

Tooling Design for Tubing

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August 28, 2009

Introduction

The requirements for medical tubing with respect to dimensional tolerances and overall quality are stricter than almost any other application. This, coupled with the small tubing sizes typically produced, presents major challenges to the producers of medical tubing. The requirements are often so exact that strict adherence to fundamental extrusion design principles are essential for companies seeking to improve their extrusion performance. While these principles are crucial for medical tubing manufacturers, they apply just as well in other industrial extrusion applications. For example, wire and cable manufacturers can benefit from these principles for their jacketing applications.

Definition of Various Draw Ratios

Tooling design for tubing is a critical issue in tubing extrusion but there is limited useful information available. Important issues in the design of tubing tooling are the various draw ratios that define the tooling and the extrusion process. The dimensions of the tip (mandrel) and die are determined by the draw down in the extrusion process. There are various draw ratios in tubing extrusion that describe how the tubing is drawn down at the exit of the die. The diameter draw ratio (DDR) is the average diameter of the tip and die divided by the average diameter of the tubing.

$$DDR = \frac{D_t + D_d}{D_o + D_i} \quad (1)$$

where D_t is the tip diameter, D_d is the die diameter, D_o is the tubing outside diameter, and D_i the tubing inside diameter, see figure 1.

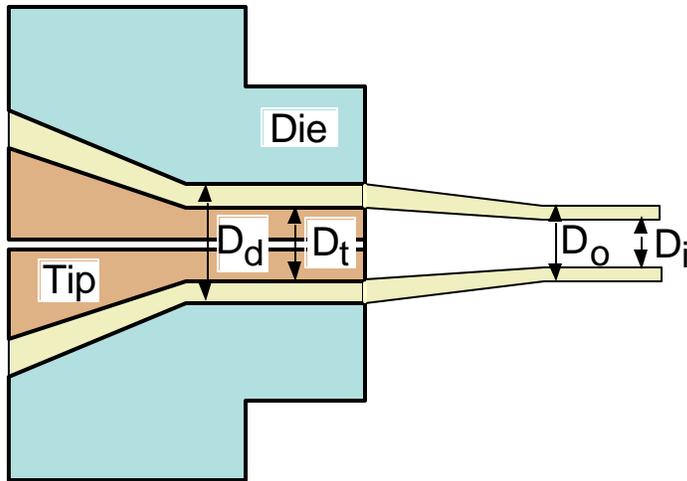


Figure 1, Definition of D_d , D_t , D_o , and D_i

Another important parameter is the wall draw ratio (WDR). This is the gap between the tip and die divided by the wall thickness of the tubing.

$$\text{WDR} = \frac{D_d - D_t}{D_o - D_i} \quad (2)$$

A third measure is the area draw ratio (ADR). This is the cross sectional area between the tip and die divided by the tubing cross sectional area.

$$\text{ADR} = \frac{D_d^2 - D_t^2}{D_o^2 - D_i^2} \quad (3)$$

It should be noted that sometimes the area draw ratio is represented by the letters DDR as an acronym for draw down ratio. Obviously, this can cause confusion with the diameter draw ratio. Often the area draw ratio is called simply the draw ratio. It is important therefore to check what exactly is meant when the term draw ratio is used. The ADR can be calculated from the WDR and the DDR as follows:

$$\text{ADR} = \text{DDR} * \text{WDR} \quad (4)$$

Thus, the wall and diameter draw ratios determine the area draw ratio in the extrusion process. A high ADR increases orientation and the chance of pinholes and breakaways. A low ADR reduces orientation and increases the chance of melt fracture.

Figure 2 illustrates area draw ratio for three different values of ADR

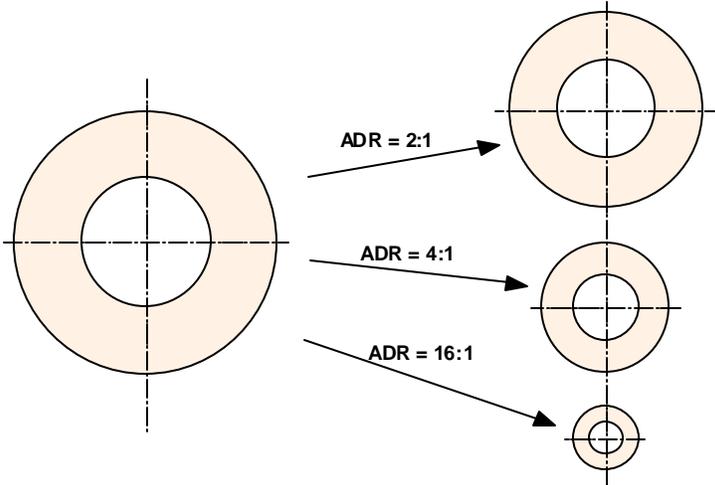


Figure 2, Illustration of area draw ratio

A fourth measure of draw down is the draw ratio balance or DRB. This is the diameter ratio of the die and tip divided by the diameter ratio of the tubing.

$$DRB = \frac{D_d/D_t}{D_o/D_i} \quad (5)$$

When the DRB equals one the annular shape of the tubing is the same as the annular shape of the tooling. When the DRB is greater than one, the ID of the tubing relative to the OD will be greater than the ID of the tooling (tip diameter) relative to the OD (bushing diameter). This is illustrated in figure 3. For a stable tubing extrusion process the DRB should be equal to or greater than one.

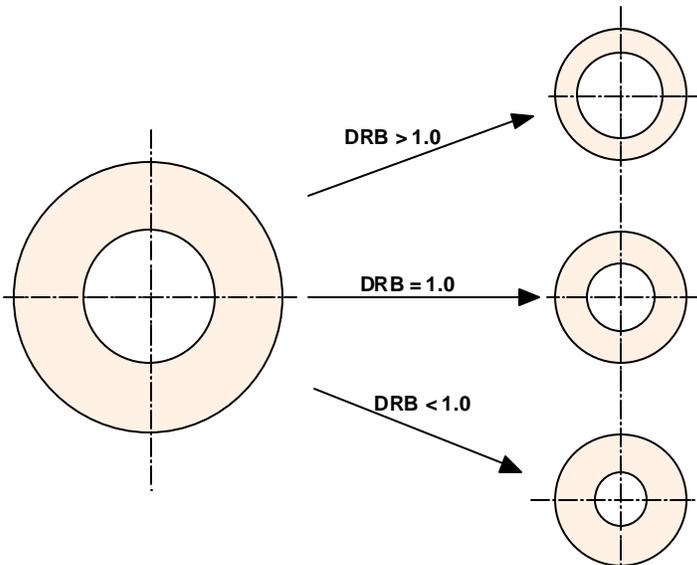


Figure 3, Illustration of Draw Ratio Balance

The draw ratio balance should be equal to or larger than one, $DRB \geq 1$. Yet another parameter that is used is the sizing ratio or SR. This is the wall draw ratio divided by the diameter draw ratio.

$$SR = \frac{WDR}{DDR} \quad (6)$$

A balanced draw occurs when the sizing ratio ranges from 1.0 to 1.3. When the SR is larger than 1.3, there is a danger of getting tear holes in the tubing. Low SR values can cause instabilities in the sizing of the tubing. Rubbers and high molecular weight polymers can be run with low SR values. Low viscosity polymers should be run with high SR values. High SR values will increase orientation and the chance of breakaways. High SR values will require higher internal and/or lower external air pressure to obtain tubing size.

The relationship between area draw ratio and draw ratio balance is shown in figure 4.

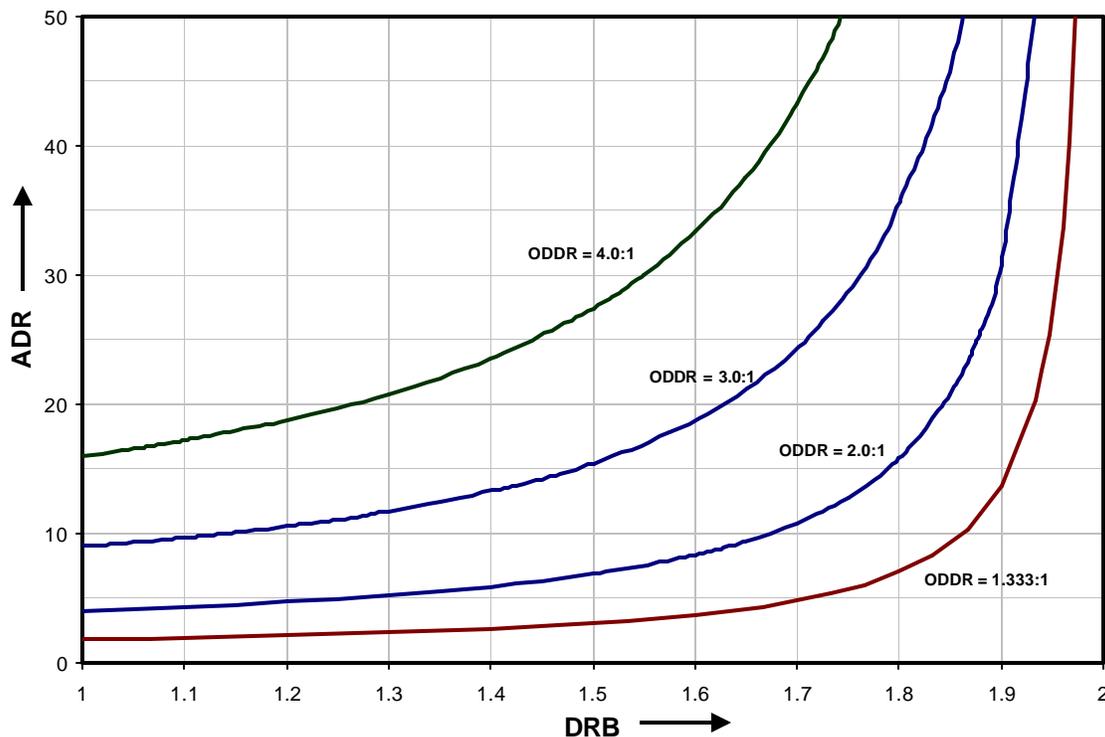


Figure 4, Area draw ratio versus draw ratio balance for several OD ratio values

The data in figure 4 is based on a bushing diameter of the tooling of 4.0 mm and a tip diameter of the tooling of 2.0 mm. Figure 4 shows several curves for different values of the OD ratio. For instance, when the OD ratio is 4.0:1 the OD of the

tubing is 1.0 mm. When the DRB = 1.0 there is balanced draw meaning that WDR = DDR. The ADR increases significantly with DRB because the wall thickness reduces with DRB. This is shown in figure 5.

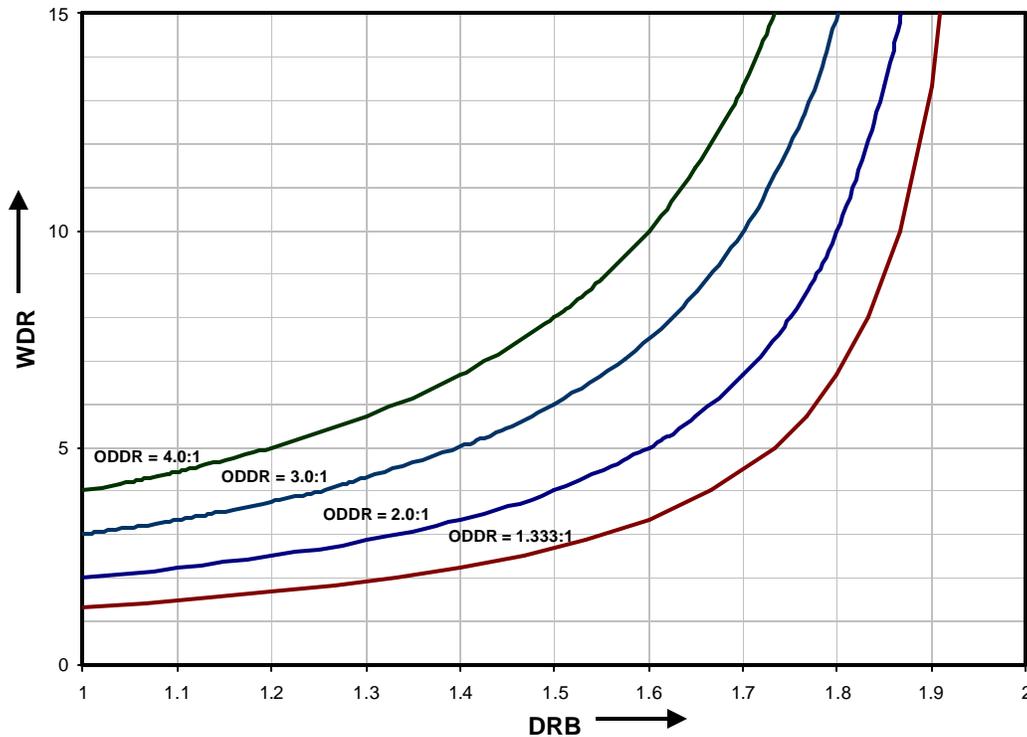


Figure 5, Wall draw ratio versus draw ratio balance for several OD ratio values

Figure 5 shows that the WDR increases with DRB, particularly when the DRB values exceed 1.5. High values of the DDR and DRB result in high area draw down ratio (ADR) values. The ADR that can be achieved in actual extrusion operations depends on the elongational deformation characteristics of the polymer.

Different polymers can be drawn down by varying amounts. Fluoropolymers, such as FEP, PFA, and ETFE, can be drawn down a great deal with ADR values of 10 to 100 and higher. With special extrusion techniques PFA can have an ADR of over 250:1. Polyethylenes have a medium ability to be drawn down, polyurethanes and polyvinyls low to medium.

Land Length

In addition to the tip and die diameter, the land length and the cone angle are important design parameters. In many situations a long land length is desired because a long land tends to:

- Reduce tip and die drool
- Increase orientation
- Reduce the chance of pinholes
- Reduce the swelling of the extrudate (die swell)
- Improve shape definition

The main drawback of a long land length is increased diehead pressure. Since the land region usually has the highest restriction to flow, a longer land can increase pressure substantially. Another drawback of a long land length is that a long tip is more susceptible to mechanical deformation; the tip can bend more easily. This is a particular concern in small diameter tubing. Typical rules for the land length are:

- Land length divided by gap between tip and die (L/H) from 10:1 to 20:1
- Land length divided by the diameter of the tip (L/D_t) from 10:1 to 25:1

The gap between the tip and the die, H , is half the die diameter minus half the tip diameter or $H = 0.5D_d - 0.5D_t$. The land length values that follow from these rules often result in excessive pressures with dealing with high viscosity materials. In many cases, therefore, the pressure drop will determine what land length is practical.

A special extrusion technique that is occasionally used is the extended mandrel. This is particularly used for thin wall tubing. In this technique the tip extends beyond the die by a considerable distance. The purpose of the extended mandrel is to obtain better shape definition. Another use of the extended mandrel is to provide localized heating of the tip using an induction coil at the die exit. This is a variation of the G-Process discussed under special features. It is a suitable method to eliminate internal melt fracture or internal die drool. The mandrel extension should be made of a ferro-magnetic material to obtain efficient temperature increase under the influence of the alternating magnetic field of the induction coil.

Taper Angles

The taper angle of the tip and die depends largely on whether the tooling is self-centering or adjustable, see figure 6.

$$\dot{g} = \frac{2(1+2n)\dot{V}}{nWH^2} \quad (8)$$

Typical values of the critical tensile deformation rate range from about 1 to 100 sec⁻¹, depending on the type of polymer. When polymer melt flows from a large to a small channel, it forms a natural streamline angle. When the taper angle of the tooling is larger than the natural streamline angle dead spots will form. This can be avoided by making the half angle of the entry to the die equal to or smaller than the natural half angle.

Special Features

In some cases a slight taper is used in the land region. Haas and Skewis [3] reported that a slight taper reduces extrudate roughness. For high draw ratios DuPont recommends [4-6] to radius the face of the tip with a radius of 0.1 of the tip diameter. In some cases a small chamfer is used on the ID of the die, e.g. 0.8-mm x 45 degrees. In order to obtain higher and/or faster draw down, a cone heater can be used according to Blair [5, 6]. This is a heater at the exit of the die used to prevent the cone of polymer from cooling too rapidly. The cone heater primarily heats the air surrounding the cone.

With materials that are susceptible to melt fracture the exit region of the tooling can be heated to temperatures considerably higher than the rest of the extruder. One approach is to use an induction heater at the die exit to heat just the region surrounding the die orifice. This is called the G-Process by DuPont [4-6]. In this process a high frequency heater is used. The heat is generated due to the metals resistance to the flow of electrons and to the hysteresis losses occurring during rapid magnetization and demagnetization.

References

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About the Author

Dr. Chris Rauwendaal - President of Rauwendaal Extrusion Engineering, Inc. since 1990; previously with American Enka Company and Raychem Corporation. Chris received a M.Sc. from Delft University and a Doctorate in Polymer Processing from Twente University in the Netherlands.

Chris is a well-known author, lecturer, entrepreneur, and consultant in the field of extrusion. He holds numerous patents and has written more than 200 articles and seven books related to extrusion, mixing, injection molding, and statistical process control. Chris has developed video training courses and interactive training programs on extrusion, injection molding, and SPC. He has been involved in technical meetings of the SPE and PPS for many years as a speaker as well as a technical program chairman. Chris is a Fellow of the Society of Plastics Engineers. He was technical program chairman for the international Plastic Extrusion Asia Conference that was held in Bangkok, Thailand March 2008 and is co-chairman for the 2010 Plastic Extrusion Asia Conference to be held in Kuala Lumpur, Malaysia March 29-30, 2010.

Chris is the developer of the CRD and VIP mixing technology that utilizes strong elongational flow to improve mixing in extrusion and molding. CRD mixing devices are successfully used in many extrusion operations. VIP mixers were recently introduced to the plastics processing industry and are gaining rapid acceptance. This technology extended in the development of a new generation of extruders and injection molding machines. The most recent development is the HHT (high heat transfer) extruder screw developed to improve cooling in foam tandem extrusion operations.