A PRACTICAL METHOD TO INCREASE THE FUSION OF RADIO-FREQUENCY WELDS

A. S. Epstein, T. Rooney, S. Wiater
Dielectrics, Inc., 300 Burnett Rd., Chicopee, MA 01020
Z. Tao
University of Massachusetts Lowell, One University Rd., Lowell, MA 01854

Abstract

Radio-frequency (RF) welding or dielectric welding has been traditionally used to weld two identical dipolar thermoplastics - such as PVC to PVC. The advantages of this type of welding are simple, low cost, short cycle time and suitable for large flat joints. The strength of the welds depends on the fusion of polymer chains at the interface. Typically, welding two identical materials provides the best fusion. In addition, the process is also sensitive to dielectric properties, such as dielectric constant and loss factor, as well as rigidity and the melt temperature or Tg of the materials to be welded.

Therefore, the process is very limited by materials. Non-dipolar or high melt temperature materials such as polyolefin, and polycarbonate (PC), which are widely used in automotive, medical devices and other applications, are generally not weldable. Also welding two or more dissimilar materials to form strong welds is another challenge for the application of RF welding.

In the this paper, the RF welding process and the material requirements will be reviewed briefly. A practical method developed by Dielectrics, Inc. to join two parts made from dissimilar materials, and even produce strong welds, will be presented. Dielectrics, Inc. is a company specialized in the design, development, and manufacture of soft thermoplastic products and components for medical OEMs and other manufacturers.

Introduction

Various joining processes are extensively used in the plastic medical device components industry because most finished assemblies are normally too complex to mold in one piece. Often, many dissimilar materials will be used within a single finished assembly. Welding processes are used for thermoplastics, in which the part joint surfaces are melted allowing the polymer chains to fuse together forming a strong weld. Another method commonly used in joining plastics is chemical bonding, in which a separate material (adhesive) is applied between two surfaces to provide strong bonds with these two materials, respectively. In addition, mechanical fastening is also used when disassembly or reassembly is required.

Radio-frequency (RF) welding, also referred to as dielectric welding or high frequency welding, is one of commonly used plastic welding processes in medical applications, such as blood bags and colostomy bags. [1, 2, 3, 4] The process uses high frequency (13 to 100 MHz, usually 27.12 MHz) electromagnetic energy to generate heat in dipolar materials, resulting in melting and forming a weld after cooling.

RF welding uses simple, compact equipment. No solvents or adhesives for welding are required. The weld appearance is very good with little flashing. Also RF welding can produce tear seams so that sealing and cutting can be combined into a single step. So it is a fast, clean, and relatively inexpensive welding process.

Radio-Frequency Welding Process

The process is conducted using an RF welding press consisting of two platens – a moveable one, and a fixed one (also called a bed). During the process, the press lowers the moveable platen and applies a high-frequency electric field produced by an RF generator. The parts to be welded are placed in a set of metal dies or electrodes and then compressed with a preset amount of pressure. RF energy flows through the material (the dielectric) while being converted into internal heat to melt the materials. Thereafter the joint cools through the dies under pressure. After the appropriate time, the press opens and the finished assembly is released. The schematic of RF welding is shown in Fig. 1 [1].

Materials for RF Welding

In RF welding, an intensive high-frequency electric field is applied on the part to be welded. In this electric field, strong dipolar polymers such as polyvinyl chloride (PVC), thermoplastics polyurethane (TPU), polyamide (PA), polyvinylidene chloride (saran), cellulose acetate, and polyethylene terephthalate (PET), undergo a dipolar polarization process. The resultant dipoles in the polymer chains tend to orient in the field direction. As dipoles try to align with a rapid reversing, high-frequency electric field, orientation becomes out-of-phase due to restricted motion of polymer chains. The imperfect alignment causes internal molecular friction heating. The generated heat then melts the joint interface of the parts. Consequently, the molten polymers chains of the two materials entangle and fuse, thus producing a strong weld. However, non- or weak dipolar and polymers such as polyolefin and polystyrene (PS) are not considered compatible with this method because dipoles are not able to be formed in a high-frequency electric field for these materials. As a result there is no molecular motion responsible for the rapid reversing electric field.

In addition, some rigid materials or material with high melt temperatures or Tgs are also not considered as candidates for RF welding because either RF is not able to melt the materials effectively or the fusion of the melt is poor. PC is a good example. Another example is rigid PVC. Although PVC was the first material used in RF process, a study showed that rigid PVC produces much weaker RF welds than flexible PVC. Rigid PVC did not weld well to itself because the material did not melt or melt complete through before weld could form. Table 1 lists the weldability of some commonly used the plastics.

It is worthwhile to note that besides inherent properties of materials, part thickness and applied clamping pressure are two key factors which impact on the strength of the welds. A thick part separates the electrodes and reduces the intensity of the electric field, resulting in less effective heating. For RF welding, part thickness usually ranges from 0.50 mm to 1.90 mm depending on the materials. For very thin films, even PC may be considered weldable. High clamping pressure facilitates heating and melt flow to form a strong joint weld.

Development in RF welding

Although RF welding process has great advantages in terms of production, a relatively narrow range of materials used in RF welding limits the utilization and development of the process.

It has been a trend in automotive industry to replace PVC parts using thermoplastic olefins (TPOs). Traditionally, some PVC parts are welded through RF welding process. However, TPOs are non-dipolar materials and are not RF weldable. In order to overcome the obstacle, TPO/dipolar material blends have been developed for RF welding process. In a study composite of polyaniline (PAN) and high-density polyethylene (HDPE) was used for welding. PAN, a conductive polymer, has great responsibility for a high frequency reversing electric field. HDPE served as insulator to separate PAN particles, resulting in a reduction of conductivity. The low conductive composite did heat very well in adiabatic heating. The composite could be heated up to a temperature of 275ºC and formed HDPE welds with good joint strength.

By introduction of a dipolar material to non-polar materials, these materials are able to be heated by RF, resulting in an expansion of material selection for RF process. In these cases, the parts are made the same material. Therefore the molecular fusion of the melt is not a serious problem. However, in some cases, especially in medical device industry, a final assembly consists of two parts made from dissimilar materials. Compatibility and molecular fusion in melt flow become essential for a strong weld.

Recently, we developed a practical method and successfully joined parts made from PC and TPU, respectively, using RF welding.

Joining Dissimilar Materials Using RF Welding

Surgical apparatuses, such as access devices and balloon dissectors, including a flexible structure secured to a rigid structure, require joining dissimilar materials to form finial assemblies. As a sample, during laparoscopic procedures, cannulas are utilized to provide an access port for surgical instruments and a conduit for introducing insufflation gases into the body cavity. In certain instances, a dissection instrument with a dissection balloon operatively connected to a distal end. The dissection balloon is inflated to separate the tissue. It is also important that a fluid seal is maintained between the dissection balloon and the exterior of the body. In short, the device requires a rigid plastic (cannula) and a flexible one (balloon) to be assembled hermetically in a single device.

In such apparatuses, the rigid access cannulas are generally made of PC which is credited by its biocompatibility, high rigidity, and toughness. The balloon dissectors are made from flexible materials. TPU and its laminar composites with TPU as skin layers are widely used because of their good biocompatibility and easy processibility.

Although solubility parameters of PC and TPU are very close, and these two materials are considered compatible, PC with high rigidity and high Tg generally does not weld to TPU very well resulting from the poor melt fusion. In addition, PC is not considered RF weldable.

In order to facilitate securing the dissection balloons to the cannulas, we introduced an RF weldable bonding layer. This thin bonding layer should have two functions: 1) the bonding layer could weld or bond to both of PC and TPU very well; and 2) it should be RF weldable. A recent study showed that heat generates more effectively through adhesive layers than bulky materials because adhesive made of materials with relatively low molecular weight. Short molecular chains provided high mobility and great free volume, resulting in effective heat generation. In addition to that, high mobility of the molecules facilitated chain penetration or fusion, producing welds with good strength. According to the criteria above, we first chose two-component liquid urethane, and later aliphatic polycarbonate-based TPU.

Two-component liquid urethane was first mixed with Tetrahydrofuran (THF) to form a concentrated solution. Then one end of the PC cannula was dipped into the urethane solution for several seconds. Because THF is a solvent of PC, it swelled and softened the rigid PC surface of the cannula, facilitating the penetration of urethane monomers into PC. Thereafter, the coating was cured and the solvent was off-gassed. A skin of polyurethane was coated on the PC. Because of good compatibility of PC and TPU, the interface of PC and TPU had good strength. After coating, the joint surface of the cannula was altered into TPU which was weldable and as same as the material for the balloon dissectors.

Later on, we developed another process using aliphatic polycarbonate-based TPU, such as Carbothane® (Noveon Inc.). Carbothane® consists of both PC segments and TPU segments. This unique structure, similar to block copolymer, can be considered as compatibilizer for TPU and PC, enhancing the strength of weld.

Carbothane® was dissolved into THF to form a suspension-mixture-like-slurry. Afterwards, Carbothane® was dip-coated on to the PC cannula producing a sleeve coating with a thickness from .002” - .006”. THF was used not only to help Carbothane® be coated on the PC part, but also to swell the surface of the PC part, increasing in penetration of Carbothane®. Based on a similar theorem, the PC segments of Carbothane® fused into the PC part, leaving urethane segments outside to be welded to the balloon dissector. Once the coating was dried and solvent was removed completely, the coated cannula was welded to the balloon dissector using RF welding process.

Peel tests were performed to evaluate the joint strength. The data reveals that the weld strength is significantly increased by introduction of a bond layer. The welds using bonding layer broke through cohesive failure, compared with adhesive failure of PC/TPU interface without a bonding layer.

In a third iteration, a compatibilizer sleeve was fabricated by dipping blown glass mandrels in the slurry and then the volatiles were off-gassed. The resulting sleeve was then welded onto the PC cannula. Although the resulting cannula surface had both PC and TPU elements, the high percentage of TPU provided a compatible surface to welded a flat die extruded film to.

Conclusion

With the introduction of a bonding layer, we successfully joined two structures made from dissimilar materials which normally provide poor weld strength. In addition, by utilizing a novel coating, a part made from typically non-weldable material may be welded easily to a traditionally incompatible part. The technique is not only valid for RF welding, but can also be applied by other welding processes, such as impulse welding. The technique both improves the weld-joining processibility, but also gives much flexibility for material selection and part design as well.

Reference

1. Grewell, D. (author), Rotheiser, J.I. (Editor).*Joining of Plastics Handbook for Designers and Engineers*. Chapter 11, Hanser Gardner Publications, Second Edition 2004
2. Plastics Design Library, Handbook of Plastics Joining, William Andrew Publishing/Plastics Design Library, Norwich, NY, pp 75-78 (1997);
3. J. Leighton, T. Brantley, and E. Szabo, *RF Welding of PVC and Other Thermoplastic Compounds,* ANTEC 1992, conference proceedings -Society of Plastics Engineers, (1992).
4. www.twi.co.uk/j32k/getfile/pjkrfweld.html
5. A.S. Epstein, S.J. Wiater, and B. Creston;

THIS PROCESS IS PATENT PENDING

Table 1: RF Weldability of Materials [1]

MATERIAL	*WELDABILITY RANKING (1-5)* *1=Best results, 5=Not possible*
ABS	2
Acetal	4
Acylics	3
Aclar	3
APET	2
Barex 210	1
Barex 218	1
Butyrate	2
Cellophane	5
Cellulose acetate	2
Cellulose nitrate	3
Cellulose triacetate	3
Ethyl cellulose	5
EVA (ethyl vinyl acetate)	2
EVOH (ethyl vinyl alcohol)	3
Nylon (PA)	2
Pelathane (not recommended w/tear-seal)	2
PET (polethylene teraphthalate)	2
PETG (polyethylene terephthalate glycol)	1
Phenol-formaldehyde	2
Pliofilm (rubber hydrochloride)	1
Polyethylene	5
Polymethylacrilate	3
Polypropylene	5
Polycarbonate	4
Polystyrene	5
Polyurethane	2
Polyurethane foam	3
Polyviny acetate	2
Polyvinyl chloride, flexible & clear	1
Polyvinyl chloride, pigmented	1
Polyvinyl chloride, opaque	2
Polyvinyl chloride, semirigid	2
Polyvinyl chloride, rigid	3
Polyvinyl chloride, flexible w/glass-bonded	1
Polyvinyl chloride, coated paper or cloth	1
Rubber	5
Saran (Polyvinylidene chloride)	1
Silicone	5
Teflon (tetrafluoroethylene)	5

For additional information, please feel free to contact the following:

Adam S. Epstein
Dielectrics, Inc., 300 Burnett Road, Chicopee, MA 01020
Toll Free: 800-472-7286
Web: www.dielectrics.com

Dielectrics