Reifenhäuser
REILOY

The Extrusioneers

Injection & Extrusion

Screw & Barrel Handbook

From metal alloys to the finished product, we offer the production of screws and barrels from a single source.

SCREW & BARREL HANDBOOK

Reifenhäuser

REILOY

A Publication Of

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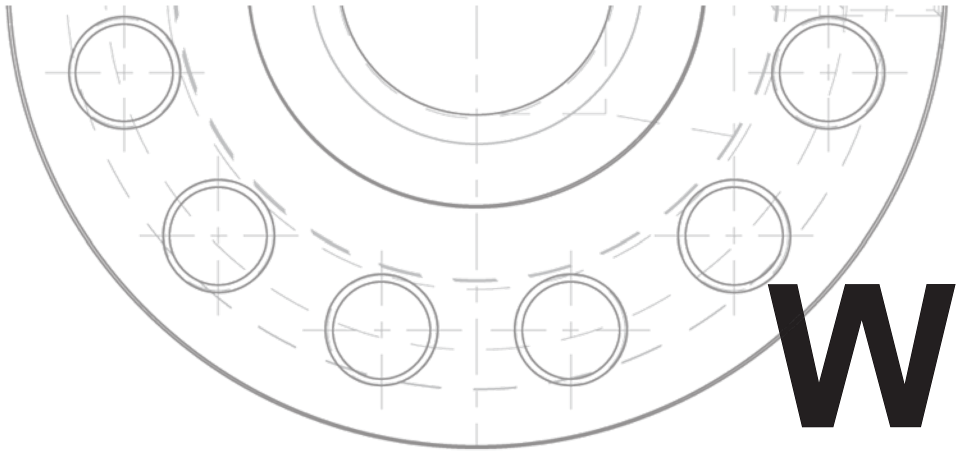

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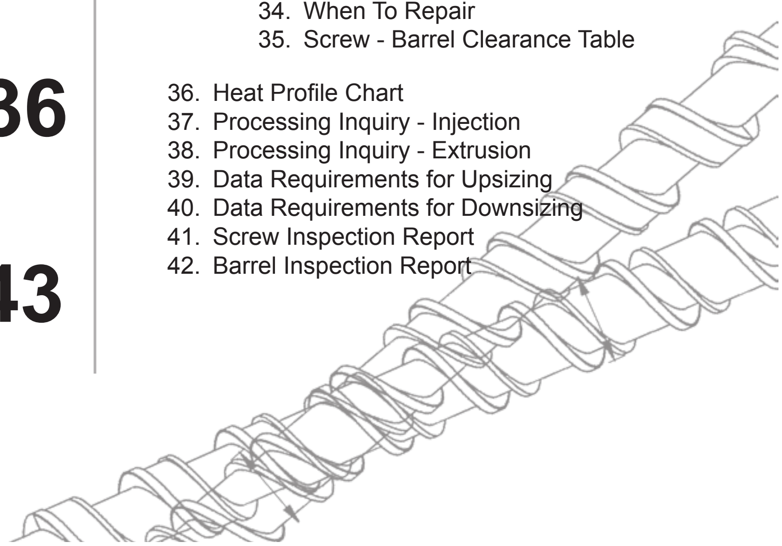


SECTION

1

SCREWS

All processors strive for repeatable and predictable processes. Being able to identify the variables that must be considered in order to achieve this is key to reaching processing goals.

SCREW DESIGN VARIABLES

A standard metering screw, that is, a single-flighted, single-stage design may be altered in its design by changing one or more of the following features: L/D (length to diameter) ratio, screw profile, channel depths, compression ratio, and helix angles.

L/D RATIO

The L/D ratio is the ratio of the flighted length of the screw to the outside diameter of the flights. The ratio is calculated by dividing the flighted length of the screw by its outside diameter.

Although several IMM manufacturers now offer a choice of injection units, most injection screws have a 20:1 or greater L/D ratio. (The L/D ratios for extrusion screws generally range from 24:1 to 30:1 with some much longer.)

Effect: The effect of changing the L/D ratio can be summarized in the following manner … the larger the ratio (longer flighted length), the:

- More shear heat can be uniformly generated in the plastic without degradation
- Greater the opportunity for mixing, resulting in a better homogeneity of the melt
- Greater the residence time

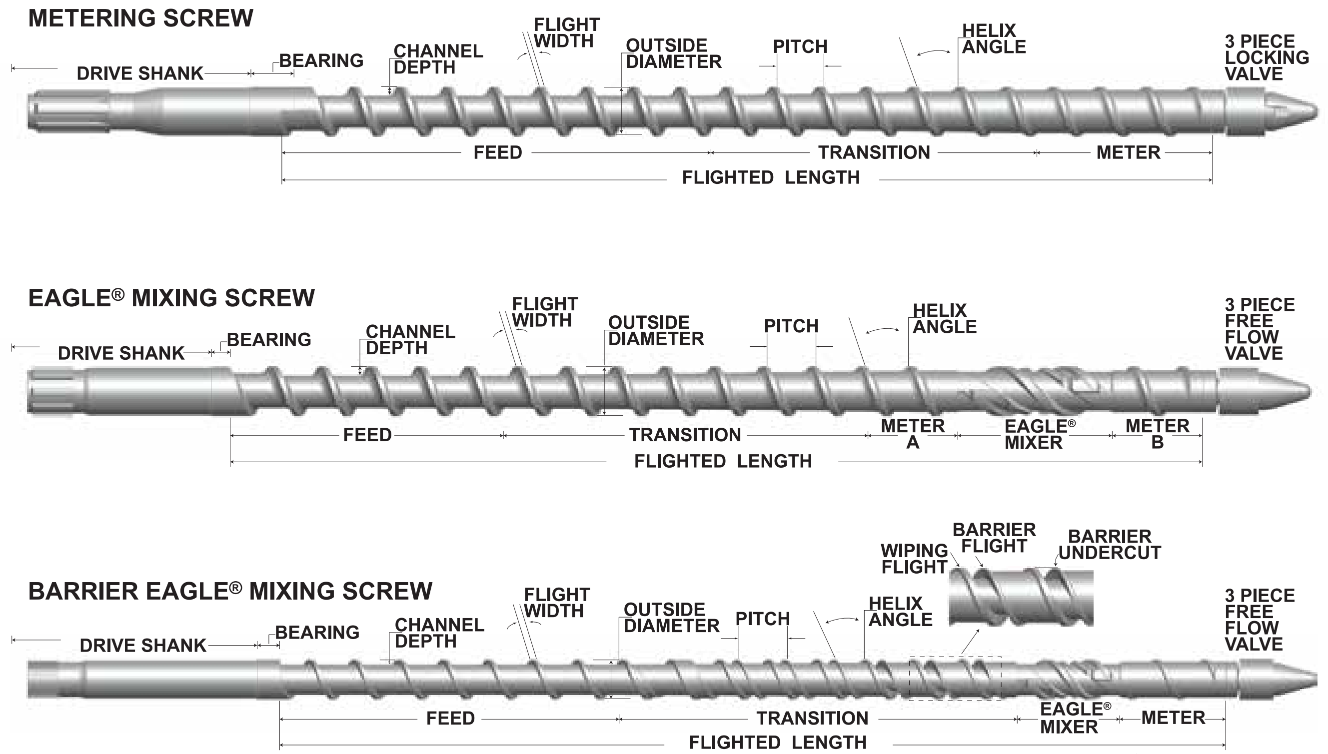
SCREW PROFILE

The standard metering screw has three processing zones: the ***feed zone, transition zone and meter zone.*** The feed zone is where the plastic first enters the screw and is conveyed forward along a constant root diameter. In the ***transition zone***, the plastic is conveyed, compressed and melted along a root diameter that increases with a constant taper. The ***meter zone*** is where the melting of the plastic is completed and the melt is conveyed forward along a constant root diameter reaching a temperature and viscosity that is necessary to form parts.

The ***screw profile*** is described as the length, in diameters or flights, of each of the three sections of the screw. A 10-5-5 profile indicates a flighted surface with 10 diameters in the feed zone, 5 diameters in the transition zone and 5 diameters in the meter zone. General purpose screws typically have a 10-5-5 screw profile. It is not difficult for the screw manufacturer to alter this profile.

Effect: The length of each zone has an impact on how a resin reaches a melt condition, as follows:

- A ***longer feed*** zone creates a greater potential throughput
- A ***longer transition zone*** results in less shear heat and more time to compress and melt the resin, and the converse is also true



- A ***longer meter zone*** allows the screw to develop more pumping pressure vital to extrusion
- A ***shorter meter zone*** allows less time to assure an isothermal (uniform) melt quality

CHANNEL DEPTHS

The channel depth in the meter zone of the screw is determined by the resin to be processed. The feed and transition zone channel depths are dependent upon the selected compression ratio and screw profile. See the Screw Design Guidelines Table on page 3 to help determine the preferred meter (channel) depth of the screw.

Effect: The channel depths influence the degree of shear heat developed by the screw and the throughput of the screw. For example: a ***shallow screw channel*** –

- Increases the shear heat imparted to the resin
- Reduces the potential throughput of the screw

A ***deep screw channel*** would have just the opposite effect, helping reduce the shear heat and potentially increasing the throughput of the screw.

COMPRESSION RATIO

The ratio of the channel volume in the feed zone to the channel volume in the meter zone is referred to as the “compression ratio”. Compression ratios typically range from 1.5:1 to 4.5:1 for most thermoplastic resins. Most injection screws classified as a general purpose screw have a compression ratio of 2.5:1 to 3.0:1. Screws designed for extremely sheer sensitive resins typically have a 1.0:1 to 1.3:1 ratio which means that the resin is simply conveyed and not compressed.

Effect: The higher the compression ratio, the greater the resulting:

- Shear heat imparted to the resin
- Heat uniformity of the melt
- Potential for creating stresses in some resins

HELIX ANGLE

The helix angle is the angle of a screw flight relative to a plane perpendicular to the screw axis. With a helix angle of 17.6568º, the distance from the front edge of a flight to the same spot on the next flight (the ‘pitch’) is the same as the diameter of the screw. This condition, where the pitch is the same as the diameter is referred to as ***square pitch***.

A reduced pitch is very common in screws that have a short L/D ratio, two stage screw design or developing mixing section. Although the helix angle is not commonly altered from the standard square pitch, such a change can have a major impact on processing.

Effect: A change to a ***smaller*** helix angle, hence more flight turns per diameter -

- Increases the axial melting length
- Conveys stiffer resins with greater ease and requires less torque
- Reduces the rate at which resin is conveyed

In two stage screws used in ***vented applications***, the design of the first stage frequently uses a smaller helix angle (less than 17.6568º) to allow the plastic a greater length in which to melt. The second stage of the two stage screws commonly utilizes a larger helix angle (such as 20 to 25º) to create a more rapid movement of the melt forward and assist in avoiding vent bleed.

INJECTION SCREW DESIGN GUIDELINES

RESIN	MOLECULAR TYPE	CRITICAL TEMP ºF (a)	DENSITY G/cm^3		SCREW DESIGN BASED ON			SELECTED TRADE NAMES
			SOLID	MELT	METER CHANNEL DEPTH (b)	TRANSITION LENGTH (c)	COMPRESSION RATIO (d)	
ABS	Amorphous	228 Tg	1.08	.97	Deep	Long	Low	Cycolac, Magnum, Lustran
CA	Crystalline*	NA	1.22	1.14	Deep	Medium	Low	Tenite
CAB	Crystalline*	NA	1.15	1.08	Deep	Medium	Low	Tenite
CAP	Crystalline*	NA	1.17	1.10	Deep	Medium	Low	Tenite
FEP	Crystalline	527 Tm	2.12	1.49	Medium	Short	Medium	Teflon
HDPE	Crystalline	278 Tm	.95	.73	Medium	Medium	Medium	Dowlex, Marlex, Petrothene, Alathon
HIPS	Amorphous	210 Tg	1.05	.97	Deep	Long	Low	Styron, Lustrex, RTP
Ionomer	Crystalline	205 Tm	.93	.73	Medium	Medium	Medium	Surlyn, Iotek, Formion
LCP	Crystalline	525 Tm	1.35	Unk	Shallow	Medium	Medium	Vectra, Xydar
LDPE	Crystalline	221 Tm	.92	.76	Medium	Medium	Medium	Petrothene, Tenite, Escorene
LLDPE	Crystalline	250 Tm	.93	.70	Medium	Medium	Medium	Petrothene, Dowlex, Escorene, Attane
PA 66	Crystalline	500 Tm	1.14	.97	Shallow	Medium	High	Zytel, Ultramid, Wellamid, Vydyne
PBT	Crystalline*	470 Tm	1.34	1.11	Medium	Medium	Low	Valox, Celanex
PC	Amorphous	302 Tg	1.20	1.02	Deep	Long	Low	Lexan, Makrolon, Calibre
PEI	Amorphous	420 Tg	1.27	1.08	Medium	Medium	Medium	Ultem
PET	Crystalline**	460 Tm	1.40	1.10	Medium	Medium	Medium	Kodapak, Petlon, Rynite (reinforced)
PFA	Crystalline	582 Tm	2.15	Unk	Medium	Short	Medium	Teflon
PMMA	Amorphous	203 Tg	1.20	1.05	Deep	Long	Low	(Acrylic) Plexiglas, Acrylite
POM	Crystalline	358 Tm	1.42	1.17	Shallow	Medium	Medium	Delrin (H); Celcon (C)
PP	Crystalline	348 Tm	.90	.75	Medium	Medium	Medium	Marlex, Hifax, Escorene, Nortuff
PPE-PPO	Amorphous	unk	1.08	.90	Medium	Medium	Low	Noryl, Prevex
PS	Amorphous	193 Tg	1.05	.97	Medium	Medium	Medium	Styron
PSU	Amorphous	374 Tg	1.24	1.16	Medium	Medium	Medium	Udel, Ultrason S
PVC-F	Amorphous	194 Tg	1.30	1.20	Deep	Medium	Low	Geon
PVC-R	Amorphous	188 Tg	1.40	1.22	Deep	Long	Low	Geon
SAN	Amorphous	300 Tg	1.07	1.00	Medium	Medium	Medium	Lustran-SAN, Tyril, Luran

(a) Tm = Melting Point Tg = Glass Transition Point (mean of temps)
(b) Degree of meter channel depth. Example: Medium for 2” (50 mm) diameter .100” to .125”.
(c) Short = 4D or less; Medium = 5D to 7D; Long = 8D or more
(d) Low - less than 2.5:1; Medium - 2.5 to 3.4:1; High - 3.5:1 and above

* Processes like amorphous
** Bottle grade material
H = Homopolymer C = Copolymer

SCREW DESIGN APPLICATIONS

In addition to the variables discussed that are available in the design of metering screws, special screw designs are often used to enhance the performance of the screw. The more common types of screw designs are **mixing screws**, **barrier screws**, **extrusion screws** and **thermoset screws**.

MIXING SCREWS

Screw variations are designed to achieve a special processing result and can be a solution to many processing problems. Although some of the special screw design features are used in combination, each will be discussed separately.

As Johannaber states in his text **Injection Molding Machines**, "The standard three-zone screw is not designed for efficient mixing. Should such duties be desired in addition to plasticating and injection, then shear and mixing elements must be employed, which cause a significant improvement in dispersing additives." His comment is equally applicable to screws used in extrusion and blow molding. There are many mixing screw designs offered in the marketplace that involve the shear and reorientation of the resin after it has been melted. It is important to remember that mixing cannot be achieved without first melting the plastic.

The terms dispersive mixing and distributive mixing are used by some authorities to distinguish the mixing of the fluids (distributive) from mixing of a fluid with a solid or unmelt (dispersive). For the sake of simplicity, however, Reiloy prefers to limit the discussion of mixing screws to those ***factors*** considered ***essential to the design***.

MIXING SCREW DESIGN OBJECTIVES

Following are objectives required to obtain optimal mixing capabilities on a screw:

1. Achieve distributive mixing of melt (fluid with a fluid - mixing of different polymers with similar viscosities)

2. Provide dispersive mixing of melt (fluid with non-fluid - avoiding agglomerates or gels)

3. Achieve isothermal melt quality and uniform viscosity at lowest possible melt temperature

4. Accomplish pumping action with minimum pressure drop to achieve maximum throughput

5. Avoid dead spots or hang-up areas causing thermal degradation or impeding color changes

There are several older designs of mixers still used today, including the well-known **Maddock** or **Union Carbide** mixers and the **Gregory.** (See Figure 1)

The **Stratablend®** mixer, manufactured by Nordson XALOY, features rows of helical grooves within channels bounded by wiping lands. The polymer is conveyed through the channels at an average shear force thereby uniformly mixing the resin, eliminating unmelted resin and discharging it without degrading or overheating.

The **Pulsar®** and **Pulsar II®** mixing sections, manufactured by Nordson XALOY, have shallow and deep levels in the meter zone channels which cause a tumbling and mixing action on the melt. This action is designed to achieve a high degree of mixing, reduces excessive shearing and avoids temperature and viscosity differentials in the resin. The Nordson XALOY **Z-Mixer™** is a dispersive and distributive mixing design that breaks solids down into fine particle sizes. It works best with resins that can accept higher shear, such as polyolefins and styrenes.

The **Meltstar™** mixing section, manufactured by Cincinnati Milacron, is a high shear, distributive mixer which splits the resin flow. The undercut "V" slots fold the resin back on itself while simultaneously kneading it.

The **Hurricane™** mixer, manufactured by Glycon, is a very aggressive mixing screw for high flow resins. The mixer adds shear and random mixing action through a series of forward channels that are decreasing in depth and reverse flow grooves that run the length of the mixer.

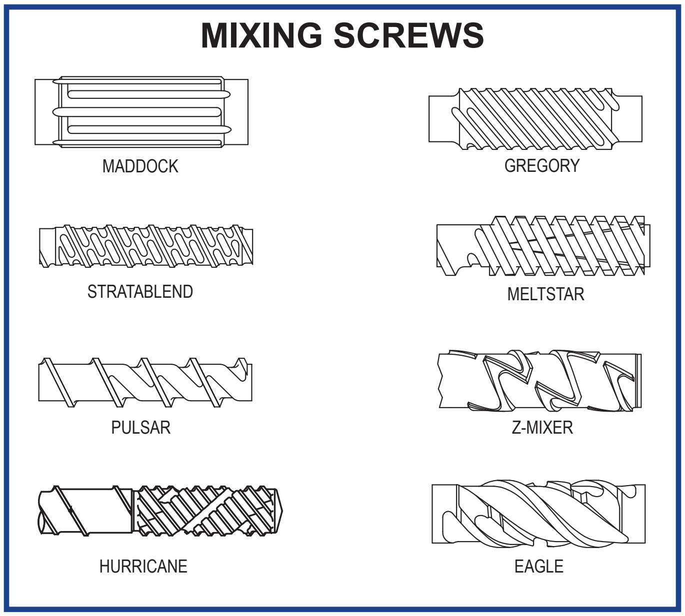


Figure 1

REILOY EAGLE® MIXING SCREW

The **Eagle®** mixing screw, manufactured by Reiloy, features alternating barrier and wiping lands, a reduced mixer root diameter, plus other features as described in the following paragraphs.

The **Eagle®** mixing section utilizes wiping lands (flights) with large helix angles to rapidly convey the melt either over alternating barrier lands or through mixing notches in the barrier lands. (See Figure 2) A reduced root diameter in the mixer, as compared with the preceding meter section, allows the mixer to accept substantially all (over 95%) of the melt volume available to it without creating a pressure drop (“bottle neck”) or causing excessive shear. Due to the reduced root diameter, the melt is homogenized (but not sheared) by its rapid conveyance and change of direction in the mixer. The **Eagle®** mixer may be used with a standard metering screw or a barrier screw, depending upon processing requirements. In addition to injection molding applications, the screw has been successfully used in blow molding and extrusion environments.

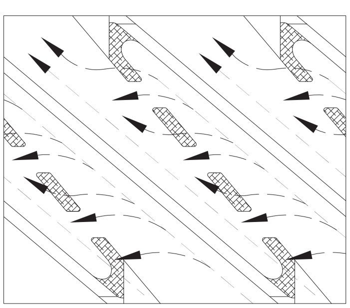


Figure 2

In addition to improved color mixing, many of the processors using the **Eagle®** have experienced improved production rates, both in recovery rate and throughput (pounds per hour). Although the design of the screw and mixer are modified somewhat for different resins, the **Eagle®** has successfully processed commodity resins as well as engineering grade resins.

BARRIER SCREWS

Mixing screws are designed to improve melt homogenization, including color dispersion. In contrast, the most efficient or “controlled” melting in resin processing is accomplished using a barrier-type screw. Control of the melting process is achieved by using two screw channels in the transition section of the screw, separated by a barrier flight. The “solids” channel retains the solids bed of resin until it is melted. As it melts, the melted resin crosses over the undercut barrier flight into the “melt” channel. As the resin moves forward, the “solids” channel decreases in volume and finally terminates, while the “melt” channel volume increases and finally becomes the meter section of the screw.

There are a large number of barrier screw designs offered by screw manufacturers. (See Figure 3)

REILOY EAGLE® BARRIER SCREW

The **Reiloy** barrier design utilizes an increased pitch with constant widths in both channels. The solids channel measures approximately twice the width of the melt channel. The volumetric area of the solids channel reduces and the melt channel increases as the resin is conveyed up the screw.

The specifications used for the barrier section of the Reiloy barrier are specifically designed for the types of resin that the customer expects to process. The screw designs for crystalline types of resin will vary significantly from those used to process amorphous resins. As a result,

REILOY EAGLE® BARRIER SCREW

the screw may be a higher shear design with a dispersive mixing effect or a lower shear design resulting in a more distributive mixing effect.

The Reiloy **Eagle**® barrier screw combines the advantages of our Eagle® mixer with the melting efficiency of the Reiloy barrier screw design. This combination equals a complete isothermal and homogeneous melt quality. It has been one of Reiloy's most effective designs for all types of injection molding environments and has also been proven successful in extrusion applications.

OTHER BARRIER DESIGNS

The **Uniroyal** design is considered the 'father' of barrier screw designs and is the basis in concept for nearly all other barrier designs. It utilizes a barrier flight with a larger helix angle than the regular flight which allows the solids channel to start wide and terminate narrow. This design employs a closed end to the barrier section.

The **Willert** design features constant widths in both channels and the solids channel about twice the width of the melt channel. The design is unique at the end of the transition zone where the primary flight becomes an undercut barrier flight and the barrier flight changes to the primary flight. This changeover adds to the mixing ability of the screw.

There are some designs that are not distinctly barrier screws nor mixing screws but perform some of the same functions. Two of these designs employ oscillating channel depths to help accomplish effective melting. Both designs are well known as the E.T. and Double Wave screws.

The **E.T.** design utilizes oscillating channel depths with alternating primary and barrier flights. This produces a mixing of the hot, molten resin with the cold, unmolten resin, improving the heat transfer from hot to cold, and increasing the screw's energy efficiency.

The **Double Wave** design features repetitively spaced alternating wave peaks in each screw channel forcing the resin alternatively to either cross the narrow undercut center barrier or squeeze over the peaks of the waves. This design and the E.T. illustrate the use of repetitive solids/melt redistribution to promote melting as contrasted with the restriction of the solids bed breakup concept utilized by the other barrier designs.

The **DM2™**, manufactured by Glycon, features a thermal "cross-over zone" positioned along the screw at a point where 70 - 80% of the polymer is melted. This allows the melt, as well as the pellets, to interact without excessive pressure buildup.

BARRIER SCREW DESIGNS

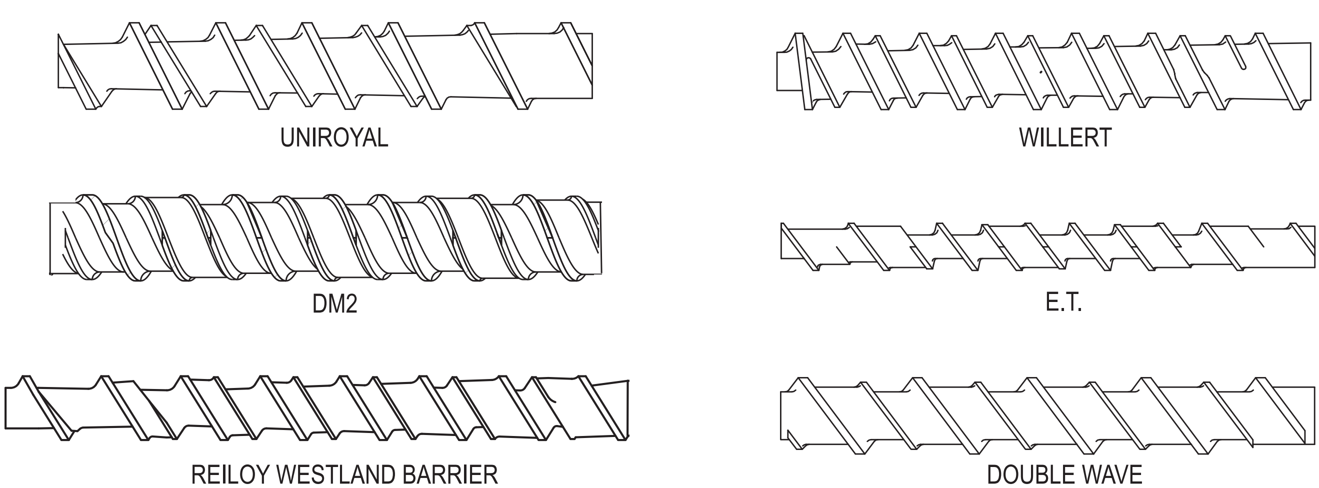


Figure 3

EXTRUSION SCREWS

Extrusion screws require greater shear capability than injection molding screws, which suggests the use of barrier designs in most cases. Due to the ability to minimize the clearance between the barrier land of a barrier screw and the inside diameter of the barrel wall, barrier screws can achieve great shear capability so necessary to extrusion processing.

EXTRUSION RESINS

Practically all thermoplastics can be processed by extrusion, but in order for the extrudate to maintain its shape until solidification, extrusion grades require a higher molecular weight associated with higher viscosity.

PROCESSING DIFFERENCES

Nearly all of the principles and guidelines presented in the previous pages, which relate to injection molding, also apply to extrusion screws. A major difference between injection molding and extrusion relates to the time the resin has to melt. In injection processing, a pellet typically has 2 to 5 minutes from the time it enters the barrel until it exits the nozzle end of the screw. This residence time allows the resin to absorb conductive heat energy (in addition to shear heat) as it works its way down the screw.

In extrusion, a pellet is typically allowed less than 2 minutes to travel from the feed pocket of the screw to the screen pack.

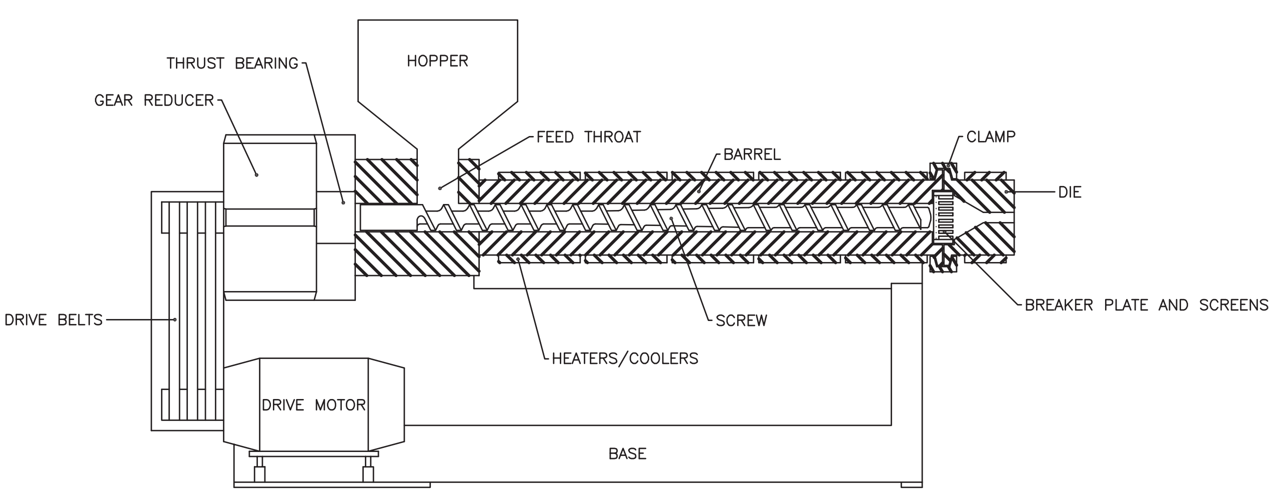
MODIFYING SCREW DESIGN FOR EXTRUSION

The most obvious difference between injection and extrusion screw design is the length of the flighted surface, or the L/D ratio. Where 20:1 ratio is common for injection screws, 24:1 is considered a short L/D ratio for extrusion and many have ratios of 30:1 or more. Due to the reduced residence time, extrusion screws must compensate by lengthening the screw. More length can generate greater throughput, uniform melt and thorough mixing.

Extrusion screws tend to have greater shear capability, resulting from the use of barrier designs and/or the utilization of a grooved feed zone in the barrel. The barrier undercut (the difference between the height of the primary flight and the barrier flight) in the barrier screw designs tend to be shallower, imparting greater shear heat to the resin. A common extruder screw profile allocates five (5) diameters in the feed section, eight (8) diameters in the meter section, and the remaining number of turns in the transition section. Compression ratios for extruder screws commonly range from 3.0:1 to 5.0:1.

A shallow feed zone channel in the screw combined with a grooved feed section in the barrel also creates shear and a more aggressive feeding of the resin. The depth, length and width of the grooves in the barrel are a major factor influencing the throughput. Due to the feeding and shearing characteristics in a grooved

EXTRUDER COMPONENTS



barrel application, a very low compression ratio screw is necessary. A ratio of .8 or 1:1 is typical in most groove feed applications.

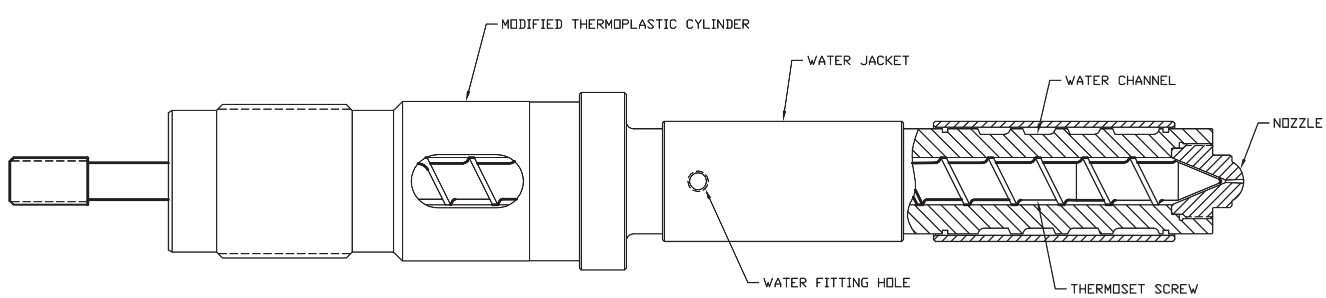
The use of ***mixing devices*** that have a more dispersive design concept (more shear, greater pressure drop) in an effort to complete the melting of the resin is more common in extrusion. In addition, mixers are useful in stabilizing the pressure and temperature of the extrudate, thus providing an isothermal melt.

As contrasted with injection molding where desirably 50% of the heat energy comes from the heater bands and a like amount from shear created by the screw, the ***mechanical energy (shear) in extrusion typically contributes 75 to 80% of the total energy***. As a result, barrel cooling in the extrusion process may be necessary.

In addition to cooling the barrel by forced air, the ***screw may be cored for cooling*** with a fluid, water or oil. A heat pipe can be used to transfer heat from the forward portion of the screw to the cooler feed zone.

The use of ***twin screws*** in a twin screw extruder accounts for a significant portion of extrusion processing. These screws may be intermeshing, counter-rotating or co-rotating and used in straight or conical twin barrels. These screws are very effective in processing powder PVC for pipe production.

THERMOSET COMPONENTS



THERMOSET SCREWS

Thermoset resins used in injection molding include phenolics, polyesters and liquid silicone rubber (LSR).

There are two major differences in processing thermoset versus thermoplastic resins: (1) thermoset resins cure rapidly if subjected to heat above a specified range and, once the resin has been thermally set, the resin cannot be softened by heating; and (2) some thermoset resins are abrasive, requiring the use of wear resistant materials for screws and barrels.

Because the thermoset resins irreversibly form (cross link) at a specific temperature, the temperature of the barrel (which is usually controlled using a water jacket) is critical. In addition, because heat can also be generated by shear, ***thermoset screws*** have characteristics that are quite different than screws used to process thermoplastic resins. Those differences include:

1. Shorter length - Thermoset screws usually have an L/D ratio between 12:1 to 16:1.

2. Compression - Thermoset screws most often have a compression ratio of 1.0:1 to 1.3:1, serving only to convey the resin through the temperature-controlled barrel.

3. Smear tip - When processing phenolics, no valve is used on the end of the thermoset screw, only a smear tip with a moderate nose angle.

4. Ring valves - When processing polyesters and liquid silicone rubber (LSR), a non-return valve assembly may be used on the end of the screw.

5. Abrasion-resistant material - The nozzle end of a thermoset screw experiences severe abrasion in processing and the entire screw (or at least the last few diameters) must be made from very wear resistant materials. Various heat-treated tool steels are commonly used.

SCREW MATERIAL GUIDELINES

As with screw design, the screw material selected for a particular application should be based on the resins that are to be processed. Some resins are abrasive and will require special steels or coatings to protect the screw from excessive wear. Other resins may develop acids and other corrosive elements requiring corrosion-resistant alloys or coatings to prevent corrosive wear.

Most screws are manufactured from a 4000 series alloy steel (usually 4140) or a nitriding steel (such as Nitralloy 135M). In most cases, these materials are either ***chrome-plated*** or ***nitrided***. Some screws are made from ***tool steels*** which, in a heat-treated and hardened condition, are very resistant to abrasive and adhesive wear. A limited number of screws are manufactured from ***stainless steels*** or ***special alloys***, or are ***totally encapsulated*** with a wear-resistant material.

Nearly all of the materials from which screws are made require a ***secondary treatment*** to provide wear resistance. Some materials are flame-hardened, nitrided or heat-treated and others are chrome-plated, coated or encapsulated. Screws that are not manufactured from solid tool or stainless tool steels have a flight hard-surfacing material weldment which forms the outside diameter of the screw flights. The screw materials, treatments and flight hard-surfacing options are presented in the chart on page 11.

An understanding of the types of materials is helpful in making a screw selection decision. There are several options available at various levels of cost and considerable difference in wear characteristics.

INDUSTRIAL HARD CHROME PLATING

Although most processors are familiar with chrome-plating, there is an important specification to be considered in purchasing a chrome-plated screw or having a repaired screw chrome-plated. The critical specification is the depth of the plating. It is not enough to plate a screw with less than .001" (referred to as 'flash chroming').

Chrome-plating should be ***at least .001" to .005" thick***.

NITRIDE

A 4140 alloy steel screw can be nitrided satisfactorily, however, a nitriding steel (such as Nitralloy 135M) has aluminum added to give a better response in nitriding hardness, both as to consistency and depth. There are two common types of nitriding: gas nitriding and ion nitriding.

Gas Nitriding is used to create a surface hardness on the screw. The hard layer of steel will vary from .007" to .014" in most applications depending upon the length of the nitriding cycle. The hard layer (usually well above 60 Rc) is achieved by heating the steel in an atmosphere of nitrogen (ammonia gas) at temperatures of 950 to 1050°F.

The nitrogen atoms are diffused into the surface of the steel, combining with nitride-forming elements, such as chromium, aluminum, molybdenum, vanadium, tungsten and titanium, to produce a very hard case, particularly for the first .002" to .005" depth (See Figure 4). Nitrided screws have very good wear resistance until the case hardness is worn away. After the surface is worn .007", wear accelerates and the screw may quickly be worn to a condition that is beyond repair.

Ion Nitriding is similar to gas nitriding, using an electrical potential to ionize low pressure nitrogen gas. The ions produced are accelerated to the surface of the steel, heating it to a temperature for diffusion to take place (ie: the uniting of atomic nitrogen with the nitride-bearing elements in the steel). Because the temperatures are lower and pressures more controllable, a more uniform case depth may be achieved. The ionization occurs in a plasma discharge process which creates a glow; hence this type of nitriding is also referred to as the 'plasma method' or 'glow discharge' nitriding.

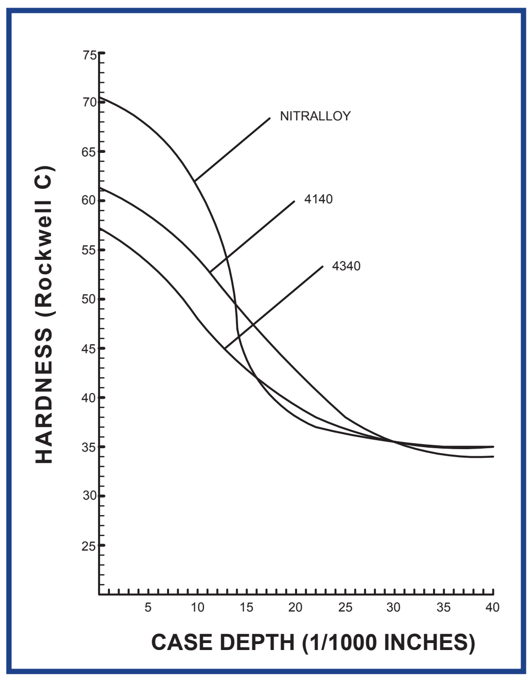
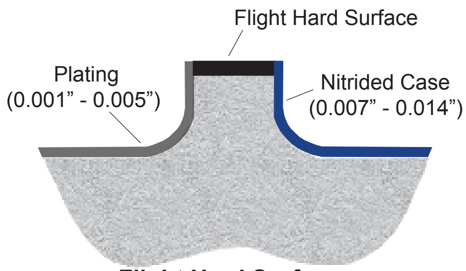
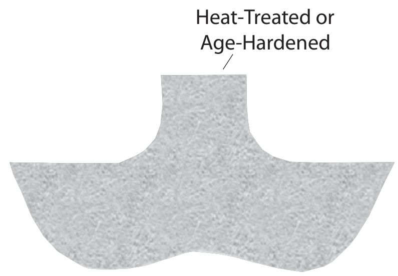


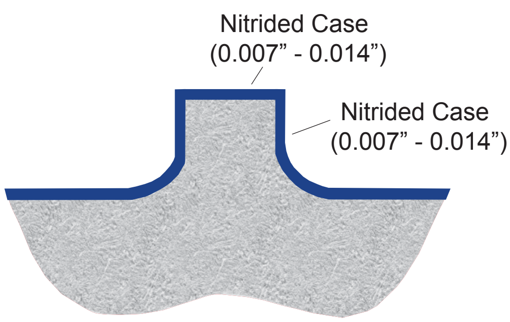
Figure 4



Flight Hard Surface



Solid Tool Steel or Alloy



Nitrided Case Surface

PARTICLE METALLURGY TOOL STEELS

Although some manufacturers produce screws made from conventional tool steels, such as D-2 or H-13, most new tool steel screws are made from tool steels produced from a Particle Metallurgy Process (PM). Rather than making the tool steel from poured ingots and rolled, the PM process utilizes atomization and isostatic compression to make the steel. Prealloyed molten steel is atomized into a spray of micro ingots (powder consistency) of a uniform size that are poured into a large canister which is sealed under vacuum. The canister is then placed in an autoclave where high heat and isostatic compression is applied. This method allows steels to be made with a much higher percent of alloys without alloy segregation.

Tool steels made by the PM process that are used for screws include ***PM3V, PM9V, PMM4*** and ***PM stainless tool steel***. These materials are produced by Erasteel Inc., Bohler-Uddeholm Corporation, and Carpenter Technology Corporation.

Crossed-cylinder wear tests conducted by Reiloy indicate that ***PM9V*** has the best wear resistance, closely followed by ***PM stainless tool steel.*** The corrosion resistance of ***PM stainless tool steel*** is comparable to conventional 420 stainless.

NICKEL ALLOYS

Processing fluoropolymers must be done with nickel alloy screws or screws that are totally encapsulated with a relatively iron-free material. ***Hastelloy C-276*** and ***Inconel 718*** are both nickel alloys that can be hardened. Both resist corrosion quite well and, although very expensive, provide an acceptable solution to the extreme corrosiveness of fluoropolymers. Totally encapsulated screws, made from appropriate materials, can also be successfully used.

TOTAL ENCAPSULATION

There are several methods used to totally encapsulate a screw with wear and/or corrosion resistant material. The methods include detonation guns, high velocity oxygen fuel systems (HVOF) and various spray weld processes. A wide selection of materials can be used ranging from the types of materials used for flight hard-surfacing to customized products containing very hard and wear resistant carbides. The XC4000 and XC1000 examples listed in the guidelines on page 11 on this Handbook are products of Surface Engineering & Alloy Company.

As long as the screw and its coating are intact, the encapsulation process produces a superior solution to preventing adhesive, abrasive and/or corrosive wear. ***If the encapsulation is cracked or nicked, a rather rapid deterioration of the base metal can occur which encourages a further "shelling off" of the encapsulation and, ultimately, severe wear of the screw.*** Encapsulated screws can be repaired but the process is rather difficult and somewhat expensive.

FLIGHT HARD-SURFACING

Most of the screws that are not manufactured from solid tool steels or special alloys have a flight hard-surfacing material welded to form the outside diameter of the screw flights. The hard-surfacing materials are predominantly cobalt-based or nickel-based. The most common ***cobalt-based*** materials include the Stellites (6 and 12) which exhibit uniform wear and are satisfactory in non-corrosive environments. The ***nickel-based*** materials include the Colmonoys (56, 57 and 83). The wear and corrosion resistance of these materials is somewhat better than the cobalt-based materials, based on the field experience of Reiloy customers. New flight hard-surfacing materials are being continually introduced to the market but none of the more commonly used types can approach the wear resistance of the tool steel screws.

SCREW MATERIAL GUIDELINES

BASE SCREW MATERIALS				ACCEPTABILITY FOR RESIN WEAR CONDITIONS				
				ABRASIVE			CORROSIVE (7)	
MATERIAL DESIGNATION	TREATMENT (1)	Rc (2)	FH (3)	NORMAL (4)	AVERAGE (5)	SEVERE 6)	MODERATE	SEVERE
ALLOY STEELS:								
4140	Flame-hardened	48-55	no	Acceptable	Poor	Unacceptable	Unacceptable	Unacceptable
4140	Chrome-plated	60-65	Optional	Good	Acceptable	Unacceptable	Good	Unacceptable
Nitralloy 135-M	Nitrided	63-70	Optional	Good	Acceptable	Unacceptable	Poor	Unacceptable
TOOL STEELS:								
PM 9V	Heat-treated	54-56	no	Excellent	Excellent	Good	Acceptable	Unacceptable
PMM4	Heat-treated	62-64	no	Excellent	Good	Acceptable	Poor	Unacceptable
PM Stainless Tool Steel	Heat-treated	54-56	no	Excellent	Excellent	Good	Excellent	Good
SPECIAL ALLOYS:								
Hastelloy C-276	Age hardened	RB 87	Optional	Acceptable	Unacceptable	Unacceptable	Excellent	Good
Nickel 718	Age hardened	43-45	Optional	Acceptable	Unacceptable	Unacceptable	Excellent	Good
XC4000	Carbide Encapsulated	70+	Optional	Excellent	Excellent	Good	Excellent	Good
XC1000	Carbide Encapsulated	70+	Optional	Excellent	Excellent	Good	Excellent	Poor

(1) Includes chrome-plating to .003”-.005” and gas or ion nitriding for 24+ hour cycle.
(2) Rockwell C hardness
(3) Flight hard-surfacing required
(4) Thermoplastics with no reinforcements
(5) Thermoplastics with up to 30% reinforcement.
(6) Thermoplastics with more than 30% reinforcement.
(7) Moderate includes cellulosics, acetals and others containing corrosive additives

BARRELS

BARREL VARIABLES

Although barrel design is in the province of the machine manufacturer, there are several choices of materials from which the barrel may be manufactured. Depending upon the high injection pressures expected to be encountered, the external portion (shell) of most barrels is a 4100 series alloy steel, micro alloy steel or a nitriding steel. The pressure retaining capacity in a micro alloy steel maintains its strength during the manufacturing process. In a 4100 series alloy steel, that same capacity can be diminished and the barrel may require the use of a pressure sleeve.

There are several alternative linings available which resist wear. These lining alternatives may be grouped into three types which relate to the manufacturing method: ***nitrided*** barrels, ***cast bimetallic*** barrels and ***tool steel-lined*** barrels. The outer shell made from 4140 or micro alloy gives the barrel much of its strength and the lining provides the wear resistance. The chart on page 15 and subsequent discussion of the lining alternatives provides a basis for selection depending upon the processing requirements.

NITRIDED BARRELS

Nitrided barrels may be made from 4140, but a nitriding steel - such as Nitralloy 135M - enables a better nitrided interior surface to be achieved. Gas nitriding is available on barrels. The facts relative to this process are the same as for screws, as described on page 9. Nitrided barrels are not recommended for use with abrasive or corrosive resins due to their inability to resist wear when processing these resins over an extended time period. Nitrided barrels are not common due to the economics of standard bimetallic barrels.

CAST BIMETALLICS

Cast bimetallic barrels are manufactured by metallurgically bonding the lining alloy to the inner surface of a pre-machined, seamless steel tube, forging or bar stock. The bonding is achieved by heating the barrel (and the lining alloy) to the point where the alloy is melted. The barrel is then spun and cooled, centrifugally casting the alloy on the inner surface of the barrel.

The resulting lining is about 1/16th of an inch (.0625") thick throughout the barrel. In the larger barrel sizes (or thin walled cylinders), a pressure sleeve made from heat treated or forged alloy steel is placed over the nozzle end of the barrel by shrink fitting. Some barrels have a "bell" end to withstand the pressures of injection, and some use a "bell" end <u>and</u> pressure sleeve.

Reiloy, a division of **Reifenhäuser Group**, produces outstanding alloys for bimetallic barrels that are used in general as well as specific high demand applications to avoid the effects of wear and/or corrosion. This product differs from other bimetallic barrels in the way it is produced. Reiloy barrels are heated by electrical fields which cover the entire surface at once. These encompassing electric fields mean the barrels can be cooled under controlled conditions. This guarantees a barrel absolutely free from distortion.

1. **Standard abrasion-resistant lining (Reiloy R121)** - All manufacturers of bimetallic barrels offer a standard cast bimetallic lining that is essentially a boron-iron alloy. Some contain varying quantities of nickel, chromium and other elements that help provide an abrasion and somewhat corrosion resistant lining. The linings provide a much longer wear life than nitrided barrels.

2. **Premium lining (Reiloy R216)** - A premium abrasion and corrosion resistant lining material is offered by manufacturers that are superior to their other linings in resisting all types of wear. Each contains a quantity of tungsten carbides dispersed in a nickel-chromium-boron matrix and some contain additional carbides, such as vanadium and titanium to enhance wear resistance. Although the matrix hardness ranges in the Rc 58 to Rc 64, it is the very high hardness of the tiny carbide particles that provide this type of lining with its resistance to abrasive wear. To the extent that the carbides are evenly dispersed in the matrix, this lining offers resistance to abrasive wear unmatched by other bimetallic or nitrided barrels.

TOOL STEEL BARRELS

Reiloy is among a limited number of barrel manufacturers capable of lining the inside diameter of a new or used barrel shell with solid tool steel (or special alloy) liner sleeves. Some manufacturers press-fit multiple sleeves (or a long single sleeve) into the barrel blank (shell) that has been bored oversize to accommodate them. Other manufacturers use a shrink-fit technique while some have been known to slip-fit the liner sleeves and then weld or pin them in place. The liner sleeves usually vary in thickness from ¼" to ½" (.250" to .500") depending upon the bore diameter of the barrel. Because the tool steels are heat-treated, many possess high tensile and yield strength but are somewhat brittle. When press-fit or shrink-fit into a 4140 alloy steel shell, the relative brittleness of the tool steel is no longer of consequence and the resulting barrel has outstanding strength.

Lining materials are selected for their resistance to wear and can be chosen from a variety of tool steels, alloys or even sleeves that have cast bimetallic linings on their inner surface. The tool steel choices include the following:

D-2 tool steel, heat-treated to Rc 58-60, is a relatively inexpensive, high carbon-high chromium steel with proven, uniform wear resistance surpassing most other steels.

PM10V is a particle metallurgy tool steel (see page 10 for a discussion of the method of manufacturing) that is heat treated to Rc 62-64. It offers a microstructure with vanadium carbides from its nearly 10% vanadium content which makes this steel one of the most abrasion resistant materials available.

PM stainless tool steel is stainless steel made by the PM process. It offers improved corrosion resistance and wear resistance. It can be heat treated to a lower hardness for use as a screw material or to a higher hardness (Rc 58-60) for barrel lining. This material provides the corrosion resistance of conventional 420 stainless and a wear resistance comparable to PM9V.

SPECIAL ALLOYS

There are those extreme applications that warrant barrels lined with special alloys due to their high abrasive or corrosive environments. These alloys, though more expensive, provide increased wear resistance for longer component life.

C-2 Tungsten Carbide offers unmatched wear resistance in most environments. This alloy is 94% pure tungsten carbide (often referred to as the hardest metal) and 6% cobalt binder. In some cases, it is totally resistant to corrosion, plus it is ideal for highly abrasive resins due to its high hardness value (79-81Rc).

Other special alloys include the nickel alloys that are used principally to combat the corrosiveness of fluoropolymer processing. Fluoropolymers can emit various concentrations of hydrofluoric acid which attack iron-based materials. Chromium does not resist HFL, leaving the iron-free bimetallics and nickel alloys as the principal barrel lining materials. ***Nickel 718*** (Inconel 718 from Inco Alloys or Pyromet 718 from Carpenter Technology) is very corrosion resistant and has proven to be a good liner material for fluoropolymer processing. It can be age-hardened to Rc 43-45 and, although not very abrasion resistant, it works well in all corrosive environments. ***Hastelloy C-276*** is another nickel alloy that is used but does not possess the hardening capabilities of 718.

HEATER BANDS

Conductive heat is generated by heater bands placed on the outside diameter of the barrel. These bands come in many different styles with varying voltages and wattages.

The three basic types of heater bands are Mica, Ceramic and Mineral Filled (MI).

Mica Bands - provide excellent thermal conductivity. These bands are basically a mica insulated nickel-chrome resistant ribbon wire. Mica Bands are capable of temperatures up to 900° F and normal watt density of 20 - 45 W/in^2 on a barrel.

Ceramic Bands - transmit heat through both conductivity and radiation. Due to the low thermal conductivity of the ceramic fiber insulation, the external surface temperature of the ceramic band heater is approximately 400° F while the inside surface is running at a temperature of 1200° F. Ceramic bands have a maximum temperature of approximately 1400° F. The typical watt density is 20 - 45 W/in^2.

Since ceramic bands are designed to utilize both radiant heat from the ceramic blocks and conductive energy from being in contact with the barrel, the fit is not as critical as other types of bands. Ceramic bands reduce power consumption by 25 to 30 percent over MICA bands.

MI Bands (mineral filled) - are for applications that require high watt density and/or high operating temperatures. MI Bands have mineral insulated tape that is used to insulate the nickel chrome resistance wire from the stainless steel sheath. It is assembled under pressure to a precise diameter with a thin, low-mass cross section providing a fast heat up and reduced cycle times.

The maximum temperature on a MI Band is approximately 1400° F with a normal watt density of 20 -150 W/in^2.

Knowing the watts of conductive heat per square inch on a barrel is important information when considering the melting process of a resin. This can be simply calculated by knowing the surface area of the barrel in each heat zone and the total amount of heater band wattage in each zone. Dividing the total watts of heater band heat in each zone into the total number of square inches of each zone provides the watts per square inch (W/in2). The formula for this calculation is:

$$\frac{\text{Total Watts}}{3.14 \text{ x Dia x Length}} = \text{Total W/in}^2$$

Keep in mind, an insulated band will require less W/in2 than one that is not insulated.

FEED THROAT TEMPERATURE

Feed throat temperature is a variable that is largely overlooked on the machine. This variable plays a significant part in overall process performance with many resins.

MICA HEATER BAND

CERAMIC HEATER BAND

MI HEATER BAND

Feed throat temperature relates to repeatable recovery times. Most machines are set up running 80ºF to 175ºF on the feed throat area. When running high temperature resins at heat settings of 600ºF to 800ºF, the feed throat temperature needs to be raised, sometimes as high as 200ºF, to accommodate the resin being processed. By having the temperature elevated, the heat is transferred to the resin earlier, helping to minimize screw blockage.

GROOVED FEED SECTION

Grooved barrels have been known to improve throughput rates up to 10% when processing with a standard general purpose screw. Grooved feed sections can also provide a more consistent recovery with regrind and large cut pellets.

These improvements have even increased when processing the grooved barrel feed section with a high performance screw such as Reiloy’s **Eagle**® or **Eagle**® barrier mixing screws. Improvements of over 40% have been achieved.

There are standard groove width and depth measurements. The wider and deeper the grooves, the more aggressive they become and the opportunity for wear is increased. Ask your barrel supplier for the specifics on these dimensions.

The number of grooves is based on the bore diameter. The length of the grooves is based on the screw diameter and takes into consideration the stroke of the screw.

MATERIALS COMPATIBILITY

The compatibility of barrel lining material with the material used for the outside diameter of the screw flight rarely, but occasionally, becomes an issue. The greater the tendency of the screw OD to rub against the barrel lining, for whatever reason, the more important material compatibility becomes. Generally, materials of the same approximate hardness and similar chemical analysis should ***not*** be used for both barrel liner and screw OD.

BARREL MATERIAL GUIDELINES

BARREL LINING MATERIAL	HARDNESS RANGE Rc	ACCEPTABILITY FOR RESIN WEAR CONDITIONS				
		ABRASIVE			**CORROSIVE**	
		NORMAL(1)	MODERATE(2)	SEVERE(3)	MODERATE(4)	SEVERE(5)
NITRIDE: (Gas or Ion)						
4140 or equivalent	63-70	Acceptable	Poor	Not acceptable	Poor	Not acceptable
Nitralloy 135 M or equivalent	63-70	Acceptable	Poor	Not acceptable	Poor	Not acceptable
CAST BIMETALLICS:						
Reiloy W121	N/A (6)	Good	Acceptable	Poor	Poor	Not acceptable
Reiloy W115	N/A (6)	Good	Acceptable	Poor	Excellent	Excellent
Reiloy W215	N/A (6)	Excellent	Excellent	Good	Good	Good
TOOL STEELS:						
D-2	58-60	Good	Acceptable	Poor	Acceptable	Not acceptable
PM10V	62-64	Excellent	Excellent	Good	Acceptable	Not acceptable
PM Stainless Tool Steel	58-60	Acceptable	Poor	Not acceptable	Excellent	Good
SPECIAL ALLOYS:						
Nickel 718 (Inconel or Pyromet)	43-45	Acceptable	Not acceptable	Not acceptable	Excellent	Excellent
Monel K-500	37-39	Acceptable	Not acceptable	Not acceptable	Excellent	Excellent
Hasstelloy C-276	RB 87	Acceptable	Not acceptable	Not acceptable	Excellent	Excellent
C-2 Tungsten Carbide	79-81	Excellent	Excellent	Excellent	Excellent	Good

(1) All thermoplastics without reinforcement or abrasive fillers.
(2) Thermoplastics with abrasive reinforcement or fillers up to 30%.
(3) Thermoplastics with 30% or more reinforcements or abrasive fillers and thermosets.
(4) Cellulosics, Ionomers, Acetals and others containing corrosive additives.
(5) Fluoropolymers.
(6) Standard HRc unmeasurable due to the extreme hardness of the carbides in this matrix.

SECTION 3

VALVES

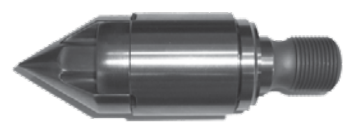
The function of the non-return valve is to allow melted resin to flow in front of the screw during plasticating and block the melt from flowing back to the screw during injection. Valves are manufactured from tool-steels or alloys that are best suited to the processing environment in which they will be used. Various tool steels that are heat-treated and/or nitrided, nickel alloys, chrome plating and special coatings are all options from which to choose.

Valves may be of a special design. However, styles most commonly used are the three piece free-flow, three piece locking, four piece valve plus side or front discharge ball check types.

THREE PIECE FREE-FLOW VALVE

Three piece free-flow valve assemblies can be designed with different flow rates. These valves are constructed of a check ring, retainer (tip) and rear seat. They can be used when processing most resins and can be custom designed for specific resins. A general recommendation is to use them for shear sensitive, medium to high viscosity and filled resins.

THREE PIECE LOCKING VALVE



Three piece locking style valve assemblies can be used with most resins. These valves are commonly standard in many foreign manufactured machines. They respond quicker to shut off or seal than the three piece free-flow. Three piece locking valves are constructed of a check ring, retainer (tip) and rear seat. The check ring is castled and interlocked into the flow channels of the tip. This causes the ring to rotate with the screw eliminating retainer wear.

FOUR PIECE VALVE

Four piece valve assemblies are designed for re-enforced or filled resins that prematurely wear the seat areas of the valve. The four pieces consist of a check ring, retainer (tip), front seat and rear seat. These valve assemblies are designed for easy replacement of the worn components without changing out the entire assembly.

BALL CHECK VALVE

Ball check assemblies are constructed of a body, ball and retainer pin or cap. They can be used in processing most resins however they are typically more restrictive than the other valve assemblies. There are several different types of ball check designs though the most common are side or front discharge assemblies. These valve assemblies are recommended for low viscosity resins where shear sensitivity is not critical.

SECTION
4

RESIN FACTORS

Proper screw selection for a given processing application is critical for success. Reiloy has documented cases where customers have improved cycle times by more than 25% by simply changing to an improved screw design. In other cases, scrap rates have been reduced from more than 5% to less than ½ of 1% by utilizing an application specific mixing screw. These facts alone illustrate the importance of screw design and its impact on processing performance.

The selection of a proper screw for a given processing application should be based on the resin or resins to be processed. If a number of different resins are to be processed with the same screw, that screw should be designed to optimize performance, allowing for all the resins to be processed with reasonable success.

Screw design is influenced by three major factors of the resins to be processed: ***degree of crystallinity, viscosity*** and ***additives*** in the resin.

DEGREE OF CRYSTALLINITY

The degree of crystallinity of a resin determines the resulting physical properties of a molded part and is important to the part designer. Equally important to the plastics processor is the fact that crystallinity also ***influences the manner in which the resin changes from a solid to melt***.

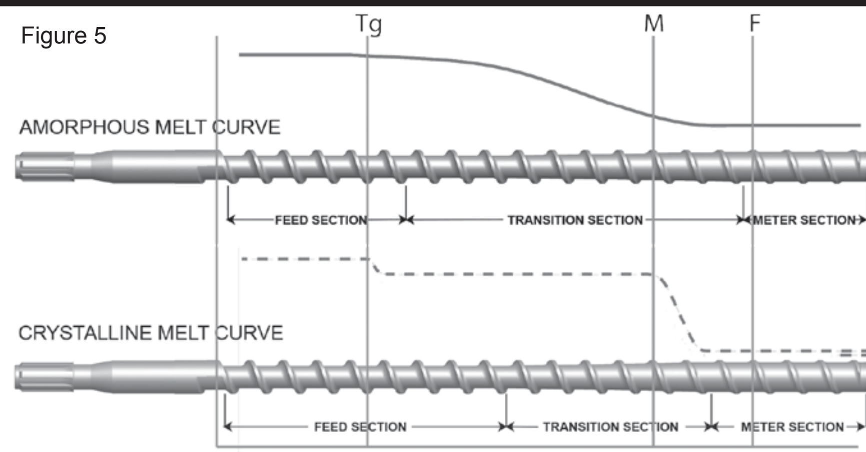
The differences in melting characteristics between highly crystalline and less crystalline (or amorphous) resins include their resistance to deformation as heat is applied, their sensitivity to thermal conductivity and their sensitivity to shear, regardless of source.

1. Melting Point - One difference between the crystalline and amorphous resins is their resistance to deformation as their temperature increases. Both resins soften somewhat at the glass transition temperature but amorphous resins continue to soften gradually until they reach a fluid state. ***Amorphous resins have no defined melting point.***

In contrast, the more highly crystalline resins remain in a relatively solid state until the temperature reaches their melting point. At the melting point temperature, crystalline resins quickly change to melt. (See Figure 5)

MELTING CHARACTERISTICS

Figure 5



Tg = Glass Transition Temperature M = Melting Point F = Fluid Flow State

2. Thermal Conductivity - Plastics are poor conductors of heat. Amorphous resins are especially slow to absorb heat and increases in temperature. Amorphous resins tend to degrade or burn (rather than melt more quickly) when rapidly exposed to higher temperatures. (See Figure 6)

3. Shear Sensitivity - As a consequence of the two differences in melting characteristics discussed above, it can be understood why amorphous resins are considered to be more shear sensitive. High shear rates result in rapid increased resin temperature which amorphous resins do not tolerate well.

It is well known that excessive melt temperatures in some resins can cause residual molded-in stresses that detract from part appearance or reduce the mechanical strength of the parts. From these considerations, it may be concluded that ***amorphous resins*** should be gradually changed from solid to melt. ***Screws with longer transition zones and deeper channel depths with lower compression ratios help protect amorphous resins*** from burning or degrading and help ensure optimum physical properties in the completed molded or extruded parts.

In contrast, the higher ***crystalline resins*** can be processed more effectively by ***screws with shorter transition zones, shallower channel depths and higher compression ratios.***

VISCOSITY (MELT INDEX)

Viscosity, or the resistance of a melt to flow, is measured by a capillary rheometer (or extrusion plastometer) and is expressed as the ***Melt Index*** (MI) of a resin. For example, a high melt index value corresponds to a low melt viscosity. A fractional MI resin refers to a resin with a MI of less than one. MI is also a measure of molecular weight, but because MI is easier to determine, it is often used rather than the molecular weight specification. A lower MI indicates a higher molecular weight. High molecular weight (low MI) resins are more viscous and process differently than medium or high MI resins. High MI resins are somewhat more difficult to melt. The higher the Melt Index, the more shallow the channel depths of the screw. More viscous resins require deeper channel depths.

RESIN ADDITIVES

Additives to thermoplastic resins influence the design of the screw, the materials from which the screw is made plus the requirements for the barrel lining. Some additives influence only the screw geometry while other additives affect geometry and materials to be used

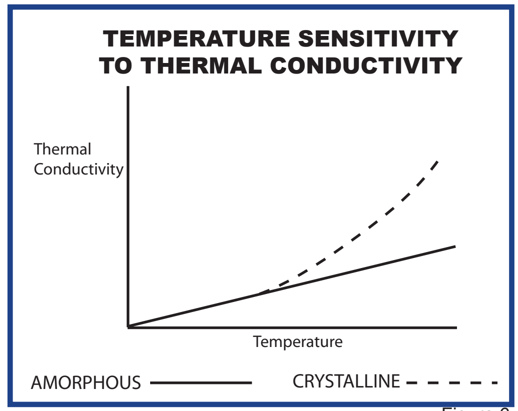


Figure 6

in making the screw or barrel lining. Reinforcement materials can affect all three considerations. Additives are grouped into two categories based on their impact on screw design and material selection for the screw and barrel.

1. Additives Affecting Screw Geometry

All ***reinforcements*** and ***fillers*** affect screw geometry. They include fibers made from glass, carbon, graphite and other materials such as calcium carbonate, silica, glass spheres, mica, talc, powdered metals, ceramic, baryte (barium sulfate), anhydrous calcium sulfate and carbon black. Many other inorganic materials are used for fillers.

These additives increase the viscosity of the melt and require screws with deeper channel depths and somewhat lower compression ratios. This design consideration is especially important with the use of fibers as to prevent breakage of glass fibers, for example, which would lessen part strength.

2. Additives Affecting Screw & Barrel Material

Special screw materials and barrel linings are selected to minimize abrasive or corrosive wear. All of the ***abrasive reinforcements and fillers*** require screws to be made from special wear-resistant steels or be encapsulated with an abrasion-resistant coating.

The more abrasive additives include glass fibers, calcium carbonate, ceramic and metal powders, and some colorants such as titanium dioxide. Premium barrel linings containing vanadium and tungsten carbides (and others) are used to minimize the rate of wear.

Other additives are corrosive and require screws made with corrosion-resistant alloys or special coatings. ***Flame retardants and coupling agents,*** for example, can develop a variety of corrosive acids at high temperatures. Barrel linings made from relatively iron-free materials and nickel alloys are necessary to avoid/reduce serious corrosive wear.

SECTION
5

PROCESSING CONSIDERATIONS

Plastics processing, whether injection molding, blow molding, extrusion or other types of processing, has become a highly refined technology with the ultimate objective to consistently produce high quality product at the lowest possible cost. It is beyond the scope of this document to discuss this technology, except as it relates to ***maximizing processing performance through the design, manufacture and effective use of machinery components***.

INJECTION MOLDING

In injection molding, the areas of processing that have a significant impact on ultimate profitability, in addition to reliable equipment, include: (1) Start-up and Shut-down Procedures; (2) Moisture Removal; (3) Heat Profile; and (4) Back Pressure. Each is discussed below.

START-UP & SHUT-DOWN PROCEDURES

Start-up and shut-down procedures are a key factor in preventing broken valve tips and screws. Moreover, if these procedures are not followed properly, they can contribute to adhesive, abrasive and corrosive wear.

1. Start-Up Procedures - Reiloy recommends following the resin manufacturer's recommendation. However, the following procedure has been shown to eliminate damage due to cold start-ups. When starting the machine, set the barrel to desired operating temperatures. After achieving temperatures at set point, let the heat soak into the screw (from 30 to 60 minutes depending on the screw diameter with larger screws requiring more time). If the soak period is too long, there will be issues feeding the resin. Once all zones have reached set point and soak time met, fill the screw and barrel with low RPM (20 or less). It is recommended that the screw be rotated at 20 RPM or less until the resin is coming out of the nozzle. This packs the resin around the screw which helps center the screw and reduces the pressure that can force it to make contact with the barrel inside diameter. Starting the machine at a higher RPM will push the resin up the screw with little to no residence time causing blockages. This in turn causes the screw to be pushed into the inside diameter of the barrel with great force providing the opportunity to accelerate wear on the outside diameter of the screw, inside diameter of the barrel and the valve assembly.

2. Shut-Down Procedures - Reiloy recommends following the resin manufacturer's recommendation. However, the following procedure has been shown to help eliminate the onset and/or progression of wear. After purging the system empty, the screw should be left in the forward position. This helps diminish the possibility of having a large mass of unmelted resin that needs to melt upon the next start-up. Another recommendation is to purge any filled resins or corrosive resins with an un-filled general purpose type resin such as PS, PP, or HDPE etc. One last reminder, the barrel should not be left at production temperature for extended periods of time as this will result in resin degradation as well as black specks and cause corrosive wear.

MOISTURE REMOVAL

It is well known that moisture must be removed from hygroscopic resins prior to processing to avoid streaks, splay or bubble formation in the completed parts. Except for polystyrenes, polyethylenes and polypropylenes, resins should be dried and/or vented. (Venting is discussed on page 25 of this Handbook.) Inadequately dried resin, when processed with high temperatures and long residence times, can result in material degradation and corrosive wear in the barrel and screw. This is especially true of resins that are corrosive due to their chemical make-up, such as PVC, POM, FEP and the cellulosics.

HEAT PROFILE

The heat profile is probably the most important and perhaps least understood factor in successful plastics processing. A heat profile decision flow chart is included on page 36 of this handbook. The ideal condition is to generate conductive energy in a way that allows control of the shear energy. An often overlooked factor is the feed throat temperature and how it affects the process. Another option for improving throughput rates in injection molding is a grooved feed section in a barrel. (See Feed Throat Temperature & Grooved Feed Sections on page 14.)

1. Heat Source - The heat required to melt the resin is developed from two sources, ***conductive heat*** from heater bands and ***shear heat*** resulting from the screw working the plastic against itself, the barrel wall and the screw surface. ***Shear heat*** is also produced by the use of back pressure and various mixing devices near the end of the screw. Some shear heat is essential to achieve a uniform melt quality, both in temperature and viscosity.

If shear is the principal or only heat source, the melt temperature will be high but achieved at the expense of higher energy cost, greater potential for resin degradation and significantly increased barrel and screw wear.

Heat developed from the two sources in approximately equal amounts (assuming a shot size of 30% to 70% of barrel capacity) ***produces the best results***. However, that rule is ***not*** applicable to extrusion.

A consistent process is developed by maintaining control of the melt temperature of the resin. The resin, being conveyed along the screw, requires shear and conductive heat to establish an isothermal melt quality at a uniform viscosity.

Failure to follow the melting and shear curves developed by the resin manufacturer may result in obstruction of flow during the plasticating process. Obstruction of flow is caused when solids get to a point of the screw were they can no longer pass. (See Figure 7) When this happens, screw recovery and/or throughput are reduced. This will generate an excessive amount of shear heat in a concentrated area, as the screw works to force the solids up the screw. This typically occurs in the late transition area of the screw.

HEAT PROFILE REFERENCE TABLE

% Shot Capacity	Residence Time	Heat Profile			
		Type	Rear Zone	Center Zone	Front Zone
25% or less	2 min or more	Ascending	As recommended by resin manufacturer	Average of Rear & Front Zones	Desired melt temperature *
25% or less	Less than 2 min	Flat	Desired melt temperature	Desired melt temperature	Desired melt temperature *
25 to 35%	2 min or more	Flat	Desired melt temperature	Desired melt temperature	Desired melt temperature *
25 to 35%	Less than 2 min	Hump	As recommended by resin manufacturer	Desired melt temperature + 30 to 45ºF	Desired melt temperature *
35 to 45%	2 min or more	Hump	As recommended by resin manufacturer	Desired melt temperature + 30 to 45ºF	Desired melt temperature *
35 to 45%	Less than 2 min	Reverse	Desired melt temperature + 30 to 45ºF	Average of Rear & Front Zones	Desired melt temperature *
More than 45%	2 min or more	Reverse	Desired melt temperature + 30 to 45ºF	Average of Rear & Front Zones	Desired melt temperature *
More than 45%	Less than 2 min	Reverse	Desired melt temperature + 40 to 60ºF	Average of Rear & Front Zones	Desired melt temperature *

*Within a range of melt temperatures between the desired melt temperature to 10ºF below that desired melt temperature.

The guidelines for initial heater band settings presented in this table are for the injection molding of non-reinforced thermoplastics with a shot size in the range of 25% to 75% of the machine shot capacity. It should be noted that residence time, screw RPM, additives and other factors are variables that must be considered when setting the heat profile.

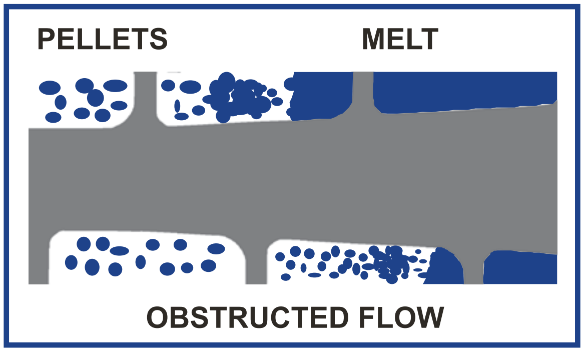


Figure 7

An ***incorrect heat profile is the most frequent cause of wear in barrels and screws*** due to the natural tendency to cool down the heater bands when a heat override condition occurs. Since most heat overrides are caused by excessive shear heat, the best way to decrease shear is to apply ***more, not less*** conductive heat from the heater bands. Changing the heat energy source used to melt the resin will not increase the temperature of the melt. In most processes, the melt temperature will be reduced.

It is the uncontrolled, excessive shear of resin that causes most abrasive wear and, through melt blockage and screw deflection (commonly known as side loading), causes adhesive wear. In addition, too much shear heat may compromise the quality of the melt which can have a negative impact on the physical properties of the plastic part. This is especially evident in processing amorphous resins, such as polycarbonate, acrylic and PVC.

Important Note: It is suggested to measure the energy required by the screw motor to rotate the screw (hydraulic pressure or electric current) during screw recovery. Readings of 40% to 60% of maximum available energy suggest that the heat produced from shear energy is in a desirable range. Greater energy consumption indicates that the screw is working very hard creating potential excessive shear. Lower readings under 40% of available energy suggest that too little shear energy is being used.

The Heat Profile Reference Table found on page 20 provides guidelines for the initial setting of the heat profile without regard to additives, screw RPM and other variables. More specific information appears in the following paragraphs.

2. Understanding Residence Time - Residence time is the time that the resin is in the barrel. Processing outside the recommended residence time can lead to problems with part quality and machine performance. Residence times that are too long or too short can produce inconsistency in melt quality and shot weight, plus also produce contamination, splay, burning and weakness in finished parts produced.

a) **Residence Time and Shot Size Are Two Different Issues**: Shot size is the amount of resin that can be injected into the mold. Residence time is the time that resin is in the barrel before being injected.

Reducing the shot size on an injection molding machine does not necessarily mean a reduction in the residence time. Limiting or increasing the stroke of a machine will change the shot size, but it does not dictate a change in the residence time.

Figure 8 on page 23 illustrates the same screw on two different machines with two different shot sizes. Due to a difference in screw stroke, if running the same product in both machines the residence time would be the same if processing with the same overall cycle time.

Therefore, if a reduction in residence time is the goal, changing the stroke is not the answer.

b) Calculating Residence Time: Residence time is based on what the screw inventories in its channels and the resin in front of the screw that is to be injected. However, the difference between the resin weight in solid state versus a molten state must be incorporated.

For example, nylon is approximately 1.14 gram/cc in weight at a solid state and approximately 1.05 gram/cc in a molten state.

To accurately calculate the residence time, Reiloy uses the solid weight of the resin in the feed section and the molten weight of the resin in the meter section. The volumetric area of each section of the screw (feed, transition and meter section) along with the L/D ratio (flighted length) is broken down in order to understand how much inventory is retained during the process.

Following is an example of the difference in residence time on a 57mm screw. One has an 18:1 L/D; the other has a 24:1 L/D. The additional specifics of the process are:

Solid Density =	1.14 gram / cc
Molten Density =	1.05 gram / cc
Cycle Time =	35 seconds
Shot Size of Part =	10 oz shot
Screw Diameter =	57mm
Screw Design =	General Purpose
Shot Capacity =	20 oz of PS

Figure 9 on page 23 illustrates the same size diameter screw with two different L/D ratios. The shot size is the same for both screws.

Calculating the residence times for the different L/D ratios result in two different outcomes. The 18:1 L/D ratio equals a 1.72 minute residence time and the 24:1 L/D ratio has a 2.17 minute residence time.

There are several ways to calculate residence time. One common way is based on the shot size of the machine and the shot weight being injected over a certain overall cycle, which is calculated as follows:

Residence Time (Minutes) or RT

RT = Inventory / Shot Size x Cycle Time / 60
Inventory = Rated Shot Capacity / 1.05 x Sd
Sd = Solid Density (Room Temperature)

Using the percentage of stroke of the machine and overall cycle time method of calculation does not include the two different weights of the resin (solid versus molten) and the L/D ratio. Assumptions then are made that the total shot capacity of the machine is equal to the total inventory of the screw.

Calculating the residence time on the data listed on page 21, using the percentage of machine shot capacity, weight of shot being injected and overall cycle, results in a residence time of 1.27 minutes.

Depending on how it is calculated and/or the difference in L/D ratio, there could be as high as a 40% difference in residence time.

This variance would create different processing conditions. Contact one of Reiloy's Sales & Process Engineers to evaluate residence times to see what opportunity there is to improve part quality and cycle time.

3. Setting the Heat Profile - Achieving the proper heat profile is the method for balancing the heat source. Although an ***'ascending*** (lower in rear zone/ higher in front zone) ***or flat'*** profile is recommended by many resin manufacturers and is used successfully in some situations, the experience of Reiloy customers has confirmed that the use of a ***'hump'*** (higher in center zone) or ***'reverse'*** (higher in rear zone) profile produces an optimum melt quality at the lowest cost where screw and barrel wear is minimized. The use of each of these profiles has merit in certain situations.

4. Adjusting the Heat Profile - The heat profile guidelines described provide a starting point and should be adjusted to produce the best melt quality at the lowest possible moldable temperature with all heater band zones cycling. Molding cycles may be reduced by adjusting the temperature downward, starting in the front zone and moving each zone back (lower) ten degrees at a time (allowing adequate cycles to evaluate each adjustment).

When qualifying your melt quality, it is recommended that the following be monitored:

a) Melt Temperature: With the correct screw design your melt temperature should be at or just under your front zone setting (within 10ºF). This should hold true whether running an ascending, flat, hump or reverse heat profile. Melt temperature that is higher than the front zone setting can be a result of obstruction of flow, incorrect screw design or a worn screw or barrel. If after increasing the temperature of the zones, the heat zone continues to override, it is a good indication that the screw or barrel is worn. Adding more conductive heat before the obstruction can relieve or minimize it and, most likely, reduce the melt temperature.

b) Barrel Heat Zone Cycling: The rear zone should always call for more heat than the center zone and the center zone should call for more heat than the front zone, no matter what heat profile being used. If this behavior is not followed, too much shear heat will be generated which is uncontrollable. The heat can be manipulated by putting more conductive heat before the zone experiencing the obstruction.

Sample Residence Time Calculation
Using The Specifications Listed On Page 21
To Determine Inventory:
Rated Shot Capacity / 1.05 x Sd
20 / 1.05 x 1.14
Inventory = 21.714
To Determine Residence Time:
Inventory / Shot Size x Cycle Time / 60
21.714 / 10 x 35 / 60
Residence Time = 1.27

Same Screw - Two Different Shot Sizes - Same Residence Time

Due to a difference in screw stroke, if running the same screw and resin in both machines, the residence time would be the same if processing with the same overall cycle time.

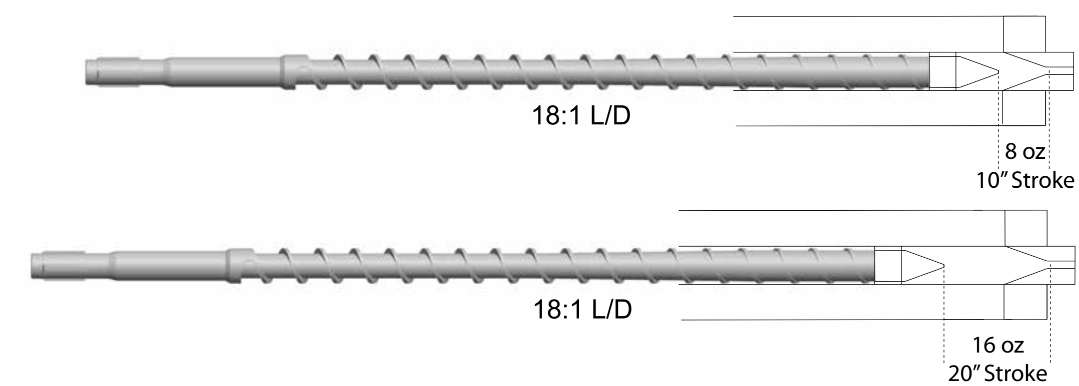


Figure 8

Different Screws - Same Shot Size - Different Residence Times

The following two drawings illustrate the same size diameter screw with two different L/D ratios having the same shot size on the machine. Calculating the residence times for the different L/D ratios will result in two different outcomes.

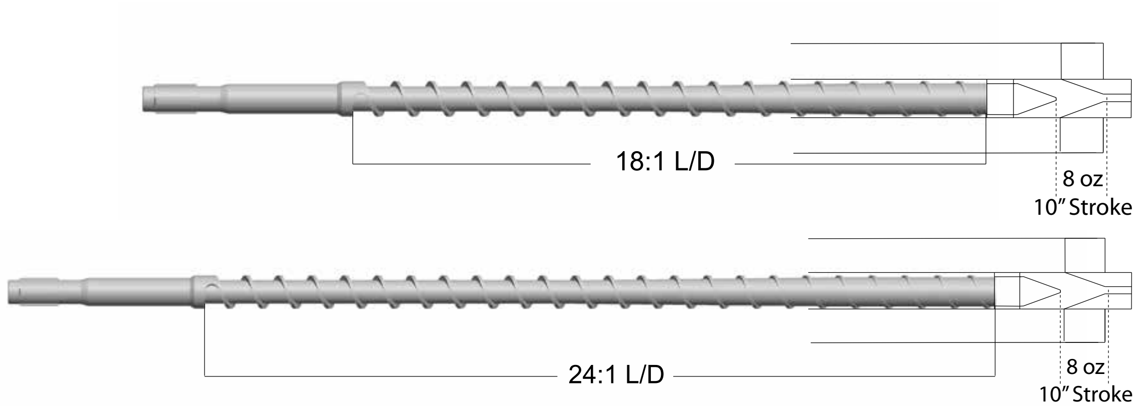


Figure 9

To make sure a proper heat profile is being used, do ***three things***: (1) ***check the pressure or electrical current used by the screw motor during screw recovery*** (it should be in a range of 40% to 60% of maximum available energy); (2) ***verify that all heater band zones are calling for heat;*** and (3) ***check the melt temperature with a pyrometer***. It should be within 10ºF of the front zone setting.

BACK PRESSURE

Back pressure results from restricting the backward movement of an injection screw during the recovery portion of the molding cycle. As a result, the screw works the resin harder and increases the melt temperature of the plastic through increased shear. It is possible to raise the melt temperature as much as 50ºF or more through the use of back pressure.

There are both advantages and disadvantages to the use of back pressure. It should also be noted that the machine itself will generate a minimal amount of back pressure without setting the controls to do so.

1. Advantages - Shear heat creates a more uniform melt temperature and viscosity. With a proper amount of back pressure, a better melt consistency improves flow characteristics and potentially better part quality. Back pressure can also enhance the mixing of color and increases melt density which can also improve part quality. Fine tuning of the plasticating process is possible through back pressure.

2. Disadvantages - Back pressure increases melt temperature, restricts the recovery of the screw and can lengthen recovery and cycle times. Due to the screw working harder, more energy is consumed increasing the cost of production.

Excessive back pressure will result in increased wear of barrels, screws and valves and, if used with glass-reinforced resins, may cause the breakage of the glass fibers, reducing the physical properties of the parts.

There are no hard and fast rules for the use of back pressure. However, it has the ability to affect almost all other variables in your process. A little back pressure helps the molding process without sacrifice in part quality or cost of production. However, ***in a continuing processing environment, back pressure should never be used as a substitute for a proper heat profile or a correct screw design!***

Processing Inquiry Sheet

For a review of your process, complete the Processing Inquiry form on page 37 or 38 and email to reiloy@reiloyusa.com or fax to 316-721-1495. This form can also be accessed on Reiloy's webpage.

COMPONENT MODIFICATIONS

In addition to the more customary designs of screws and barrels, there are modifications that can be made to those components to achieve improved processing results or desired special effects. These modifications include upsizing or downsizing an injection unit, and venting.

UPSIZING INJECTION UNITS

Increasing the capacity of an injection unit without replacing the entire unit is possible and the modification can usually be accomplished at a much lower cost. The capacity of the existing hydraulic or electrical system, the barrel design, and resins to be processed are among the factors to be evaluated in confirming the feasibility of upsizing. (See Data Requirements for Upsizing sheet on page 39.)

Upsizing involves a new barrel, screw, valve and end cap. The ***new barrel*** will have the same mounting configuration with a larger bore. The ***new screw*** is manufactured with the same drive design but larger outside flight diameter. If a reduction in L/D is not desired, a longer screw can be made and the barrel length also extended. The existing ***end cap*** must be modified or a new one manufactured to fit the changed bore diameter of the barrel. A ***new valve*** is also required to fit the changed unit.

DOWNSIZING INJECTION UNITS

The need to downsize an injection unit usually arises from one of three reasons: 1) higher injection pressures are required; 2) shorter residence times are desired; and/or 3) shot size control is needed.

Excessive residence times can result in polymer degradation causing surface defects and/or the loss of physical properties (such as impact strength). Resins especially sensitive to excessive periods of high heat include: PC, ABS, PVC, acetals, cellulosics and others that contain flame retardants. (See Data Requirements for Downsizing sheet on page 40.)

Residence time (the time a resin is in the barrel before injection) should ideally be at least 2 minutes and not more than 5 minutes. ***Corrective measures*** to counteract high residence times include: ***(1) lowering screw RPM; (2) reducing back pressure; and (3) reducing barrel heat in the feed zone.*** If these remedies are not effective, the only remaining cure is to reduce the shot capacity of the machine, hence, downsizing the injection unit.

Calculating residence time is an important step in the downsizing evaluation process. Although there are several equations involved in the calculation, the following simplified formula provides results with reasonable accuracy. (See sample calculation on page 22.)

Residence Time (Minutes) or RT

RT = Inventory / Shot Size x Cycle Time / 60

Inventory = Rated Shot Capacity / 1.05 x Sd

Sd = Solid Density (Room Temperature)

Downsizing an injection unit involves a ***new barrel*** with a smaller bore of a standard size. Usually the length is shortened to allow a 24:1 L/D. A ***new screw*** with a removable sleeve on the drive and a standard diameter is manufactured and supplied with a ***new end cap*** and ***valve*** to fit.

Caution: Downsizing creates the potential of ***higher injection pressures*** utilizing the existing controls with a smaller barrel. Special care must be taken to insure that the new barrel will have adequate yield strength to offset the higher pressures. In many cases, modifications are made to the molding machine to limit injection pressures.

Failure to take one or more of the precautionary steps described above could result in serious damage and/or injury to equipment or personnel.

VENTING

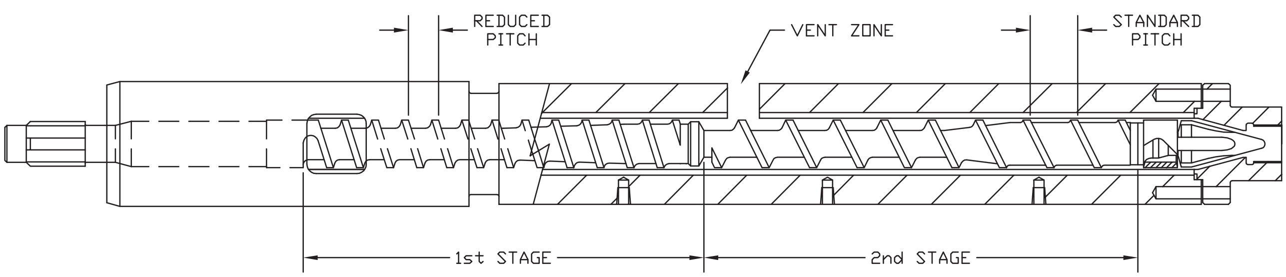
Vented barrels have been used in injection molding and extrusion for a number of years and until the 1980's a two-stage screw of greater length (26:1 L/D and longer) was utilized. In the 1980's, standard length (20:1 L/D) screws began to be used for venting applications in Europe and the United States.

The ***first stage*** of the screw consists of feed, transition and metering zones utilizing a reduced pitch (2/3 to 3/4 of a square pitch) to allow the resin a greater length of channel (and longer time) in which to melt. The melting process is usually completed by the use of a blister ring (or shearing device) at the forward end of the first stage meter zone which eliminates unmelt and thins the melt.

The ***second stage*** includes a decompression zone, which is located under the vent, allowing water vapor and other gases to be exhausted. A recompression and second stage meter zone follow which ready the melt for injection.

There are arguments for and against vented processing. Arguments which ***favor venting*** include: (1) reduced processing costs by avoiding the drying of the resin; (2) the elimination of unwanted volatiles which enhance the ability to perform secondary operations on the part, such as painting or plating; and (3) simplification of making a resin change by omitting the pre-drying requirement.

VENTED BARREL AND SCREW CONFIGURATION



The ***disadvantages of venting*** include the following potential problems: (1) loss of physical properties of parts resulting from excessive heat caused by shear in the shorter transition zone of the first stage of the screw; (2) variance in part quality caused by resin entering the barrel with greater or lesser moisture content; and (3) reduced production rate resulting from longer cycles and the inability to operate successfully at larger percentages of the injection stroke.

If venting is selected, ***the use of a screw with 26:1 to 32:1 L/D is recommended***. Although shorter two-stage screws have been used successfully, Reiloy believes the longer screw offers better melt quality, higher production rates, a wider processing window and greater opportunity to perform secondary operations on the part.

EXTRUSION

There are some ***major differences*** in the processing considerations for injection molding and for extrusion. Again, only the factors involving the machinery components and their impact on processing profitability will be discussed.

HEAD PRESSURE

After the melt (extrudate) leaves the screw, it is forced through a filter made of wire screens and a breaker plate - a heavy metal disc with holes in it. First, the screens filter out contaminants such as decomposed plastic and foreign particles. Second, the screens and breaker plate improve mixing and, combined with the die, create head pressure which assists in achieving final melting and an isothermal extrudate of consistent viscosity.

The filter screens (usually 2 to 4) are arranged with the most coarse against the breaker plate and the finest immediately after the screw. The screens are a square mesh and rated by the number of squares per inch, such as 20, 40, 60 and 100. Because the ***screens become dirty and plug up, they must be replaced manually or automatically with a screen changer.***

The head pressure is a form of ***back pressure*** induced from the screens, breaker plate and die. Changes in die resistance have a major impact on the process. ***The greater the resistance, the higher the melt temperature and better mixing but greater demand for horsepower.*** It also means lower production per hour.

HEAT PROFILE

Although the residence time in extrusion is nearly non-existent, a 'hump' and 'reverse' heat profile does aid in the efficient melting of the resin and in the achievement of a high quality extrudate. Ideally the pellets in the feed zone should stick to the barrel wall and move freely on the screw. As the pellets are scraped from the barrel wall by the screw flights, they mix with other pellets and begin to form the solids bed which is conveyed to the transition zone. As the solids bed enters the transition zone, the added heat from the barrel wall helps melt the solids bed and aids the screw in shearing the resin while moving it forward under increased compression. The ability of the early flights in the feed zone to 'grab' the pellets and form them into the solids bed is referred to as 'bite'. The proper temperature in the feed zone is necessary to create the optimum 'bite' which is needed to maximize the production rate.

EXTRUSION INSTABILITIES

As set forth in Rauwendaal's book, **Polymer Extrusion**, extrusion instabilities may be classified based on the time frame in which they occur.

High frequency instabilities may occur in the form of 'shark skin' or melt fracture. 'Shark skin" appears as a consistent ridged surface distortion with the ridges running perpendicular to the extrusion direction. This condition is presumed to be a die related problem and can be minimized or eliminated by reducing the screw RPM and increasing the die temperature.

Melt fracture is a distortion of the extrudate in the form of ripples, spiraling or forming the appearance of bamboo. Although there is no agreed cause of melt fracture, it can be minimized by streamlining the die, increasing the die temperature and running at a lower RPM.

Screw frequency instabilities occur, to a small degree, simply due to the nature of the flight interruption at the feed zone. It may become more pronounced by increases in the helix angle of the screw or the placement of certain types of mixing sections too near the meter end of the screw. Usually these instabilities are not serious inhibitors to the extrusion process.

Low frequency instabilities are often associated with solids bed breakup resulting from accelerating the solids bed through the transition zone at a rate exceeding the melting capability of the screw. The solids bed tends to break up erratically and causes sudden changes in the head pressure and the output rate. Lower compression screws and/or longer transition zones seem to reduce the inconsistent and premature breakup of the solids bed. A slower screw RPM also aids in reducing this problem.

The condition described above is often indicative of an inadequate screw design where the screw is incapable of melting the plastic at the rate desired. This can quite often be confirmed by reducing the screw RPM and satisfactory extrudate is generated but at an unsatisfactory rate.

Slower frequency instabilities can be caused by temperature fluctuations along the extruder barrel. Malfunctioning heater bands or slow time-proportioning temperature controls contribute to the problem.

The observance of the ***ammeter reading*** helps identify these problems. More than a 5% deviation between the high and low amp requirements, based on recording them for a minute or so, indicates a problem to be addressed. If pipe or tubing is being extruded and ovality is an important consideration, ***deviations of less than 2% can be critical***. As previously discussed, sometimes surging can be relieved by a change in the heat profile in the feed and transition zones. In extreme cases, ***assuming the proper screw*** is being used, only a gear pump between the extruder and the die can eliminate the problem.

Calculating Throughput

An important method of measuring the effectiveness of the process is comparing the theoretical or calculated throughput to actual production. If there is a significant deviation between the two, it indicates a problem that needs to be addressed. The measure of the metering section to pump resin against zero resistance is referred to as drag flow. Drag flow may be calculated using the following formula:

Where: **D** = screw diameter

Mfd = meter flight depth

RPM = screw speed

Sg = specific gravity

Pounds/Hour = D^2 x 2.3 x Mfd x RPM x .9 x Sg

Ounces/Second = Pounds/Hour x .00444

A comparison of the calculated versus the actual production rate can be helpful in diagnosing extrusion problems. The calculations do not include the effect of grooved feed sections nor starve feeding.

If the **actual throughput is near or greater than the calculated value**, there is very likely a heat override occurring in the transition section of the screw and potential for surging is present. In simple terms, the screw is feeding more than its design is capable of melting at the existing screw speed. If **actual output is below the calculated value**, it is indicative of a high die resistance (die, breaker plate or screens) or a problem in solids conveying in the feed zone. It could also indicate a worn screw on the OD of its flights.

Sample Throughput Calculation

D = 2.244
Mfd = .121
RPM = 100
Sg = 1.05 (PS)

Using the above specifics, the calculated throughput for Ounces/Second would be:

To Determine Pounds/Hour

D^2 x 2.3 x Mfd x RPM x .9 x Sg

5.036 x 2.3 x .121 x 100 x .9 x 1.05

Pounds Per Hour = 132.4

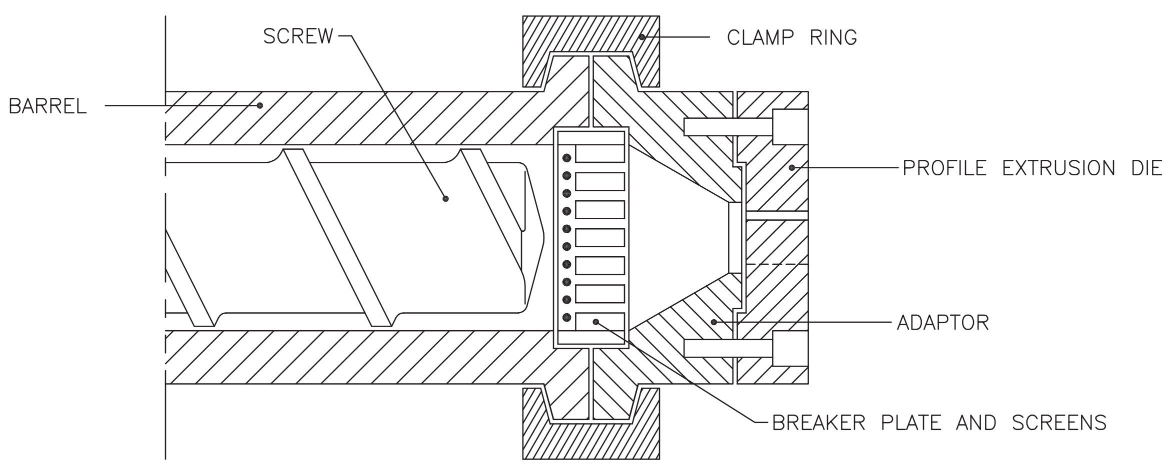
To Determine Ounces/Second

Pounds/Hour x .00444

132.4 x .00444

Ounces Per Second = 0.59

EXTRUDER HEAD COMPONENTS



SECTION 6

SCREW & BARREL MAINTENANCE

Proper maintenance is vital to a plastics processing operation, as it helps in preventing premature and excessive wear. It can also play a big role in keeping energy consumption costs down.

ASSEMBLY & DISASSEMBLY

Special care must be taken when assembly and disassembly are required. These components have very tight tolerances and sealing surfaces that must retain the molten plastic at extremely high temperatures and pressures.

Before assembling the screw into a barrel, make sure both components are clean and free of any plastics or damage. The screw must slide freely into the barrel by hand. If greater force is required, damage may occur to the screw and barrel during the first few hours of operation.

All seal faces such as the end cap and nozzle must be clean to provide a good seal against the mating part. Failure to ensure a tight seal may result in leaking of molten plastic, which can be harmful to anyone working around the machine, and may cause damage to equipment.

Due to the heat applied to these components during operation, it is necessary to apply a nickel based anti-seize compound to all threads and screw drives before assembling. This will allow for these components to run for greater lengths of time without seizing and make it much easier to disassemble in the future.

HOW TO INSTALL A THREAD ON END CAP

The proper installation of thread on end caps is essential, not only in the continual operation of the machine, but perhaps most importantly, in the ease of removal when exchanging components or doing routine maintenance.

Improperly installing an end cap can cause it to seize on the barrel, making removal extremely difficult, impossible and/or hazardous.

In some cases, Reiloy has been forced to machine end caps out of barrels sent in for inspection. Incidences of maintenance workers coming close to injuring themselves with flying wrenches used trying to loosen an end cap are, unfortunately, common.

The following procedures for the proper installation of thread-on end caps (barrel heads) will hopefully keep these scenarios to a minimum:

1. Make sure threads and seat surfaces on the barrel and the end cap are clean and free of any damage.

2. Thread end cap into barrel by hand to insure the threads are free of any debris and that the fit is good.

3. Remove and apply anti-seize to the threads.

4. Thread the end cap ¾ of the way into the barrel.

5. Allow end cap and barrel to reach the same temperature (approximately 350° F).

6. Continue threading end cap using standard end cap wrench until the seal faces engage.

7. Using a three (3) pound hammer, strike the end cap wrench one time to seat the two seal faces. Good discretion must be used when seating the end cap.

Due to the thermal expansion of alloys, failure to have the end cap and barrel at the same temperature when seating the two together can cause the end cap to seize to the barrel, making it difficult to remove it later.

The same can happen if the proper anti-seize is not used. A copper or nickel base anti-seize that has a temperature range exceeding 800 degrees Fahrenheit is recommended.

BOLT ON END CAP ASSEMBLY INSTRUCTIONS

It is extremely important to tighten any sealing surface (end cap and nozzle) properly. The mating surfaces must be clean of plastic or debris and come together evenly and square to provide a good seal. Page 30 provides detailed instructions for bolt on end cap assembly installation. When thread on nozzles are used, and torque wrenches are not available, extreme care must be exercised when tightening, keeping in mind that over tightening will cause damage to the sealing surfaces.

Because there are differences in the thermal expansion in the steels that are used for barrels, end caps and nozzles, it is necessary to retorque the end cap bolts and nozzles after the machine has reached operating temperature.

REMOVING THE SCREW

While the machine is at operating temperatures, purge all resin out of the screw and barrel. Using screw pull-back, retract the screw to its fully retracted position. With the hydraulic pumps off and all electricity to the machine turned off, remove the screw drive retainer and end cap (barrel head). Keep in mind these components are extremely hot. Turn the power on to the machine and allow the barrel heat to reach operating temperature. Slowly inject the screw forward until it is in the full forward position. Using screw pull back will disconnect the screw from the drive quill. Continue screw pull back until the drive quill is in the fully retracted position. Place a bar inside the quill and use inject forward to push the rod against the screw, forcing the screw out of the barrel. This may have to be done several times to get the screw where it can slide out freely. Turn heater bands off and allow barrel to cool.

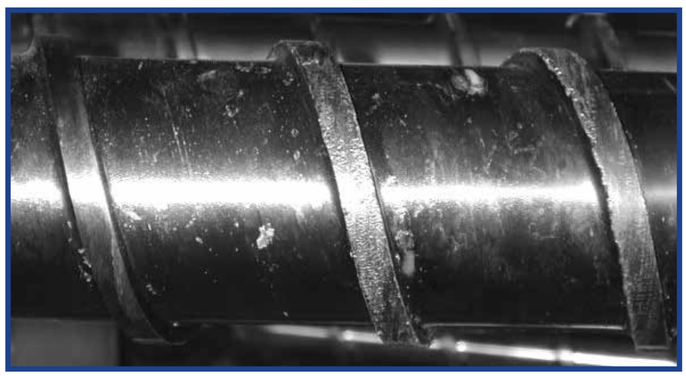
COMPONENT WEAR

There are three types of wear that occur in barrels, screws, valves and other components. An understanding of the nature and causes of adhesive, abrasive and corrosive wear is essential to the selection and use of these components. Knowledge of wear sources can help in its prevention.

ADHESIVE WEAR

Adhesive wear occurs when two metals rub together with sufficient force to cause the removal of material from the less wear resistant surface. If the two metals have a comparable chemical analysis and hardness, a galling action can occur when one metal is actually welded to the other causing high and low spots where material is added or removed.

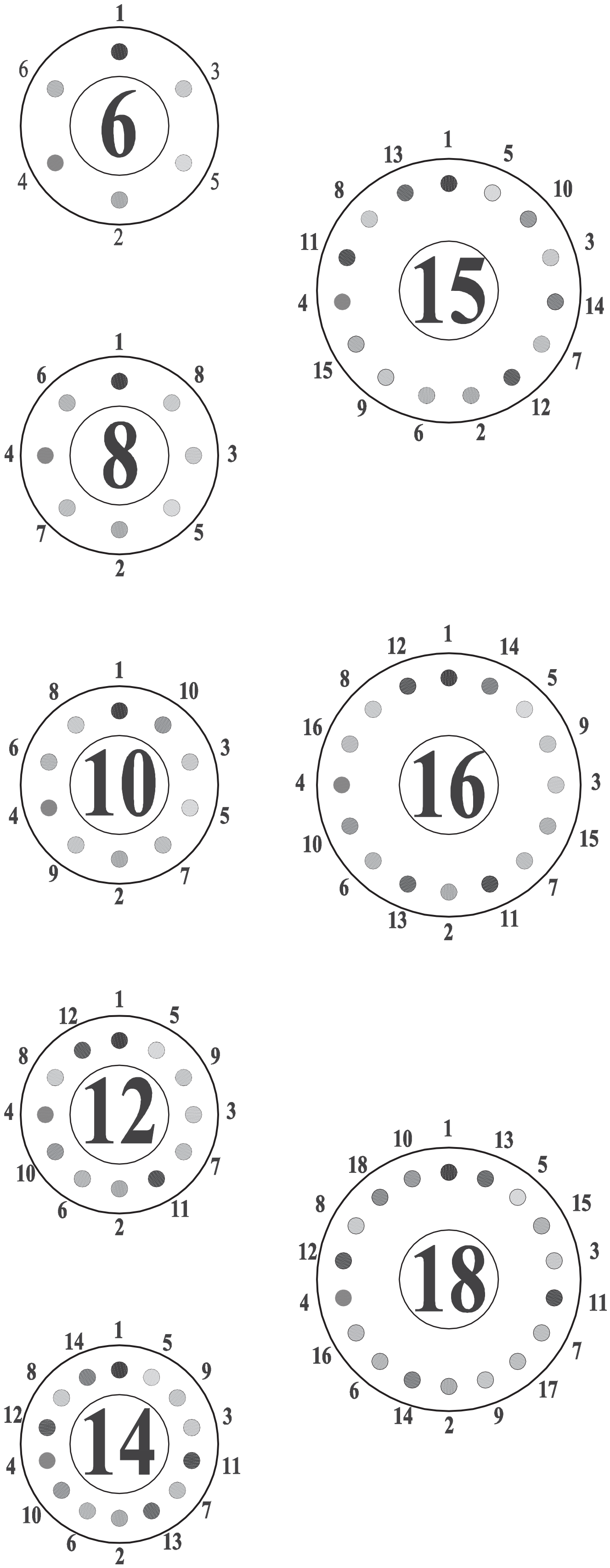
The screw and barrel can come into contact with each other during operation. The screw is cantilevered in the barrel and is supported only at its shank and by the plastic in the barrel. When conditions cause excessive contact between the two components, adhesive wear and/or galling will occur on the screw flight OD and the barrel walls.



Severe Adhesive Wear

Moderate Adhesive Wear

There are several ***causes*** of adhesive wear and/or galling, all of which can be prevented through the proper design, manufacture and use of the machinery components.



END CAP ASSEMBLY INSTRUCTIONS

STEP 1: Lubricate bolt threads in area of engagement. Also lubricate face of bolt using a nickle based anti-seize compound.

STEP 2: Install all bolts finger tight.

STEP 3: Number bolts so that torquing requirements can be followed.

STEP 4: Apply torque in 20% (1/5) increments of required torque, loading all bolts at each increment before proceeding to the next sequence.

STEP 5: Repeat final torque sequence when the barrel is at operating temperature.

NOZZLE ADAPTER BOLTS		
BORE DIAMETER	TORQUE FT. LBS.	N · M
(30mm)	22	30
(36mm)	27	37
(38mm)	30	40
(40mm)	24	35
(50mm)	64	90
(57mm)	83	115
(65mm)	98	135
(69mm)	145	200
(75mm)	150	205
(80mm)	195	265
(90mm)	301	410
(105mm)	512	700
(115mm)	886	1200
(135mm)	1110	1500
(155mm)	1750	2375

1. Improper Screw Design

If the design of the screw is not adequate to generate the necessary melting capacity, the unmelted resin can result in an uneven plugging of the flow in the screw channels, causing the screw to deflect against the barrel wall. This condition will occur more readily with new rather than old components that have considerable wear. The same condition can occur with a properly designed screw running in a barrel with an improper heat profile as described in the processing section on page 20.

2. Wrong Component Materials

To avoid adhesive wear and/or galling, the chemical analysis and/or hardness of the screw and barrel materials must be different. This 'compatibility' of materials must be considered when selecting screw and barrel materials, as discussed on page 15.

3. Incorrect Heat Profile

In an effort to process resins at their lowest melt temperatures, low heater band settings in the transition and feed zones can cause the resin to melt almost solely from shear heat generated by the screw. If the shear heat is not uniform, the same restrictive condition described in item (1) will occur, causing screw deflection and consequent adhesive wear and/or galling.

4. Poor Manufacturing Workmanship

Inferior plating, flight hard-surfacing or nitriding of screws, improper heat treatment of components or lack of straightness in the barrel or screw can cause adhesive wear and/or galling.

5. Improper Machine Alignment

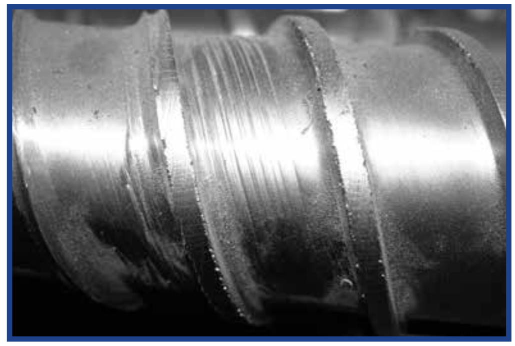
An injection molding machine or extruder can be found to be out of alignment causing continual contact between the barrel and screw. Although this may be the last item to be checked, misaligned components can and do occur. Laser alignment may be required.

ABRASIVE WEAR

Abrasive wear occurs when abrasive particles in the resin come into contact with the screw or barrel. The scouring effect of the hard particles wears away the metal in the screw or barrel, most often in the transition section. Foreign particles such as screw flight particles, chrome plating and other objects can also gouge the barrel or screw or even break segments out of the screw flights.

Abrasive particles in the resin can be reinforcements, such as glass fibers or spheres, calcium carbonate and powdered metals or ceramics. All cause

Severe Abrasive Wear



Moderate Abrasive Wear

abrasive wear, especially if the components are not made from high quality wear resistant materials.

Abrasive wear can also occur when processing non-reinforced resins if too much of the energy required to melt the resin is generated by shear. Cold pellets moving into the transition section of the screw are compressed and sheared causing a scrubbing action resulting in abrasive wear.

Although the processing of heavily reinforced resins will inevitably result in abrasive wear to the barrel and screw, many of the causes of this type of wear can be delayed or prevented. The ***causes of abrasive wear*** include:

1. Improper Component Materials

The failure to use wear resistant materials in barrel linings and on screw surfaces allows abrasive wear at a much more rapid rate. The selections of these materials are discussed on pages 11 and 15 of this Handbook.

2. Inadequate Screw Design

A screw design that is too aggressive (compression ratio too high or transition section too short) can contribute to premature abrasive wear. An overly aggressive screw design can cause excessive shearing of the resin contributing to the scouring effect of abrasive, reinforced resins. This condition was discussed in the screw design section beginning on page 1.

3. Incorrect Heat Profile

Heater band settings that are too low in the feed and transition zones can cause too much shear in melting the resin. The excessive shear causes abrasive wear on the root and flight radii of the screw and on the barrel lining. The same condition can result from heater band failure where inadequate conductive heat is used to melt the resin. For this reason, many molders of reinforced resin use a 'reverse' or 'hump' heat profile.

4. Excessive Back Pressure or Head Pressure

In some cases, back pressure is used to compensate for an improper screw design in an effort to complete the melting of the resin. Excessive back pressure increases the scouring effect of the resins (especially reinforced resins) against the screw and barrel. It can also segregate modifiers or fillers in a resin, creating a part with inferior physical properties.

5. Failure to Use Magnets

Another form of abrasive wear occurs when foreign particles enter the barrel. The use of magnets, screens or filters can prevent gouging and fracturing of components caused by processing nuts, bolts and the like.

CORROSIVE WEAR

Corrosive wear results from acids that are generated in plastics processing which attack the surfaces of barrels and screws. Corrosive wear is characterized by pitting and usually occurs in the last few flights of the transition zone and in the metering zone. The pits can also collect melt, burn or degrade it and result in black or burned particles in the parts.

There are several resins that can generate acidic gases at high temperature. They include polyvinyl chloride (which releases hydrochloric acid), acetals (formic acid), fluoroplastics (hydrofluoric acid) and cellulosics (acetic, butyric and propionic acids).

In addition, flame retardants, coupling agents and some foaming agents release acids, including bromic and sulphuric acids.

Despite their acid-generating characteristics, these resins can be successfully processed using the proper screw designs and corrosion-resistant component materials. The ***causes of corrosive wear*** include:

1. Improper Component Materials

Corrosion-resistant materials are available for barrel linings and screws. Stainless steels in a hardened condition, nickel alloys, special flight hardsurfacing materials and iron-free barrel linings all help avoid corrosive wear. These materials are discussed on pages 9 thru 13 of this Handbook.

2. Incorrect Shut-down and Start-up

Shut-down and start-up procedures that permit the soaking of the resin at operating temperatures for an extended time will ultimately cause corrosive wear. This is especially true if any moisture is allowed to permeate the resin. Shutting down without cleaning the barrel of plastic and without leaving the screw in the forward position not only encourages corrosion but can also contribute to cold start-up breakage.

3. Inadequate Screw Design

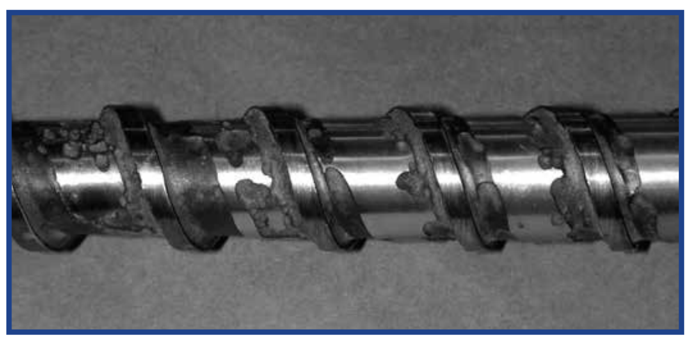
Screw designs that cause excessive shear heat also contribute to corrosive wear. Some resins that do not conduct heat as well as others (shear sensitive) can be burned or degraded, allowing corrosion to occur.

4. Inadequate Moisture Removal

Hygroscopic resins absorb moisture readily and must be dried before processing. They include: ABS, PMMA, FEP, PA, PBT, PC, PET, POM, PPO, PVC, SAN, PSU and PEI. If moisture is allowed to remain in the resin, it can unite with other elements to produce corrosives at operating temperatures.

5. Incorrect Heat Profile

The same conditions that can result from improper screw design (excessive shear heat) can also result from an improper heat profile or runaway heater bands. These conditions contribute to corrosive wear.



Corrosive Wear

6. Excessive Residence Time

If the shot size is very small relative to the shot capacity of the machine, lengthy residence times will result. The over-soaking of the resin at high temperatures can encourage corrosion in some resins.

As you evaluate wear in your processing environment, keep one important consideration in mind: **All of the causes of excessive wear can be prevented!**

COMPONENT REPAIR / REPLACEMENT GUIDELINES

The repair and/or replacement of machinery components at the proper time is an important element in maximizing processing performance. Well-defined guidelines should be established for the inspection of components and for the criteria for the repair or replacement of components. These guidelines should be clearly written and approved by management as a matter of policy. The techniques and study results presented in the following paragraphs should reinforce this approach.

SCREW REPAIR

The decision to repair a screw rather than purchase a new replacement should be based on: (1) the size of the screw; (2) the amount of wear on the root of the screw; and (3) the design of the screw. Reiloy recommends:

"If the design of the worn screw matches your processing needs and the root is not worn enough to alter that design, rebuild it."

Exception: On smaller screws (under 50mm or 2"), a new tool steel screw with increased wear resistance can be purchased at a cost comparable to having a chrome screw rebuilt.

Screw repair consists of rebuilding the flights to the OEM diameter specification and rechroming or renitriding the surface, if required. A properly rebuilt and polished screw can be as effective as a new one and an economical alternative to a new screw purchase.

BARREL REPAIR

The decision to reline a barrel rather than replace it should be based on the economics of the situation. Moreover, if relining is the choice, the length of the reline should also be based on a well-defined guideline. Reiloy's recommendation is:

"Reline that portion of the barrel necessary to permit the blending of no more than a .003" step from the nominal bore diameter of the new liner to the ID of the worn barrel; however, in no case should the liner be less than the stroke of the injection molding machine plus two inches."

This guideline protects from leaving an abrupt step where plastic can gather and burn or degrade. It also avoids having the valve assembly travel over a seam line in the repaired barrel.

WEAR MEASUREMENT

Barrels and screws should be measured during down-time for a mold change or line alteration, or during a specified time set aside for machine maintenance. These components are relatively easy to measure if the appropriate equipment is used. ***After a proper cleaning and cooling to room temperature***, wear can be measured and recorded so that repair or replacement alternatives can be evaluated.

MEASURING EQUIPMENT

Equipment to measure wear in barrels and screws can be procured from vendors who should include instructions on their use. A ***long-range dial bore gauge*** is needed for measuring barrel wear. They are available in various diameter ranges and lengths depending upon barrel size. A ***flight micrometer*** (with a gauge block as an integral component) is necessary in measuring screw OD wear. These instruments are available from several sources and are made specifically for screw measurement. They are also available in various sizes.

MEASURING SCREW WEAR

Screw wear should be measured and the results recorded on a Screw Inspection Report (see page 41) in the following manner:

- Clean the screw, ***while hot***, with a soft wire brush and copper or brass gauze and ***allow to cool to room temperature***. If an oven is used to clean the screw, take care to avoid temperatures higher than 800ºF. Higher temperatures, caused by an oven or the careless use of an acetylene torch, can cause screw warpage, chrome-plating degradation and surface blemishes. Remove any burrs observed after cleaning.
- Measure the flight diameter every other flight with a flight micrometer. It is preferable to mark the flights and take two measurements at opposite axis at each mark. Record the results on the report.
- Measure the diameter of the root between every other flight in the feed section and in the meter section with a micrometer or caliper and record the measurements.
- Examine and record the condition of the root for under-cuts or "washout" conditions. Examine the nose threads and shank for wear requiring repair. Note any cracks or chipped plating. Check the screw for straightness by rolling on a flat table or surface plate.

MEASURING BARREL WEAR

Wear on the bore of a barrel should be measured in the following manner:

- Clean the barrel ID, ***while hot***, of any adhering plastic with a soft wire brush and copper or brass gauze and allow to ***cool to room temperature***.
- Set the dial bore gauge to the nominal bore diameter of the barrel using a micrometer. Take a gauge reading throughout the length of the barrel at 2 to 3 inch intervals and record the result on a Barrel Inspection Report form. (See page 42).
- Examine and note the condition of the feed hole area for heavily worn "washout" spots, and record other conditions requiring repair (cracks, gouges, bent condition, faulty end cap or nozzle adaptor) on the report.

WHEN TO REPAIR

A question often asked is "How much wear on a barrel or a screw justifies the repair or replacement of that component?" The answer varies depending upon several factors relating to the resins being processed and the parts being produced. ***Two very important studies*** have been made that quantify the effect of barrel/screw wear.

In his book **Polymer Extrusion**, Chris Rauwendaal states: ***"Considering the standard clearance is .001 D; a doubling of the standard clearance causes a reduction in melting rate of about 25 percent. A tripling of the standard clearance causes a reduction in melting rate of about 35 percent."***

A second study conducted by Davis-Standard and presented at ANTEC in 1992 concluded that: ***"If the screw/barrel clearance of new components is doubled, low viscosity resin production will be reduced as much as 20% to 25 %, regardless of head pressure or RPM. The reduction in higher viscosity resins can be 10% to 13%."***

Several studies also conclude that above normal barrel and screw clearance results in increased melt temperature of the resin.

Clearly, if the resin being processed has a low viscosity with high flow rates, a doubling of the screw/barrel clearance may result in a production rate that is not economically acceptable. Conversely, significant wear may be tolerable if non-precision or black parts are being produced from high viscosity resins.

Reiloy has studied the maximum clearance dimensions specified by six injection molding machine manufacturers and have calculated an average of the clearance for various barrel bore diameters. Those ***maximum clearances*** are set forth in the table on page 35. If the tolerances specified in the guidelines published by Reiloy were applied (for both barrel and screw), the ***minimum clearances*** as shown in the table would result.

A "normal" clearance between a new barrel and a new screw from the manufacturer might well be an average of the maximum and minimum clearances shown. Based on the information in the studies and our past experience, Reiloy suggests a ***guideline for repair/replacement*** as follows:

"If the combined wear of the barrel and screw is twice the normal OEM clearance, the barrel or screw (or both) should be repaired or replaced."

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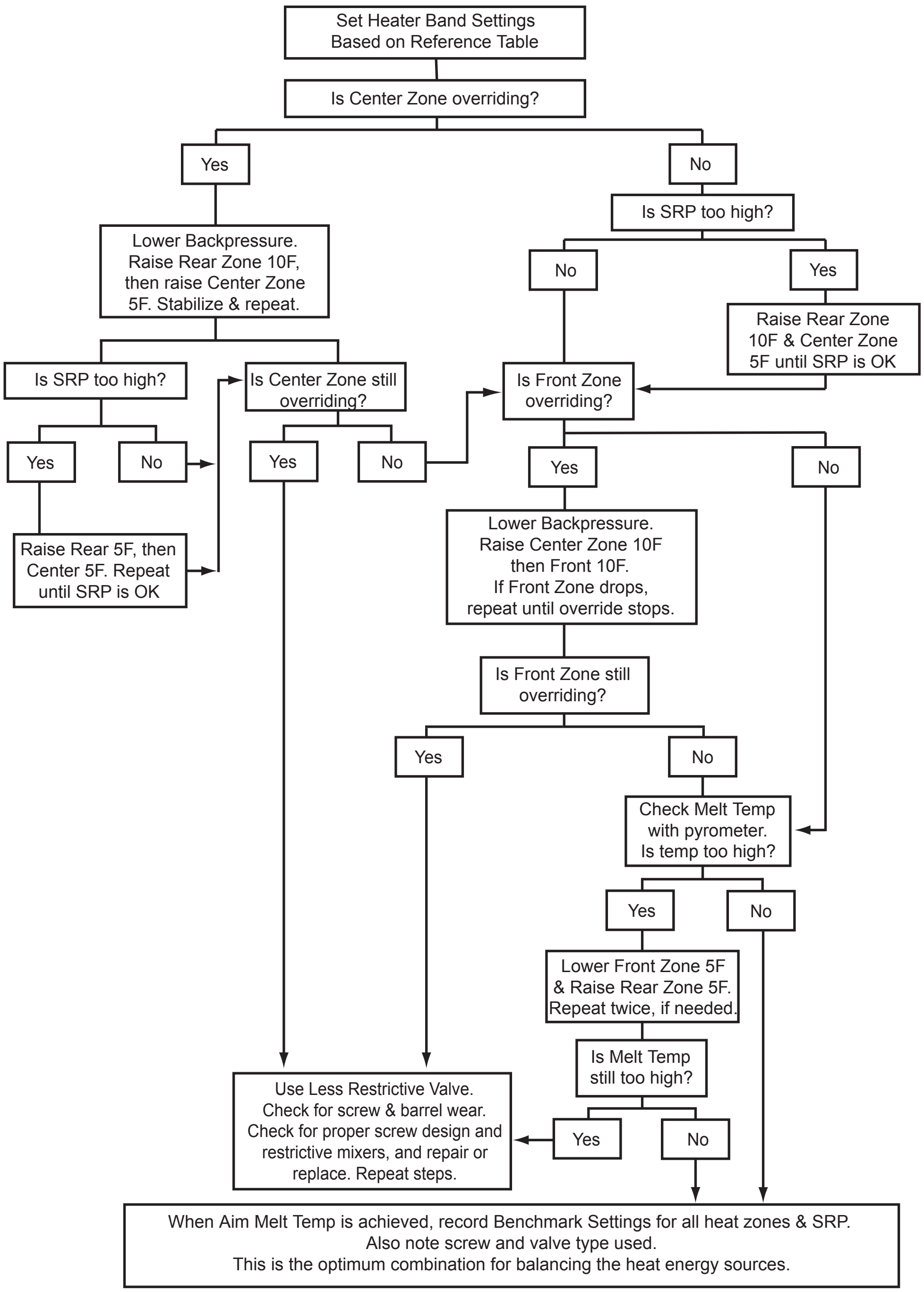
SCREW / BARREL CLEARANCE TABLE

Bore Diameter MM	(Inch)	Avg. Min. Clearance (Inch)	Avg. Max Clearance (Inch)	Repair / Repl Clearance (Inch)
12	(1/2”)	0.006	0.008	0.014
19	(3/4”)	0.006	0.009	0.015
30	(1 1/4”)	0.006	0.009	0.015
35	(1 3/8”)	0.007	0.010	0.016
40	(1 1/2”)	0.007	0.010	0.016
45	(1 3/4”)	0.007	0.010	0.017
50	(2”)	0.007	0.010	0.017
55	(2 1/4”)	0.008	0.011	0.018
60	(2 3/8”)	0.008	0.011	0.018
65	(2 1/2”)	0.008	0.011	0.018
70	(2 3/4”)	0.008	0.012	0.019
75	(3”)	0.008	0.012	0.019
80	(-)	0.008	0.012	0.019
83	(3 1/4”)	0.009	0.013	0.021
90	(3 1/2”)	0.009	0.013	0.021
100	(4”)	0.009	0.013	0.021
105	(4 1/4”)	0.010	0.014	0.023
115	(4 1/2”)	0.010	0.014	0.023
125	(-)	0.010	0.015	0.025
133	(5 1/4”)	0.010	0.015	0.025
135	(-)	0.010	0.015	0.025
140	(5 1/2”)	0.010	0.015	0.025
155	(6”)	0.011	0.016	0.026
160	(6 1/4”)	0.011	0.016	0.026
180	(7”)	0.012	0.017	0.028
200	(-)	0.013	0.019	0.031
225	(-)	0.015	0.021	0.035
250	(9 3/4”)	0.016	0.022	0.038
260	(10 1/4”)	0.019	0.025	0.043

HEAT PROFILE DECISION CHART



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PROCESSING INQUIRY

DATE:
REFERENCE:

CUSTOMER INFORMATION	MACHINE INFORMATION
Company:	Manufacturer:
Address:	Model & SN:
City/State:	Clamp Force:
Contact:	Capacity (ozs):
Phone/Fax:	Diameter & L/D:
Email:	Maximum Stroke:

PROCESSING INFORMATION

Material:	Heat Profile: Rear -	Aim Melt Temperature:
Additives: % Regrind:	Middle -	Actual Melt Temperature:
Colorant:	Front -	Screw Motor Hydraulic Pressure:
Melt Index: Density:	Nozzle -	Residence Time:
Cycle Time: Recovery:	Screw RPM:	
Shot Size (oz./g):	Back Pressure:	

SCREW DESIGN INFORMATION

Mixer: Type -	Flight Depth: Feed -
Location -	Meter -
Barrier Type:	Compression Ratio:
Flight Width: Feed - Meter -	Zone Length: Feed -
Valve Mfgr:	Trans -
Valve Type:	Meter -

PROCESSING PROBLEM

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PROCESSING INQUIRY EXTRUSION

DATE:
REFERENCE:

CUSTOMER INFORMATION	MACHINE INFORMATION
Name:	Manufacturer:
Address:	
City-State:	Model & SN:
Contact:	Diameter & L/D:
Phone/Fax:	
Email:	Maximum Motor Amp Rating & HP:

PROCESSING INFORMATION

Material & Manufacturer:		Aim Melt Temperature:	**HEAT PROFILE:** Zone 1 (Rear)
Additives:	%Regrind:	Actual Melt Temperature:	Zone 2
Colorant:		AMP Draw:	Zone 3
Melt Index:	Solid Density:	Head Pressure:	Zone 4
Melt Density:	Output:	Screw RPM:	Zone 5
Screen Pack:			Zone 6

SCREW DESIGN INFORMATION

		Zone 7
Mixer: Type -	Flight Depth: Feed -	Zone 8
Location -	Meter -	
Barrier Type:	Compression Ratio:	Die 1
Flight Width: Feed -	Zone Length: Feed -	Die 2
Meter -	Trans -	Die 3
	Meter -	Die 4

PROCESSING PROBLEM	REILOY USA USE

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DATA REQUIREMENTS FOR UPSIZING INJECTION MOLDING MACHINE

DATE:		CONTACT:	
CUSTOMER:		PHONE NUMBER:	
ADDRESS:		FAX NUMBER:	
CITY, STATE, ZIP:		EMAIL:	

MACHINE SPECIFICATIONS:	
Manufacturer:	
Shot Capacity (ounces):	
Clamp Force (tons):	
Model & Year:	
Length of Injection Stroke:	
Rated Maximum Injection Pressure (psi):	
Bore Diameter:	
Overall Length of Barrel:	
Screw L/D Ratio:	
Length Screw Shank Extends Back From Cylinder When Screw Is In The Forward Position:	
Distance Injection Unit Sled May Be Moved To Allow For Lengthened Barrel:	
UPSIZING REQUIREMENTS:	
Shot Capacity (ounces):	
Bore Diameter:	

RESINS TO BE PROCESSED AND DENSITY:

OTHER REQUIREMENTS AND REASON FOR UPSIZING:

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DATA REQUIREMENTS FOR DOWNSIZING INJECTION MOLDING MACHINE

DATE:		**CONTACT:**	
CUSTOMER:		**PHONE NUMBER:**	
ADDRESS:		**FAX NUMBER:**	
CITY, STATE, ZIP:		**EMAIL:**	

MACHINE SPECIFICATIONS:	
Manufacturer:	
Shot Capacity (ounces):	
Clamp Force (tons):	
Model & Year:	
Length of Injection Stroke:	
Rated Maximum Injection Pressure (PSI):	
System Pressure (PSI):	
Bore Diameter:	
Barrel Diameter (OD) at Nozzle End:	
Overall Length of Barrel:	
Screw L/D Ratio:	
Length Screw Shank Extends Back From Cylinder When Screw Is In The Forward Position:	
Distance Injection Unit Sled May Be Moved To Allow For Shortened Barrel:	
DOWNSIZING REQUIREMENTS:	
Shot Capacity (ounces):	
Bore Diameter:	

RESINS TO BE PROCESSED AND DENSITY:

OTHER REQUIREMENTS AND REASON FOR DOWNSIZING:

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Screw Inspection Report

Date:	
By:	

Identification Number:	Machine Number:	Manufacturer & Tonnage:	
L/D Ratio:	Flight Length:	Overall Length:	Flight Diameter:
Shank Type:	Flight Width:	Profile:	Mixer:
No. of Stages:	Root Diameter Feed Zone:	Root Diameter Meter Zone:	Compression Ratio:
Screw Base Material:		Screw Flight Hardsurfacing Material:	
Resins Run:		Date In Service:	
Condition of Shank:		Condition of Nose Threads:	
Condition of Root:		Condition of Flights:	

Flight Diameter Measurements		**Flight Diameter Measurements (continued)**	
Flight No.	Flight Diameter	Flight No.	Flight Diameter

Comments Regarding Wear Condition:		
Date of Last Repair:	Done By:	Repair/Replacement Recommendation:

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Barrel Inspection Report

			By:
			Date:
Identification Number:	Machine Number:	Manufacturer & Tonnage:	
Lining Material:	Date in Service:	Bore Length:	Bore Diameter:
Resins Processed:	Date Last Inspected:	Overall Length:	Stroke Length:
Condition of Bore:			
Condition of Feed Hole:			

Measurements		**Measurements (continued)**	
Inches from Stroke End	Bore Diameter .000" (+/- Nominal)	Inches from Stroke End	Bore Diameter .000" (+/- Nominal)

Comments Regarding Wear Condition:		
Date of Last Repair:	Done By:	Repair/Replacement Recommendation:

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SELF EXAMINATION
Test Your Knowledge of
Screw and Barrel Technology

1. The three major resin factors that influence the design of a screw are:
   A. Degree of crystallinity
   B. Viscosity
   C. Additives
   D. All of the above
2. The L/D Ratio is:
   A. Ratio of the flighted length of the screw to its outside diameter
   B. Ratio of the barrel OD to the screw OD
   C. Ratio of the flighted length to the screws' overall length
   D. None of the above
3. The three zones on a standard metering screw are:
   A. Transition Zone, Meter Zone, Cold Zone
   B. Meter Zone, Feed Zone, Cold Zone
   C. Feed Zone, Transition Zone, Meter Zone
   D. Feed Zone, Transition Zone, Mixing Zone
4. The ratio of the channel volume in the feed zone to the channel volume in the meter zone is referred to as:
   A. Helix Ratio
   B. Conveying Ratio
   C. Channel Ratio
   D. Compression Ratio
5. The most efficient or "controlled" melting in resin processing is accomplished using a:
   A. Barrier-type screw
   B. Mixing screw
   C. Standard metering screw
   D. Variable pitch screw
6. The time that the resin is in the barrel before being injected is referred to as:
   A. Shear Time
   B. Barrel Process Time
   C. Residence Time
   D. Melt Time
7. The most obvious difference between injection and extrusion screw design is:
   A. The length of the flighted surface (L/D)
   B. The compression ratio
   C. The channel depths
   D. The heater bands
8. The heat required to melt the plastic in the barrel in injection molding is developed from two sources, conductive heat and:
   A. Residence Heat
   B. Shear Heat
   C. Profile Heat
   D. Transition Heat
9. Wear that occurs when two metals rub together with sufficient force to cause the removal of material from the less wear resistant surface is called:
   A. Adhesive Wear
   B. Abrasive Wear
   C. Profile Heat
   D. Transition Heat

10. Wear caused from reinforcements such as glass fibers or spheres, calcium carbonate and powdered metals or ceramics is called:
    A. Abrasive Wear
    B. Adhesive Wear
    C. Corrosive Wear
    D. Shear Wear
11. Wear that is characterized by pitting and usually occurs in the last few flights of the transition zone and metering zone is called:
    A. Adhesive Wear
    B. Corrosive Wear
    C. Abrasive Wear
    D. Shear Wear
12. Generally, materials of the same approximate hardness and similar chemical analysis should not be used for both barrel liner and screw OD.
    A. True
    B. False
13. Improper start-up and shut-down procedures can be a major contributor to premature wear of the screw, barrel and valve components.
    A. True
    B. False
14. Proper start-up and shut-down procedures should be understood by all personnel and implemented to prolong the life of components subject to wear.
    A. True
    B. False
15. Screw and barrel measurements should be taken while the components are hot and at operating temperatures.
    A. True
    B. False
16. The standard three-zone screw is:
    A. Efficient for mixing
    B. Efficient for processing of all resins
    C. Not designed for efficient mixing
17. Residence time is not important with today's advanced resin formulations.
    A. True
    B. False
18. Using excessive back pressure can increase the life of the screw, barrel and valve components.
    A. True
    B. False
19. Too much or too little residence time is a good reason to consider a machine upsize or downsize of the injection unit.
    A. True
    B. False
20. Too much barrel and screw clearance will accelerate additional wear and add excess heat in the melt.
    A. True
    B. False

ANSWERS: 1 = D; 2 = A; 3 = C; 4 = D; 5 = A; 6 = C; 7 = A; 8 = B; 9 = A; 10 = A; 11 = B; 12 = A; 13 = A; 14 = A; 15 = B; 16 = C; 17 = B; 18 = B; 19 = A; 20 = A

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