How screw design affects processing

Steven Covey once said, "Begin with the end in mind". It's all about the part. Not everything can be said in this paper with regard to all that affects part quality. Part design, mold design, use of regrind, percentage of capacity of the press being used, runner systems, drying procedures and temperatures, etc. all play a part in product outcome. Our focus here will be concerned specifically with how screw design affects processing.

Key factors in design.

We begin with the plastic. Plastics are manufactured materials often referred to as polymers. Factor one concerns the crystallinity of thermoplastic materials. These materials can be generally divided into two main types; amorphous and semi-crystalline (often just referred to as crystalline). The definitions refer to the shape of the molecular structures. Crystalline molecules are packed close together and are aligned in an orderly fashion. Amorphous materials have molecules going in all different directions. Those structures make a difference when processing. Let's compare them.

General Morphology	
Crystalline:	*Amorphous:*
Excellent Chem. Resistance	Poor Chem. Resistance
High Strength	Low Strength (exception is PC)
Low Viscosity	High Viscosity
Abrupt Melt Temp.	Non-abrupt Melt Temp.
Critical Time / Temp.	Non-critical Time / Temp.

Characteristics	
Crystalline:	*Amorphous:*
Sharp melting point	Broad softening range
Usually opaque	Usually transparent
High shrinkage	Low shrinkage
Fatigue-wear resistant	Poor fatigue/wear

Examples	
Crystalline:	*Amorphous:*
Acetal (POM)	ABS
Polyester (PET,PBT)	Acrylic (PMMA)
Polyamide (nylon) (PA)	Polycarbonate (PC)
Polyethylene (PE)	Polystyrene (PS)
Polypropylene (PP)	PVC

Crystalline materials are in general more difficult to process. They have a rather abrupt melting point. They do not gradually soften but remain solid until the right amount of heat has been absorbed and then change quickly into a melted state. These materials process best with screws that have short transition sections and higher compression ratios. (Compression ratios and flight profiles will be explained further on in this paper.) In addition, a screw with a longer L/D ratio is preferred since it will allow more time to heat the pellets before they reach the transition section.

Amorphous materials gradually soften as they are heated. Higher temperatures will not produce a melted state any sooner but will often degrade and burn the polymer. These materials tend to be shear sensitive so it is important to use lower compression ratios and longer transition sections.

The second factor that needs mentioning is the possible introduction of fillers. The resulting screw design consideration is to drop the compression ratio and go with deeper flight depths. In other words, a non-filled nylon designed screw will be slightly different than a screw designed for nylon that is incorporating 40% glass fillers. It is important to ensure that the introduced fiber is not damaged by too much compression.

A third factor concerns the viscosity of the polymer. Viscosity is the term used to describe the resistance to flow. A material with a high viscosity is more resistant to flow than a material said to have a low viscosity. The more resistant to flow the material is, the deeper the flight depth must be, thereby allowing better material flow and reducing the likelihood of overheating the material.

Again, the goal is to produce a homogenous melt.

Elements of screw design

The aim of the feedscrew is to provide proper melt as the polymer goes from a solid to a liquid state. The screw has several factors that have a bearing on that process. They are L/D (length/diameter) ratio, compression ratio, zone lengths, and channel depths.

L/D ratio
This ratio is the relationship of the flighted length to the diameter of the screw. Usually an injection screw that is 20/1 will have 20 flights. Most injection screws will be between 17/1 and 24/1. OEMs will often design a press to accept a grouping of injection units that allow for flexibility in molding. As the screw diameter changes in that grouping so does the L/D ratio. The L/D ratio is a fixed ratio. In other words, if a customer sent us a 50mm 20/1 screw for us to rebuild or redesign, the ratio must remain the same (unless a downsize or upsize conversion is needed). The advantage of a longer L/D ratio is that more shear heat can be uniformly generated without degradation. In addition, the screw can be easily designed for better mixing. The advantage of a shorter L/D ratio is that it will often provide less residence time and requires less torque.

Compression ratio
This ratio is used to tell us how much the screw is squeezing the plastic as it moves from the feed section through the transition section and into the metering section. These zones will be talked about later. The ratio is determined by dividing the feed zone flight height by the metering zone flight height (see diagram below). OEM screws, which are often referred to as GP (general purpose) screws, are designed to process as many thermoplastics as possible. The compression ratios vary from OEM to OEM and from size to size. Most OEM GP screws range between 2.2:1 and 2.8:1 compression ratio. Concor uses a 2.5:1 for a GP profile. Obviously a GP design cannot process all materials with equal efficiency. The higher the compression ratio the more shear heat that is produced. This is where the polymer crystallinity comes into play. Amorphous materials tend to use lower compression ratios and crystalline materials tend to use higher compression ratios. Care needs to be taken when processing

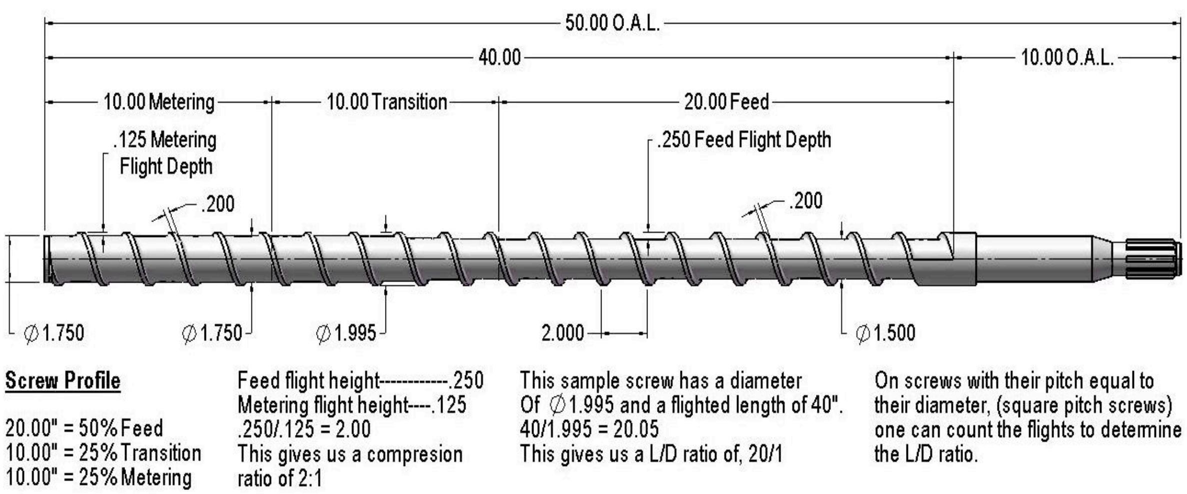
shear sensitive amorphous materials so a lower compression screw is preferred. (See below for crystalline and amorphous design comparison)

Zone lengths

A feedscrew has three distinct sections: feed, transition (compression), and metering. The feed section is at the back end of the screw, where material is introduced into the barrel. The screw's root diameter remains constant until the transition section. Material is fed forward as external heat from the heater bands begins to soften it. The transition section is where most of the polymer melting takes place. The material is compressed as it moves up the transition zone going from the feed depth to the shallower metering depth. The compressing of the polymer creates the heat source that produces most of the melt. A longer transition zone creates less shear heat thereby not degrading amorphous materials. The metering section starts near the discharge end where the root diameter again becomes constant. Final melting takes place in this zone, bringing the resin to the proper temperature and viscosity to form a quality part. The length of the metering section is dependant on the resin's heat sensitivity. The more heat sensitive, the shorter the metering section. General purpose zone lengths vary from OEM to OEM and from size to size but most incorporate a longer feed section.

Channel depth

The flight height (flight depths) in the metering section is critical to optimum processing. The material being processed will determine the flight depth and consequently dictate the feed depth (compression ratio) and the zone lengths. Again, the more exposure of the material to the barrel wall, as in shallow flight heights, the more heat will be introduced, and the greater the risk to shear sensitive resins. Amorphous materials (ABS, PC) generally require deeper flight depths. Once the metering flight height is determined, the feed flight depth can then be calculated. Keep in mind that a screw with a 3:1 compression ratio can be very different from another screw with a 3:1 compression ratio. How can this be? It all goes back to the flight depths. One screw may have a flight depth in the feed section of .300 and a metering section depth of .100 giving you are 3:1 compression ratio. The other screw has a flight height in the feed of .450 and a flight height in the metering of .150 resulting in a 3:1 compression ratio. (.300/.100 = 3:1) (.450/.150 = 3:1) The screw with the deeper flight depths will process shear sensitive materials better than the other screw.



Illustrated injection screw profile

Typical design profiles

GP design. Concor's general purpose design would consist of a 2.5:1 compression ratio, have a long feed section, a long transition section and a short metering section.

Nylon design (crystalline). A typical nylon design would consist of a high compression ratio, have a long feed section, a short transition section and a short metering section.

Polycarbonate design (amorphous). A typical PC design would consist of a low compression ratio, have a short feed section, a long transition section and a even shorter metering section.

Conclusion

For many custom molders the challenge has been to process as many materials as possible with a general purpose screw. By now you have come to understand some of the reasons why some materials process better than others when using a GP screw. If your focus is always on a homogeneous melt and good resulting part quality, it may be necessary to consider a screw designed to optimize processing. Remember, it's all about the part. Proper screw design is critical and leads to less downtime, less scrap and higher profits.