

Advanced Coextruded Multilayer Tubing Allows Smaller, Thinner, More Functional Catheter-Based Devices

Breakthroughs in multilayer tubing extrusion technology enable next-generation catheter-based medical devices.



ADVANCED COEXTRUDED MULTILAYER TUBING ALLOWS SMALLER, THINNER, MORE FUNCTIONAL CATHETER-BASED DEVICES

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INTRODUCTION

In the medical device industry, the trend toward minimally invasive surgical techniques is the driving force for smaller, more innovative medical devices. Devices for vascular and other applications continue to reach deeper into the anatomy with more therapeutic technology, and medical device manufacturers are demanding polymeric tubing that boasts greater precision, tighter tolerances, and increased functionality. As tubing designs become more complex, so does the extrusion technology to produce them. Multilayer extrusion technology has been at the forefront of these advances. Multilayer extrusion, or coextrusion, is the extrusion of multiple layers of material simultaneously to produce multilayer tubing. Multilayer technology is primarily used to improve functionality; for example, to combine a weldable material with one that has other performance characteristics, like lubricity. These constructions can also increase performance and possibly reduce overall assembly and material costs, making the medical device more cost effective for the customer. Other key functionalities may include active material layers, such as hydrophilic, bioresorbable, or drug-eluting layers. The technology and materials now used to produce multilayer products for today's medical devices have advanced greatly and provide the designer with a wealth of opportunities for optimizing size, materials, and functionality.

Using multilayer tubing in medical devices allows designers to:

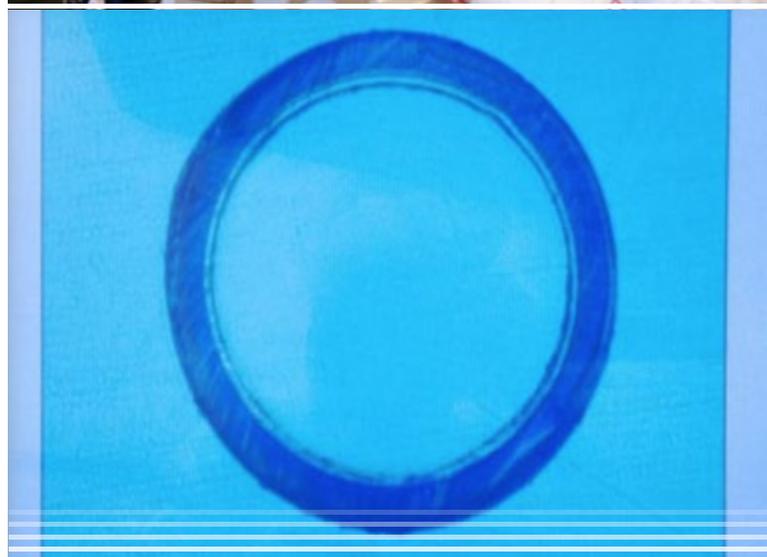
- *Create tubing with different properties for the exterior and interior surfaces*
- *Combine materials with different properties to create unique tubing characteristics*
- *Locate active materials in their optimal layer*
- *Locate bondable materials inside or outside to facilitate device assembly*

MULTILAYER EXTRUSION EQUIPMENT

In the past, manufacturing multilayer tubing consisted of technicians cobbling together an assortment of various extruders and downstream equipment borrowed from other extrusion lines within the company. With this inferior method, it was highly probable that the various extruders were all in the same plane, resulting in longer flow channels, increased pressure, and increased residence time of the material. Frequently, the required layer ratios of the tubing would not match the optimal output of the extruders, which could result in screw speeds being too high or too low. Tubing with inferior mechanical properties could be created from shear degradation or high material residence time. Compounding these issues was a myriad of operator interfaces on various extruders, sizing tanks, and haul-off that the operator would have to monitor throughout the production run. The outcome would often be poor tubing performance characteristics and process-control issues. As a result, in some cases, successful development runs conducted by engineers or highly skilled technicians could not be transferred to production.

Modern multilayer extrusion processing equipment is much more likely to be a fully integrated line, with a single operator interface to monitor, control, and record the entire extrusion system in real time. The extruder for each polymer layer is selected to deliver the required output speed ranges that do not compromise the mechanical properties of the material. They are positioned to minimize material residence time, and generally one or more of the extruders may be mounted vertically or at a 45° angle. One or more of the extruders in the multilayer system is likely to be a micro extruder with outputs as low as 50 grams per hour, allowing for individual layers of only a few microns thick. Manufacturers of these micro extruders use innovative extruder throat designs to ensure standard plastic pellets carry forward well in the feed section of the extruder, with no loss of stability.

Today's systems also have inline measurement systems, monitoring not only the outer diameter but also the wall thickness and inner diameter, using refraction of infrared light technology or ultrasonic technology. These systems often provide closed-loop control to the extruders, puller,



Offline measurement of microbore multilayer tubing at 300x magnification.

and pneumatic or vacuum sizing to ensure the most accurate dimensional control is maintained throughout the extrusion run.

The use of such statistical process control (SPC) systems is driven by customer expectations and improves the ability to meet the increasing demands of regulatory authorities such as the US Food and Drug Administration. However, accurate inline measurement of the thinnest layers continues to pose challenges. Currently, multilayer manufacturers must use offline measurement of discrete samples using video measurement systems with magnification up to 350x.

MATERIALS

Many thermoplastic materials can be coextruded to create multilayer tubing for a particular application. The most common materials are those that have traditionally been used to make medical tubing: polyamide, thermoplastic elastomer (TPE), polyurethane, polyvinyl chloride (PVC), and polyolefins. These materials can be customized to include drug-eluting ingredients, radiopacifiers, fillers, and/or colors. However, the designer must take into account the material's processing temperature, flow characteristics, and melt viscosity. For example, it would not be possible to coextrude a high-melt-temperature, high-viscosity material like polyether ether ketone (PEEK), which has a melt temperature of approximately 660°F, with a material like polyethylene, which has a melt temperature of approximately 260°F, because the temperature differential is too great. Compatible materials will bond when extruded together. A tie layer must be used to combine two chemically dissimilar materials. This layer provides no additional mechanical functionalities and simply bonds the outer and inner layers.

Multilayer extrusion technology is particularly suited to expensive novel or active materials that have been developed for a specific function because it allows these materials to be located appropriately. Common examples are when a drug-eluting material needs to be on the outer layer, or a highly lubricious material needs to be placed on the inner layer. Since multilayer tubing allows for thin layers of these materials to be placed where they are most effective, it can contribute to cost savings.

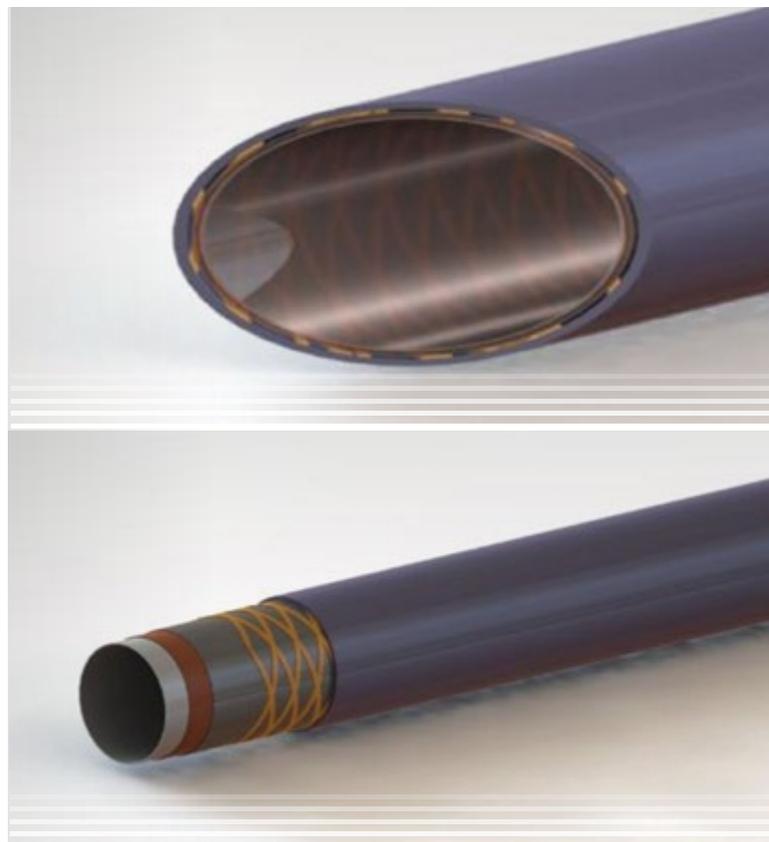
COMMON USES FOR MULTILAYER TUBING

Multilayer extrusion tubing products can offer additional functionality through multiple material combinations and can facilitate, reduce, or even eliminate secondary assembly processes. The most successful component designs involve a partnership between medical device designers in the early stages of the design phase and the extrusion experts who have the necessary knowledge of materials and processing. Following

are some of the applications that have successfully used multilayer extrusion technology, on its own or in combination with other technologies.

DELIVERY SYSTEMS FOR TRANSCATHETER VALVE REPLACEMENT

Percutaneous replacement of diseased heart valves is an emerging therapy that offers an alternative to the traditional surgical approach for high-risk patients. In this minimally invasive procedure, a guidewire is placed through the femoral access site (in the groin), similar to an angioplasty procedure, and guided into the chambers of the heart. An introducer sheath is inserted over the guide wire, and the valve delivery system is then introduced. Once the replacement valve is correctly positioned inside the diseased native valve, it is deployed. The patient is fully conscious throughout



Braiding laid over transparent thin-wall trilayer tubing and laminated with varying-durometer sheaths.

the minimally invasive procedure. The tubing required to deliver the valve to the site is a highly specialized component. The distal end must be easily steerable so it can be guided directly into the chambers of the heart. The tubing needs to be pushable, so the proximal end needs to be more rigid. It must also have excellent kink resistance, and the inner diameter needs to be lubricious for smooth, unobstructed delivery of the replacement valve. Another key requirement is that the tubing wall must be as thin as possible to maximize the delivery channel diameter for the replacement valve without the tubing losing any of its functionality.

In designing this particular component, the designers faced a number of challenges. Polytetrafluoroethylene (PTFE) lubricious liners, which are often the industry standard for delivery systems, could not be used due to concerns over the effects of gamma radiation during the sterilization process. Other concerns included obtaining PTFE liners with the ultrathin walls necessary for this application, as well as achieving a good bond with the other materials in the component. To ensure the tubing did not kink or deform as it navigates through the anatomy to the heart, it was necessary to incorporate a braided layer into the component. The distal end of the component needed to be more flexible for trackability, and the proximal end of the component needed to be less flexible for pushability.

The resulting design was a 5-layer component, comprising an ultrathin-wall multilayer tube, a layer of stainless steel braid, and various polyether block amide sheaths of different durometers on the outer layer of the component to increase the overall flexibility from proximal to distal end.

The multilayer tube used on the inner diameter of the component consisted of high-density polyethylene (HDPE), a tie layer, and polyether block amide, with a wall thickness of less than 0.008" and an outer diameter ranging between 25 Fr and 35 Fr. HDPE was used on the inner layer for its low-friction properties. The outer layer was polyether block amide for an excellent bond with the outer sheath tubes, ensuring no delamination across the braided layer. The stainless-steel braided layer provided the necessary structural rigidity and kink resistance. By using a multilayer construction instead of several

single-layer tubes, the wall thickness could be kept to a minimum, and assembly time and costs were reduced.

PERCUTANEOUS TRANSLUMINAL CORONARY ANGIOPLASTY

Percutaneous transluminal angioplasty (PTA) and percutaneous transluminal coronary angioplasty (PTCA) are performed to treat vessel narrowing. In both procedures, a wire is passed from the femoral artery in the groin (or, at times, from the radial artery or brachial artery in the arm) to beyond the area of the artery being treated. A balloon catheter advances over the wire to the segment that is to be treated. When the balloon is inflated, it compresses the plaque and stretches the artery wall to expand, improving blood flow. During the procedure, a stent may also be placed at the site of the occlusion.



Microbore multilayer tubing for PTA/PTCA applications, shown with the eye of a sewing needle.

Microbore multilayer tubing can be used to make the inner shaft tubing of PTA and PTCA catheters. Using a multilayer extrusion in this application enhances the performance characteristics of the finished catheter while reducing overall wall thickness to less than 0.002", in some cases. The inner shaft is typically a 3-layer tube comprising a lubricious material (usually HDPE) on the inner layer to ease the passage over a guidewire. Polyamide or polyether block amide is used for the outer layer for weldability with other components in the

device. The middle layer consists of a tie or bonding material used to join the incompatible inner and outer layers of material. With recent material developments, it is now possible to use lubricious inner-layer materials that are compatible with the outer-layer materials. These materials can be lubricity-enhanced polyamides or fluorocarbon-based materials—there is no longer a need for a tie layer sandwiched between the outer and inner layers. Using materials in the middle layer to change the mechanical functionality of the tubing, rather than merely bonding the inner and outer layer, opens nearly endless possibilities for the designer.

In addition, multilayer technology is increasingly used to manufacture other tube components within PTA and PTCA devices, such as balloon tubing and outer-body tubing. Using multilayer tubing with an incorporated stiff middle layer can significantly reduce overall wall thickness. Alternatively, maintaining the wall thickness could increase burst resistance compared with that of a single-layer tube.

INFUSION TUBING

Infusion tubing is used to deliver drugs to the body. Traditionally, flexible PVC, which contains plasticizers and other additives, was the material of choice for this application because of its low cost, excellent antikink properties, ease of processing, and assembly using solvent bonding. However, PVC is not compatible with insulin, nitroglycerine, and oncology drugs such as paclitaxel. The active ingredients of such drugs absorb into the PVC tubing, resulting in a loss of potency, and only a portion of the desired dose reaches its target. More hazardously, the infusion solution can dissolve the plasticizer and other additives contained within the PVC, which inevitably end up in the patient.

Because of its inertness, polyethylene has excellent compatibility properties, but is difficult to bond and has poor antikink properties. The ideal solution is multilayer tubing containing low-density polyethylene (LDPE) on the inner diameter for compatibility and PVC on the outer diameter. The LDPE layer acts as a barrier, ensuring there is no loss of active ingredients through the absorption of the infusion solution, or

contamination due to migration of additives within the polymer material. The outer layer of PVC optimizes kink resistance and ensures that the tubing can still be assembled by solvent bonding, packaged, and sterilized in the same way as standard infusion tubing. Chemical compatibilities like these are common challenges that can be easily overcome with advancements in multilayer tubing technology.

SUMMARY

Advances in multilayer tubing have come a long way in providing increased capability to procedures that were previously difficult to execute. The versatility of materials used in multilayer tubing creates virtually endless combinations that can easily overcome medical challenges—and still remain competitive in the market. The innovative use of multilayer tubing in medical design has revolutionized the way we solve a plethora of medical problems. With future advances in extrusion-tooling and machine-design technology, and improvements to process control and measurement systems, we hope to see even greater precision, with smaller, thinner, and more functional multilayer tubing. Over time, multilayer extrusion lines will become more specialized and incorporate a combination of other extrusion technologies, such as multilumen extrusion, tapered extrusion, over-the-wire extrusion and interrupted/intermittent layer extrusion.

TYPICAL MULTILAYER CONFIGURATIONS

Multilayer Component	Desired Primary Property on Inner Layer	Inner Layer Material	Desired Primary Property on Outer Layer	Outer Layer Material
PTA/PTCA Inner Tubing	Lubricity	HDPE	Bondable to adjacent device components	Nylon 12
Infusion Tubing	Chemical inertness	HDPE	Flexibility	PVC
Tungsten-Polymer Marker Band	Radiopacity	80% Tungsten-filled PUR	Smoothness	PUR
Implantable Central Venous Catheter	Flexibility	PUR	Antimicrobial	Silver ion-filled PUR
Coronary Implant Delivery System	Lubricity	HDPE	Bondable to adjacent device components	Pebax®

ABOUT VENTION MEDICAL

Vention Medical is a global integrated solutions partner with more than 30 years of experience in design, engineering, and manufacturing of complex medical devices and components. Vention Medical specializes in components and services used in interventional and minimally invasive surgical products including catheters, balloons, extrusions, polyimide and composite tubing, heat shrink tubing, braid-reinforced shafts, cleanroom injection molding, and finished device assembly and packaging. Visit Vention at ventionmedical.com.

CHOOSING A MULTILAYER EXTRUSION SUPPLIER

The most successful component designs involve a partnership between medical device designers in the early stages of the design phase and the extrusion experts who have the necessary knowledge of materials and processing. When evaluating a potential supplier for your multilayer requirements, consider your need for engineering and design assistance, including quick-turnaround prototyping, material expertise, and manufacturing capabilities, including up-scaling, cost-effectiveness, process validations, and quality certification.

ENGINEERING AND DESIGN SUPPORT

Is the potential supplier well staffed with experienced engineers who can help you refine your concepts and design the custom tools to produce them? What prototyping methods are available? Can they produce prototypes within 2–3 weeks? Are they able to do any secondary operations required?

MATERIALS EXPERTISE

Does the supplier have the expertise and experience to help you choose the proper materials for your application? Are engineers available to help you evaluate the physical specifications of your product and determine the optimal process parameters?

MANUFACTURING CAPABILITIES

Does the supplier have a quality system certified to ISO 13485:2003 and ISO 13485:2012? Does the supplier have state-of-the-art, fully integrated multilayer extrusion lines? Is the supplier equipped for short and long extrusion runs? Do they offer assembly and secondary operations? Can the supplier conduct process validation runs? Does the supplier have a controlled environment for its manufacturing area?

QUALITY

Does the supplier practice audited quality-control production? Do they maintain advanced inspection equipment, such as video microscopes and laser micrometers? Can they perform raw material testing, in-process inspection, statistical process control (SPC), and end-product testing? Will the supplier supply final inspection data and SPC data from the extrusion runs?