.

Figure 5
Schematic of Screw Design for Injection Molding TEFLON* and TEFZEL*




Suggested dimensions of screw

| Diameter (D) | | Pitch (P) | | Depth of feed section ($h_1$) | | Depth of metering section ($h_2$) | | Width of land (W) | |
|---|---|---|---|---|---|---|---|---|---|
| in. | (mm) | in. | (mm) | in. | (mm) | in. | (mm) | in. | (mm) |
| 1½ | (38.1) | 1½ | (38.1) | 0.255 | (6.5) | 0.085 | (2.159) | 0.150 | (3.810) |
| 1¾ | (44.5) | 1¾ | (44.5) | 0.291 | (7.4) | 0.097 | (2.464) | 0.175 | (4.445) |
| 2 | (50.8) | 2 | (50.8) | 0.330 | (8.4) | 0.110 | (2.794) | 0.200 | (5.080) |
| 2½ | (63.5) | 2½ | (63.5) | 0.420 | (10.7) | 0.140 | (3.556) | 0.250 | (6.350) |

it is recommended that a 3-turn transition zone be used, while for TEFLON* a ½-turn transition section is recommended. Although other screw designs have been used successfully, the two designs described are **recommended**.

## Nozzle

Figure 6 shows a conventional type, reverse tapered nozzle recommended for TEFLON* fluorocarbon and TEFZEL* fluoropolymer resins. The bore should be as large as possible and tapered to prevent dead spots or rapid changes in resin velocity. The sprue should extend into the nozzle ½ to 1 in./ 13 to 25 mm to prevent formation of a cold slug. An included angle of 4° is suggested to permit the material in the tapered portion of the nozzle to be withdrawn with the shot. To decrease the possibility of peening the nozzle bore, which in turn could prevent removal of chilled material from the nozzle, it is recommended that the radius of the nozzle orifice exit be 10 mils/0.25 mm as indicated in Figure 6. To provide a smooth, uninterrupted flow path, the nozzle bore must match the adapter and be equipped with its own separate heater and temperature control.

## Non-Return Valve

The non-return or check ring valve, shown in Figure 7, prevents the molten resin from flowing backward along the screw flights during the injection process. The flow path must be streamlined and the joint between the valve and the screw must be smooth and tight in order to avoid areas of stagnant resin flow or holdup. The tip of the screw should be pointed to provide a streamlined flow path for the resin and to reduce the free volume in front of the screw after injection. A leaking valve will cause poor control of part packing and tolerances.

Figure 6
Conventional Reverse Tapered Nozzle

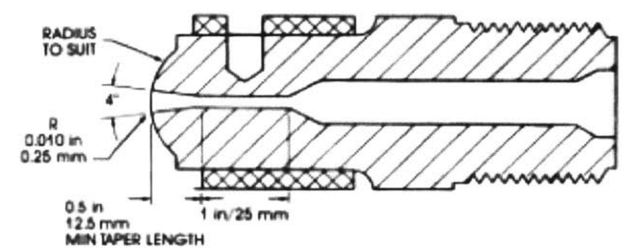
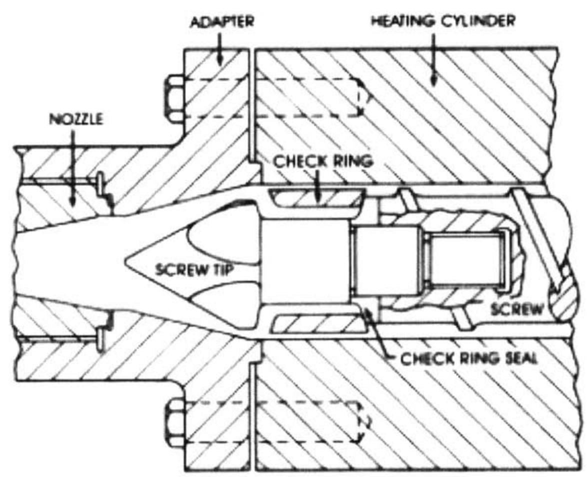



Figure 7
Design of Adapter and Non-return Valve



## Smear Head

A smear head, Figure 8, which can be used in place of a non-return valve, is a device that uses a small diametral clearance with the cylinder over an extended land length, thus restricting backward melt flow during the injection stroke of the screw. When the screw is rotating during retraction, the melt is forced forward through a narrow annulus; this shearing or smearing action increases melt temperature, improves mixing, and reduces effective packing pressure. The smear head may be preferred over the non-return valve for the following reasons:

- Less tendency for resin stagnation
- Lower possibility of overpacking the mold (with attendant delamination for TEFLON®)
- Less tendency to form streaks in the molded part
- Less abrasion on relatively soft corrosion-resistant alloys

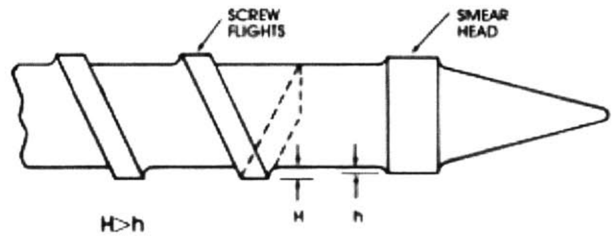
It is suggested that a check ring non-return valve be used when injection molding TEFZEL® 210, due to the resin's lower viscosity. When molding TEFLON® PFA and FEP or TEFZEL® 200 and 280, a smear head would normally be used in place of the non-return valve.

Check rings may be constructed of Hastelloy C or Monel 400. Since no indestructible material of construction for check rings is known, wearing of the check ring should be monitored.

## Temperature Control

It is recommended that three independently controlled heater zones be used for the cylinder and one for the adapter. A separate controller should be used on the nozzle. The heater controllers must be capable of accurate temperature control up to 700°F/371°C for TEFZEL® and up to 800°F/427°C for TEFLON® FEP and PFA. This level of control requires a heater watt density of 30 to 40W/in²/4.6 to 6.2 W/cm².

Figure 8
Smear Head




## Hydraulic System

When injection molding TEFLON® fluorocarbon and TEFZEL® fluoropolymer resins, it is often necessary to use an extremely slow injection rate in order to avoid either surface or internal melt fracture. The hydraulic system, therefore, should be capable of producing a very uniform and controlled ram speed as slow as 60 seconds per shot. A higher injection rate is permissible with TEFZEL® 210 since it does not melt fracture as readily as other fluoropolymers. Thus, the hydraulic system must be capable of producing high rates of ram speed as well as very low rates.

## Streamlining

It is most important for the entire flow path of the resin through the machine to be streamlined and that there be no areas of stagnation. Localized holdup, such as may exist in the non-return valve of a reciprocating screw machine, can lead to thermal degradation of the resin and unacceptable production.

## Sizing Injection Machines

In conjunction with the weight of the part and the runner, these melt densities should be considered for adequate injection machine size at normal processing conditions:

- for TEFLON® FEP and PFA ~0.054 lbs/in³ (~1492 Kg/m³)
- for TEFZEL® ~0.047 lbs/in³ (~1298 Kg/m³)

Clamp tonnage should be appropriate to cavity mold pressure and the area of the mold cavity which will oppose the clamp tonnage. One expects that a clamp pressure of 5 tons/in² of projected area should be adequate for molding parts from Du Pont fluoropolymers.

# Mold Design

## Materials of Construction

Mold cavities can be constructed from corrosion-resistant materials such as Hastelloy C, Monel, or Duranickel, but these materials provide a degree of corrosion resistance far greater than is usually necessary. Should unprotected tool steel or hardened stainless steel be used, the mold should be thoroughly cleaned before storage with a moderately alkaline material (e.g., ammonia water), dried, and coated with a rust preventative to avoid rusting and pitting. This procedure is particularly important where high humidity conditions prevail. Rusting and pitting may be avoided by plating the mold with either nickel or chrome (chrome should not be used with TEFLON* PFA) to a thickness of ½ to 1 mil/0.013 to 0.025 mm; to avoid stripping the plating from the mold, use a high quality plate devoid of pinholes.

## Sprue Bushing

The diameter of the sprue bushing should be at least 1/16 in./1.6 mm greater in diameter than the main runner and just slightly greater than the nozzle orifice. Generally, a standard taper of ½ or ¾ in./ft/4 or 6 mm/m is used.

## Runners

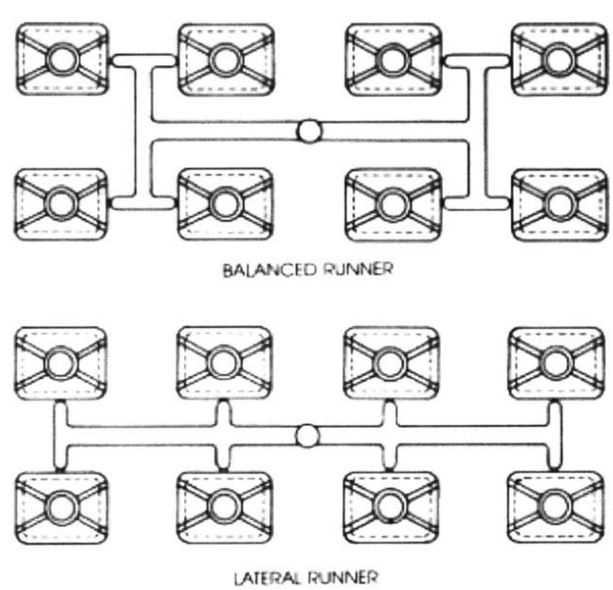
In order to minimize both heat and pressure losses, large diameter, full round runners of the shortest possible length should be used. A second preference would be trapezoidal runners which are usually easier to machine than round runners. Runner walls should be free of any restrictions and should blend smoothly into the gates.

Generally, the thicker the molded part, the larger and shorter the runner should be. Parts of average thickness, up to approximately 0.5 in./12.7 mm, require a runner diameter of 0.25 in./6.4 mm or larger. Thicker parts require the runner diameter to be ½x to 1x the thickness of the part. The runner length or layout dictates the amount of scrap produced and the pressure drop. Both "balanced" and "lateral" runner systems are shown in Figure 9. A runner system is "balanced" when the resin flow distances between cavities and sprue are equal. When the number of cavities results in a complex or lengthy resin flow the "balanced" runner system is not recommended. A "lateral" runner system can be used with both short and long resin flow distances in most instances.

## Gates

Gates should either be as large as possible or eliminated altogether. The land, or length, of the gate should be kept very short. Rectangular tab or fan type gates, generously flared into the mold cavity, are preferred over round gates, since they provide a more

**Figure 9**
**Runner Systems Used in Injection Molding**



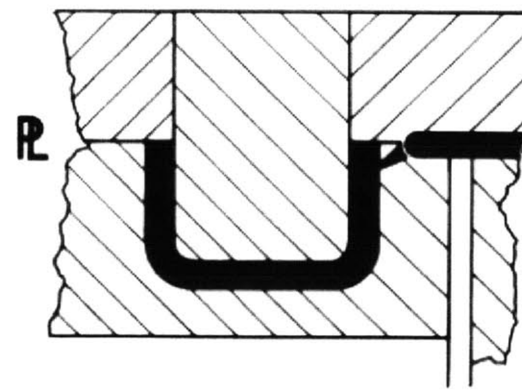
effective means of reducing stress in the resin. Round gates generally are easier to remove from a part but do not permit the same degree of independent control of cavity fill and gate freeze-time as rectangular gates do. The thickness (diameter) of the gate should be ½ to 1x the thickness of the part. Transitions from the runner to the gate to the part should be smooth, with no abrupt changes in the direction of resin flow.

Diaphragm or ring gates can be used for molding cylindrical parts where concentricity is critical or where weld lines cannot be tolerated. Pinpoint gates should be avoided except when molding small parts which are injected very rapidly as with TEFZEL* fluoropolymer resin. Tunnel gating, as shown in Figure 10, can also be used for TEFZEL*.

Gate locations should be at the following points:

- Where the part will not be highly stressed by bending motion or by impact while in use.
- So that weld lines occur in non-critical areas.
- Wherever finishing the gate site would be unnecessary or inexpensive.
- At or near the thickest section in order to minimize sink marks and to avoid pushing resin through a thin section to fill a thicker one.
- At locations consistent with venting requirements (vents are normally required at weld lines or at the bottom of blind cavities).
- In the center of a circular part.

Figure 10
Tunnel Gate




## Other Considerations

When the necessary functional and appearance requirements of the part have been established, the final part design should be made with the following considerations in mind:

- Generous filleting.
- Streamlined angles and intersections.
- Uniform wall thickness (if different wall thicknesses are required, blend as gradually as possible).
- Simplicity (the overall design should be kept as simple as possible).

In addition, the following are good practices for consideration:

- Post-molding operations such as drilling holes in the part are usually preferred to the incorporation of pins.
- The number of cavities should decrease as the complexity of the part increases.
- Jetting, the rapid flow of a thin resin stream across a mold cavity, should be avoided.

## Mold Heating

Although a mold can normally be heated by use of a high temperature circulating oil heater, when an injection molding process requires a mold temperature in excess of 375°F/191°C, electrical heating should be used. Both halves of the mold should be insulated from the platens to reduce heat losses. Sheets of "Transite" board† 0.25 in./6.4 mm thick are satisfactory for this purpose.

†John Manville Company, Ken-Caryl Ranch, Denver, CO 80217

# Dimensional Considerations

## Tolerances

The achievement of close tolerance molding is contingent upon precise control of operating parameters, such as resin feed rate to the cylinder, cylinder and melt temperature, ram or screw speed, pressure, and the overall cycle, all of which must be kept constant. Mold design is also a critical factor in meeting specified tolerances.

In any manufacturing process, as tolerance requirements tighten, the process becomes more complex and expensive. Generally, plastic parts are capable of functioning with wider tolerances than metal counterparts because of the higher inherent resiliency of plastic. Figure 11 shows some suggested tolerances for plastic parts.

A few general comments and cautions relating to tolerances are:

- Tolerances should never be specified closer than necessary.
- Cost increases when close tolerances are specified on several dimensions of a part.
- Do not specify close tolerances for parts with major variations in wall thickness.
- It is not good practice to specify fine tolerances across a parting line or for dimensions controlled by movable cores or sliding cams.

Table 3. Estimated Mold Shrinkage

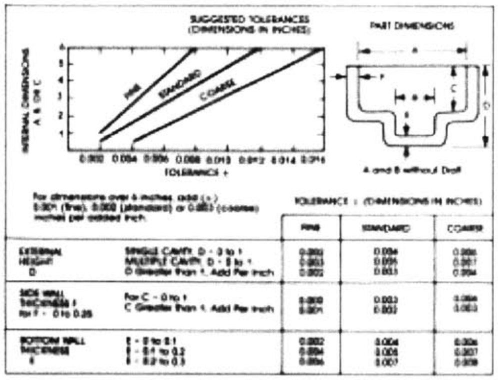
| Thickness of Molded Article | | Shrinkage | |
|---|---|---|---|
| in. | (mm) | mils/in. (mm/m) | % |
| 1/8 | (3.2) | 35-40 | 3.5-4.0 |
| 1/4 | (6.4) | 40-45 | 4.0-4.5 |
| 1/2 | (12.7) | 45-50 | 4.5-5.0 |
| 3/4 | (19.1) | 50-60 | 5.0-6.0 |

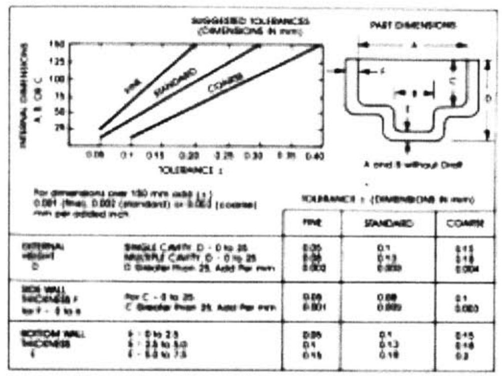
## Shrinkage

Listed below are the basic factors affecting the shrinkage of parts injection molded from fluoropolymers:

- Increasing either part thickness or mold temperature increases the part shrinkage, since changes of this nature result in a slower cooling rate for the part, which in turn produces a higher level of crystallinity (order) along with some relaxation in internal stresses.
- Most plastic parts exhibit directional shrinkage differences: part shrinkage is lowest in the direction of resin flow due to the relatively high degree of molecular orientation in that direction. Generally, the straighter the path, the lower the shrinkage, which leads to the conclusion that it is advisable to design the part and locate the gates so as to create the straightest flow path in that direction having the greatest restriction upon dimensional tolerance.
- An increase in injection pressure causes a decrease in shrinkage.
- Generally, parts molded at higher stock temperatures will exhibit higher mold shrinkage.
- The addition of filler material reduces part shrinkage.
- Table 3 shows estimated mold shrinkage versus thickness for TEFLON* FEP and PFA.
- Figure 12 shows estimated mold shrinkage versus thickness for TEFZEL*.
- Figure 13 shows estimated mold shrinkage versus mold temperature for TEFZEL*.

Figure 11
Suggested Tolerances



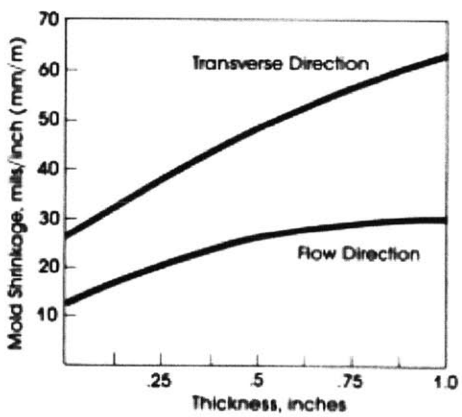




## Shrinkage Allowance

If accurate part dimensions are required, shrinkage allowance should be determined by test molding the part in question. Listed below are the steps recommended for construction of a mold:

1. Machine a single cavity in the production mold base using the specified dimensions for the cavity and oversized dimensions for mold parts which form the inside dimensions.
2. Machine the sprue bushing and all the runners up to the points where future production cavities will be inserted.
3. Perform several trial moldings with the single cavity mold and determine the best molding conditions for production of satisfactory parts.
4. Check the dimensions of the molded article after it has been maintained at its expected operational temperature for 24 hours.
5. Use the shrinkage data obtained from step 4 to design the proper dimensions for the production cavities.
6. Machine the production cavities to the correct dimensions and insert them into the production mold base used for the single cavity test mold.
7. Without altering the runners or gates, mold a part under the previously established conditions. Any compensation required for slight differences in dimensions can be accomplished by slight variations in the molding conditions.

Figure 12
Mold Shrinkage vs. Thickness for TEFZEL® 200




Mold Temperature = 200°F/93°C
Melt Temperature = 625°F/330°C
Injection Pressure = 10,000 psi/70 MPa

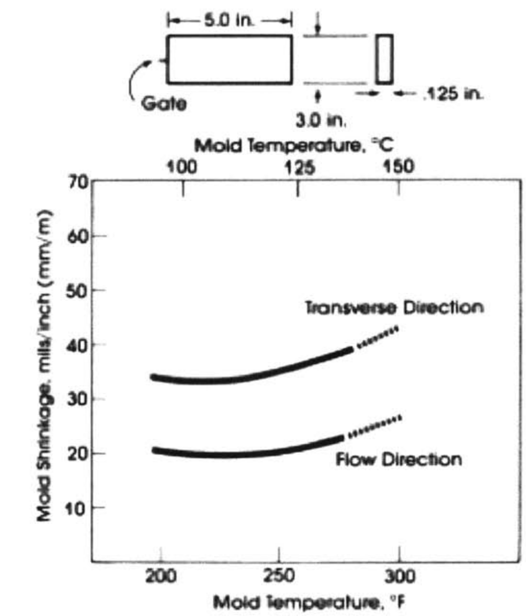
## Heat Treating

Heat treatment or annealing, is a process which minimizes the shrinkage experienced by a part during its operational life. Annealing consists of exposing a molded part to a temperature slightly higher (approximately 10-15°F/5-8°C) than its intended operating temperature for approximately 15 minutes per 0.125 in./3.175 mm of part thickness and then cooling very slowly; the time is measured from the point at which the part reaches the desired temperature. The slow cooling allows relaxation of internal stress, thus minimizing any dimensional change during the service life of the part.

The actual amount of additional shrinkage induced by annealing is a function of mold temperature, i.e. the hotter the mold, the less shrinkage is seen upon annealing the part. This suggests that if the mold temperature were to be set at a point higher than the service temperature of the part, no additional annealing would be required.

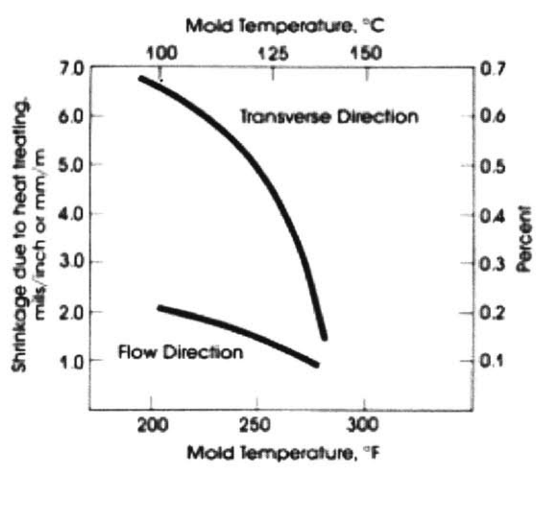
EXAMPLE: Figure 14 shows the relationship between shrinkage induced by heat treatment and mold temperature; in this example, the plaque shown in Figure 13 had been heat aged for 72 hours at 300°F/149°C. The data show that additional shrinkage induced by heat treatment approaches the order of 0.10% as the mold temperature approaches 275°F/135°C.

Figure 13
Mold Shrinkage vs. Mold Temperature for TEFZEL® 200




Part Thickness 0.125 in/3.2 mm
Melt Temperature 625-650°F/330-345°C
Injection Pressure 7,000-10,000 psi/50-70 MPa

Figure 14
Shrinkage after Heat Treatment vs. Mold Temperature for Plaque of Figure 13 (TEFZEL® 200)



# Molding Operation

## Shutdown and Startup Procedure

If molding equipment is turned off without following proper shutdown procedures, resin degradation may occur and severe corrosion of the equipment could also result if the equipment is constructed of non-corrosion resistant materials. When overnight shutdown without cleanup is desired, the following shutdown procedure is recommended:

1. Reduce all temperature controllers to the following levels:
   a) 600°F/316°C for TEFLON* PFA or FEP fluorocarbon resins
   b) 550°F/284°C for TEFZEL* fluoropolymer resin
2. When all temperatures have been dropped to the levels indicated in Step 1, purge the machine to a dry condition, leave the injection screw in the forward position, and finally shut off the power supply.

The restart procedure is as follows:

1. Starting with the temperature controllers for the nozzle, then for the adapter, then the rear barrel, followed by the front barrel and finally the middle barrel, sequentially raise all the temperature controllers at each zone to the following levels:
   a) 600°F/316°C for TEFLON* PFA or FEP
   b) 550°F/284°C for TEFZEL*

   A heat soak of 1 hour may be necessary to melt all resin and heat all metal components to these set temperatures.
2. Start the machine slowly after all temperatures have stabilized, setting the temperature controllers to operating levels.
3. Commence production when operating temperatures have been reached.

## Cleanout Procedure

The following steps outline a suggested cleanout procedure:

1. While maintaining operating temperatures, start rotating the screw and continue to rotate it until the resin ceases to flow from the nozzle.
2. Reduce cylinder temperatures to the following levels:
   a) 600°F/316°C for TEFLON* PFA or FEP
   b) 550°F/284°C for TEFZEL*
3. Shut off the screw and remove both the nozzle and the adapter. Be sure to clean the nozzle, while it is hot, with a soft metal scraper and copper mesh. Oven burnout is not required and should be avoided.

NOTE: At this point a purge compound of ground cast acrylic or polyethylene may be used when molding either TEFLON* FEP or TEFZEL* resins.

4. Slowly remove the hot screw from the cylinder, cleaning it with a wire brush.
5. Clean the inside of the cylinder with copper mesh wrapped around a boiler tube brush for a tight fit; then wipe the cylinder clean with a lint-free cloth.

When operating in equipment constructed of corrosion-resistant metal, it is permissible to leave a purge (either ground, cast acrylic or polyethylene sheeting) in the equipment overnight without danger of damage to the metal.

## Basic Operating Conditions

Typical basic operating conditions are listed in Table 4. Some additional basic guidelines are listed below:

**Melt Temperature (resin leaving the nozzle)**

- Decrease the melt temperature as holdup time is increased.
- Runner, gate, and orifice size are additional factors to be considered.

**Temperature Profiles**

- When operating with high melt temperature and a long holdup time (10 to 15 mins.), the rear zone should be set at a lower temperature than the front zone in order to minimize resin degradation.
- When operating with short holdup times, the temperature of the front and rear zones should be set at the same point.
- The location of the heater thermocouples, the machine size, the speed and the type of the injection screw, shot size, and cycle time are additional factors for consideration.
- Occasionally, high melt temperatures result from mechanical working of the resin melt.
- If the temperature of the rear zone is too high, bridging may occur, resulting in erratic feed.
- If the temperature of the rear zone is too low, high torque loads created by the partially melted resin could cause the screw to stall, thereby reducing the plasticating capacity of the equipment.

**Injection Speed**

- Allowable ram speed is dictated by the smallest channel through which the molten resin must pass.
- A rough or rippled surface indicates an inappropriate injection speed was used. If surface appearance is rough or frosty, injection speed was too fast; and conversely, if a rippled surface results, the injection speed was too slow.
- Shot size, melt temperature, and mold temperature are additional factors for consideration.

**Injection Pressure**

- Injection pressure should normally be as low as possible.
- Low injection pressure reduces frozen-in stresses and improves dimensional stability.
- To reduce sink marks or improve weld lines, injection pressure should be increased.
- Equipment and part design must also be considered.

**Screw Rotation**

- Generally, screw rotation should be as slow as possible.
- High screw speeds, combined with the appropriate back pressure, are used occasionally to produce high melt temperatures necessary for the molding of long, thin parts.

**Mold Temperature**

- Extremely hot molds should not normally be used for thick-walled sections.
- When the resin flow path is long relative to the part thickness, higher than normal mold temperatures are required.
- Increasing mold temperature reduces the probability of delamination (of TEFLON®).
- When adjusting mold temperature consideration should be given to interrelated parameters, such as part geometry, surface finish, pressure drop, effect upon cycle time, stresses, ejectability of the part, and shrinkage.

**Back Pressure**

- Back pressure should normally be kept as low as possible.
- Increasing back pressure, however, can sometimes be an effective technique to increase the stock temperature.

**Overall Cycle**

Overall cycle time is influenced by a number of interrelated manufacturing variables, such as process temperatures and pressures, part geometry, tolerances, warping, and ejectability. Cycle time is usually estimated on the basis of 30 to 40 seconds per 0.125 in./3.2 mm of thickness. Except for thin sections, the longest portion of the cycle is often devoted to the ram-in-motion.

"Packing" the resin, which involves leaving the ram in the forward position while under pressure, should be kept to a minimum. Normally, packing is used only when molding thick sections to reduce sink marks or eliminate voids. Excessive packing usually results in delamination of the part for TEFLON® FEP and PFA, but generally not for TEFZEL®. Use of a smear head reduces the possibility of overpacking.

**Record Keeping**

Typical formats suggested for recording molding data and for mold inspection and repair information are located in the "Miscellany" section of this guidebook.

Table 4. Suggested Molding Conditions for Du Pont Fluoropolymers

| Example Temperature & Profile | TEFLON® FEP fluorocarbon resin | TEFLON® PFA fluorocarbon resin | TEFZEL® fluoropolymer resin |
|---|---|---|---|
| Rear Cylinder, °F | 600-625 | 600-630 | 525-575 |
| °C | 315-329 | 315-332 | 273-302 |
| Center Cylinder, °F | 625-650 | 625-650 | 575-625 |
| °C | 329-343 | 329-343 | 302-330 |
| Front Cylinder, °F | 700 | 700 | 575-625 |
| °C | 371 | 371 | 302-330 |
| Nozzle, °F | 700 | 700 | 650 |
| °C | 371 | 371 | 343 |
| Mold Temperature, °F | >200 | 300-500 | RT-375 |
| °C | >93 | 149-260 | RT-190 |
| Stock Temperature, °F | 650-720 | 650-750 | 575-625 |
| °C | 343-382 | 343-399 | 302-329 |
| Injection Speed | Slow | Slow | Moderately Fast |
| Injection Pressure, psi | 3,000-8,000 | 3,000-8,000 | 3,000-15,000 |
| MPa | 21-55 | 21-55 | 21-103 |

# Auxiliary Operations

## Reuse of Resin

TEFLON® FEP fluorocarbon and TEFZEL® fluoropolymer resins can be reworked without significantly sacrificing the properties inherent to the virgin material. TEFLON® PFA has been reworked up to six times without loss of tensile properties or significant increase in melt flow number. However, when reworking resin a number of important precautions should be observed.

Resin for rework must be kept clean since contamination may change its processing characteristics or impair its properties. It is necessary to use corrosion-resistant equipment and to follow the proper equipment cleanup procedures, previously outlined in this guide, to aid in avoiding resin contamination.

Reworked resin should be cut to a size and shape approximately equal to that of virgin resin. A conventional, unchilled, rotary knife cutter equipped with a screen is suitable for obtaining a cut with a minimum of shredding. If the cut obtained upon reworking is too fluffy, it will not feed well enough when blended with virgin resin to permit uniform delivery. Fluffy-cut resin should be extruded as beading and cut into molding pellets.

## Pigmentation

Both TEFLON® and TEFZEL® resins may be pigmented with commercially available pigments that are thermally stable at the molding temperatures of the resins. Inorganic pigments are the best choice. The simplest method for coloring resin is to blend the unpigmented resin with color concentrates (available from Du Pont) although pigments may also be dry blended by the following procedure:

1. Dry the desired pigment overnight at 300°F/149°C in a vacuum oven or a non-circulating air oven to remove absorbed gases and moisture.
2. Weigh the pigment and if greater opacity is desired, add and blend the appropriate amounts of titanium dioxide pigment to the color pigment.
3. Place the resin pellets in a clean container, such as the original shipping carton, and then screen the pigment through a 100-mesh screen directly onto the pellets.
4. Dry blend the color and the pellets by rolling or tumbling the mixture for at least 15 minutes.
5. Use the pigmented resin pellets within 30 minutes or store them in an airtight container to prevent the absorption of moisture.

## Thin-Section Molding

Generally it is difficult to injection mold very thin sections with most thermoplastic resins, particularly where a relatively large surface area is involved.

With TEFLON®, anything below 0.1 in./2.5 mm may be considered a thin section. When processing thin sections, a faster ram speed must be used since a full shot is of primary importance. There is, however, a problem in obtaining both a full shot and a part free of delamination. The latter product property can generally be obtained only with a slow ram speed, an operating condition that usually produces a resin freeze in the gate or cavity for a thin-walled section before a full shot can be obtained. Therefore, a high mold temperature in the range of 400°F/204°C is necessary to minimize the tendency toward delamination. Packing should not be used, i.e., the ram should be retracted as soon as the mold is full.

Laminations in parts of TEFLON® FEP and PFA may become apparent in a section which appears and feels smooth when it is subjected to either heat aging or repeated flexing. If a part is to maintain a good, smooth surface after being flexed, it must be thick enough to permit a slow ram speed.

Delamination is not a characteristic of TEFZEL® and the precautions needed to avoid it with TEFLON® are not needed when molding TEFZEL®.

## Glass-Reinforced TEFZEL® Fluoropolymer

Glass-reinforced TEFZEL® has the potential to be produced on a faster cycle than unreinforced resin, since short glass fibers remain well dispersed without straining-out in pinpoint gated molds used in the production of very small parts. Injection molding with reinforced resin differs from the molding process without reinforcement in three ways:

1. **Injection Rate**

The injection rate should be as high as possible to produce the smoothest possible surface, since a part molded at too low an injection rate will have a surface with rough, glass-rich areas. Larger gates may be required to achieve the necessary rapid injection rates, and a higher level of mold venting may be needed since a fast fill rate has a tendency to trap air. If the mold does not have adequate venting, trapped air is rapidly compressed to extremely high pressure, producing localized temperatures high enough to scorch portions of the surface area.

2. **Injection Pressure and Packout**

Glass fiber reinforced TEFZEL* resin should be injection molded at relatively high pressure in the range of 15,000-20,000 psi/105 to 140 MPa and packed out at high pressure until the mold gate is completely frozen. (These conditions are unlike unreinforced TEFZEL* which is injection molded at the lowest practical injection pressure with little or no packout). In the fabrication of heavy-walled parts, too low a pressure or inadequate packout may result in a molded part with either a void or a pulpy core.

3. **Shrinkage**

For glass-reinforced TEFZEL* in the thickness range of 0.125 to 0.25 in./3 to 6 mm, mold shrinkage is 1 to 3 mils/in. or mm/m in the flow direction and approximately 25-35 mils/in. or mm/m in the direction transverse to the flow. Transverse shrinkage, which is strongly influenced by mold cavity pressure, can in some instances, be reduced 40-60% to 15 mils/in. or mm/m by use of large gates, nozzles, sprue bushings, and short runners to reduce the injection pressure drop from the cylinder to the mold cavity. Since the highly directional nature of shrinkage in reinforced materials can produce warpage, close attention should be paid to proper part design and gate location to minimize the shrinkage effect.

# Safety

Since their discovery, millions of pounds of TEFLON* fluorocarbon resins have been processed at temperatures in excess of 662°F/350°C, and subsequently placed in end-use applications, many of which have been at or above rated use temperatures. In this period, spanning more than forty years, there have been no reported cases of serious injury, prolonged illness, or death resulting from the handling of these resins. This record includes the experience of Du Pont personnel, hundreds of processors, and thousands of end-users who handle these resins every day.

However, when heated to processing temperatures, TEFLON*, as well as other plastics and organic materials, gives off fumes that are objectionable from the standpoint of health and safety.

Also, when grossly overheated, plastics and organic materials, including TEFLON*, undergo some decomposition and actual breakdown in chemical structure.

Fumes from the pyrolysis of many resins and elastomers, as well as those from naturally occurring polymers like rubber, coal, silk, and wood, may be toxic.

Over the years, much effort has been spent at the Du Pont Haskell Laboratory for Toxicology and Industrial Medicine in careful investigation of fluoropolymer resin. In addition, Du Pont research laboratories have studied intensively the thermal behavior of fluoropolymer resins. A number of other laboratories, including those in the United States Department of Health and Human Services, have conducted similar studies related to the safety of these resins.

The knowledge gained through these studies is summarized in these publications, **which should be carefully read prior to the handling or processing of any Du Pont fluoropolymer:** "TEFLON* Fluorocarbon Resins—Safety in Handling and Use" (E-35824-1) and "TEFZEL* Fluoropolymer Resins—Safety in Handling and Use" (E-64073).

The major safety consideration for injection molding fluoropolymers and other organic polymers is the installation of exhaust hoods to remove off-gases released from hot polymers into work areas. Exhaust hoods over the die and at the hopper heater are recommended. Extruding into water—either a quench tank or a partially filled container—for purging is also recommended.

The safety in handling and use bulletins mentioned above contain data for the design of hoods to capture the gases generated by injection molding of fluoropolymer resins.

Proper procedures and controls must also be maintained to assure that the molding operation will never exceed specified operating temperatures or equipment design pressures. "Blow backs," gas releases from autocatalytic polymer degradation initiated by high temperatures, are possible, although the TEFLON* resins are among the most stable of organic polymers and therefore more resistant to this hazard. TEFZEL* is much more susceptible to autocatalytic degradation than the TEFLON* polymers, suggesting extra care and attention to good operating practices.

# Miscellany

## Troubleshooting Guide

There are many variables in the injection molding process which affect product quality. The following table is a troubleshooting guide which can be used to help define causes of specific problems.

It should be noted, however, that many injection molding problems are compounded by the interaction of more than one variable. The symptoms of more serious problems tend to mask minor ones. Thus, successful troubleshooting may require careful observation, and the tackling of several problems in sequence.

Technical assistance on extrusion problems is available through your Du Pont representative.

# Troubleshooting Guide

| SUGGESTED REMEDIES / PROBLEM | Black specks in part | Burn spots on part | Cold slug in part | Cracks in part | Discoloration of part | Erratic screw retraction | Flash | Laminations in part | Part sticks in mold | Poor weld lines | Ripples on part | Short shots | Shot-to-shot part weight variation | Sink marks | Sprue sticking | Surface roughness | Unmelted Resin | Voids in part | Warpage |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Increase injection pressure | | | | | | | | | | X | | X | | X | | | | X | |
| Decrease injection pressure | | | | X | | | X | X | X | | | | | | | X | | | X |
| Increase injection rate | | | | | | | | | | X | X | X | | | | | | | |
| Decrease injection rate | | X | | X | | | X | X | X | | | | | X | | X | | X | X |
| Increase ram forward time | | | | | | | | | | | | | X | X | | | | X | |
| Decrease ram forward time | | | | X | | | X | X | X | | | | | | X | X | | | X |
| Increase melt temperature | | | X | X | | | | X | | X | | X | | X | | X | | X | X |
| Decrease melt temperature | X | X | | | X | | X | | X | | X | | | X | | | | X | |
| Increase mold temperature | | | | | | | | X | | X | | X | | | | X | | | |
| Decrease mold temperature | | | | X | | | X | | | | X | | | X | | | | | |
| Increase cylinder temperatures | | | X | | | X | | | | | | | | | | | X | | |
| Increase back pressure | | | | | | X | | | | | | | | | | | X | | |
| Use reverse taper nozzle | | | | | | | | | | | | | | | X | | | | |
| Decrease cycle | | | | | X | | | | | | | | | | X | | | | |
| Increase cycle | | | | | | | | | | | | | | | | | X | | X |
| Check pad size (cushion) | | | | | | | | | | | | X | X | X | | | | X | |
| Enlarge nozzle orifice | | | | | | | | | | | | X | X | X | | | | X | |
| Increase clamp pressure | | | | | | | X | | | | | | | | | | | | |
| Check screw retraction | | | | | | | | | | | | | X | | | | | | |
| Increase taper | | | | | | | | | | | | | | | X | | | | |
| Check for burrs/radius of nozzle | | | | | | | | | | | | | | | X | | | | |
| Increase nozzle temperature | | | X | | | | | | | | | X | | X | X | | | | |
| Increase size of gate | | | | | | | | X | | | | X | | X | | | | X | |
| Enlarge vents | | X | | | | | | | | X | | X | | | | | | X | |
| Change gate location | | X | | | | | | X | | | | X | | | | | | | |
| Reduce screw speed | | | | | X | X | | | | | | | | | | | | | |
| Check for contamination | X | | | | X | | | | | | | | | | | | | | |
| Check for resin stagnation | X | | | | X | | | | | | | | | | | | | | |
| Check materials of construction | X | | | | X | | | | | | | | | | | | | | |
| Check for resin cross-contamination | X | | | | X | | | X | | | | | | | | | | | |
| Thoroughly purge or clean barrel and screw | X | | | | | | | | | | | | | | | | | | |

# DU PONT POLYMER PRODUCTS DEPARTMENT

## MOLDING DATA RECORD

| | | | |
|---|---|---|---|
| JOB | MOLD DESCRIPTION | MACHINE SET-UP INSTRUCTIONS | SPECIAL INSTRUMENTATION |
| OPERATORS | SCREW USED | | SAFETY CHECK |
| ENGINEERS | PRESS NO | NOZZLE # | |

| DATE / TIME | Run Number | Resin | Lot Number | TEMPERATURES (°C) (°F) | | | | | MOLD | | | PRESSURES (MPa) (PSI) | | | | CYCLE TIMES (sec) | | | | | | | | | WEIGHTS (g) | | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Rear | Center | | Front | Nozzle | Fixed | Movable | Melt | Injection 1st Stage | Injection 2nd Stage | Clamp (Tons) | Back | Injection | Hold | Open | Overall | Booster | Ram in Motion | Screw Retraction | Pad (Inches) | RPM | Full Shot | Part Only | |

COMMENTS ON MOLDING OPERATION, START-UP, ETC.

PAGE NO.

# DU PONT POLYMER PRODUCTS DEPARTMENT
# MOLD INSPECTION AND REPAIR RECORD

MOLD NAME ______________________ MOLD NUMBER ______________________

PART NUMBER(S) MOLD SIZE:

CUSTOMER'S
PART NUMBER(S) ______________________ ________ X ________ X ________
length width height

FITS FOLLOWING MACHINES ______________________

______________________ DATE RECEIVED ______________________

SPECIAL SET-UP EQUIPMENT REQUIRED ______________________

Mark (✔) if item is O.K. for next run. Mark (R) if item must be repaired before next run. Give brief explanation.

| MOLD CONDITION | | | | | | | | | | | | | DESCRIBE MAINTENANCE REQUESTED | DATE | DESCRIBE MAINTENANCE COMPLETED | DATE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Insp date | Sprue bushing | Runner | Puller (sprue) | "A" cavity & cores | "B" cavity & cores | Ejectors | Cooling flow | Side action | Vents | Wiring & heaters | Other | Other | | | | |
| | | | | | | | | | | | | | | | | |
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**For more information on *Teflon®* coatings:**


**DuPont**
***Teflon®* Industrial Coatings**
Chestnut Run Plaza
P.O. Box 80702
Wilmington, DE 19880-0702

(800) 441-7515
Fax: (302) 366-8602

**Europe**

DuPont de Nemours (Belgium)
A. Spinoystraat 6
B-2800 Mechelen
Belgium
Tel.: 33-15-441188
Fax: 33-15-441160

**Pacific**

DuPont Australia, Ltd.
254 Canterbury Road
Bayswater, Victoria 3153
Australia
Tel.: 61-3-9721-5617
Fax: 61-3-9721-5690

**Japan**

DuPont K. K. (*Teflon®* Finishes)
4th Floor, Chiyoda Honsha Building
5-18 Sarugaku-cho, 1-chome
Chiyoda-ku, Tokyo, 101 Japan
Tel.: 81-3-5281-5888
Fax: 81-3-5281-5899

**Asia**

DuPont China, Ltd.
Room 1122,
New World Office Building
(East Wing)
Salisbury Road
Kowloon, Hong Kong
Tel.: 852-2734-5459
Fax: 852-2368-3512

DuPont Korea
4/5th Floor Asia Tower
#726 Yeoksam-dong, Kangnam-ku
Seoul, Korea
Tel.: 82-2-222-5385
Fax: 82-2-222-5478





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## C.4 Testing Splices

**Tension Tests:**

Prediction for Pull Tests (assuming room temperature)

| | |
|---|---|
| Strength rating of wire: | 33,000 lb/in$^2$ |
| Strand diameter: | 0.004 in |
| Area: | $\pi\,(0.004/2)^2$ in$^2$ |
| Number or strands: | 19 |
| Max. weight per strand: | [rating of wire] * [area of strand] |
| | ≈0.415 lbs |
| Max. weight per wire: | [Pounds per strand] * [19 strands] |
| | ≈7.88 lbs |

Therefore, the expected breaking weight for 26 AWG wire is 7.88 lbs.

Individual Pull Tests (at room temperature)

| Test # | Break point (lbs) | Test # | Break point (lbs) | Test # | Break point (lbs) | Test # | Break point (lbs) |
|---|---|---|---|---|---|---|---|
| 1 | 8.5 | 14 | 9.3 | 27 | 9 | 40 | 8.1 |
| 2 | 8.1 | 15 | 9.1 | 28 | 8.9 | 41 | 8.4 |
| 3 | 8.5 | 16 | 8.6 | 29 | 9.1 | 42 | 8.7 |
| 4 | 8.7 | 17 | 8.5 | 30 | 8.8 | 43 | 9.1 |
| 5 | 9.2 | 18 | 9.1 | 31 | 9 | 44 | 9 |
| 6 | 9.4 | 19 | 9.1 | 32 | 8.7 | 45 | 8.9 |
| 7 | 8.7 | 20 | 9.2 | 33 | 8.6 | 46 | 8.8 |
| 8 | 8.5 | 21 | 9 | 34 | 8.9 | 47 | 9.1 |
| 9 | 9.2 | 22 | 9.5 | 35 | 8.9 | 48 | 9.2 |
| 10 | 9.2 | 23 | 8.8 | 36 | 9.3 | 49 | 9.5 |
| 11 | 9.7 | 24 | 8.9 | 37 | 8.7 | 50 | 9.3 |
| 12 | 9.1 | 25 | 9.5 | 38 | 8.8 | - | - |
| 13 | 9 | 26 | 10 | 39 | 9.9 | - | - |

| | | |
|---|---|---|
| **Average:** | **9.0** | **lbs.** |
| **Standard dev.:** | **0.38** | **lbs.** |

Tension Tests with Heat

| test ID: | set max (F) | actual max (F) | weight (lb) | insulation | note: |
|---|---|---|---|---|---|
| 2/18 #1 | 575 | 700+ | 5 | bubbled | weight applied 10 min before test |
| 3/24 #1 | 620 | 750 | 2 | bubbled | destroyed getting splice out of mold |

Observation: Wires break at high temperature even when tension is low.

**Individual Bend Tests:**

| | trial 1 | trial 2 | trial 3 | aver. | standard dev |
|---|---|---|---|---|---|
| 0 Flexes | 7.9 | 8.3 | 7.7 | 8.0 | 0.2 |
| 1 Flex | 8.9 | 7.3 | 7.7 | 8.0 | 0.7 |
| 2 Flexes | 9.2 | 9.2 | 8.3 | 8.9 | 0.4 |
| 3 Flexes | 11.1 | 7.2 | 11.9 | 10.1 | 2.1 |
| 4 Flexes | 8.7 | 8.2 | 9.3 | 8.7 | 0.4 |

**Spark Tests:**

Small, portable spark testers are available, such as from Clinton Instrument (www.clintoninstrument.com, e.g. model HV-35). It should be noted that portable units have lower maximum voltages than traditional spark testers. Experts should be consulted for the appropriate testing voltage and time, based on the smallest gauge wire involved.