Screw Surfacing Materials for Wear and Corrosion Resistance

There are only a few things in life that are truly inevitable. Screw and barrel wear just happens to be one of them.

And it is no wonder if you consider the type of environment the components must function in.

In a screw plasticating unit like an extruder or injection molding machine, the clearance between the screw and the barrel must be small in order to promote good heat transfer. If the alignment is not precise when the screw is rotated — especially at high speeds — then the screw will come in contact with the barrel I.D., causing some type of wear. The wear occurs either in the barrel or screw, depending on which material is more wear resistant. And all this applies, even before the resin is considered. Once you add a high-viscosity resin, with abrasive components, subject it all to high processing temperatures and pressures, you have a very harsh environment.

In injection molding these conditions are exacerbated due to the reciprocation of the screw and the stresses that are caused by the start-stop action.

The amount of wear will vary with the type of resin and the different operating conditions. As the components wear the performance of the machine and the part quality will suffer. The first step in minimizing the effects of wear is to fully understand the mechanisms that cause wear. Then you can apply the right metallurgical combination to fight back. This article will examine these mechanisms, the effect they have on performance, and solutions to minimize the effects of wear.

ABRASION OR MECHANICAL WEAR

Abrasive wear is probably the most common type of wear in the plasticating unit. It occurs when two materials of differing hardness come into contact. The harder material — whether it is metal fragments or glass reinforcing fillers — tends to progressively remove material from the relatively softer material. If abrasion is allowed to continue unchecked, it will result in a gradual decrease in machine performance and, eventually, complete failure.

In abrasive wear, the most common culprits are the fillers and additives in the resin. Other causes of abrasive wear that are commonly overlooked are processing conditions and screw design. A poor screw design that requires a high temperature profile, along with high screw backpressure (in the case of injection molding) will put a tremendous amount of stress on the screw and barrel. Abrasive components in the material, under these conditions, can be extremely destructive.

It is important to remember also that wear does not progress in a linear fashion. It may have taken 6 months to wear 0.010 inch, for example, but it might take only two more months to wear another 0.010 inch.

ADHESION

This type of wear mechanism operates whenever two metal surfaces — the screw flights and barrel wall, for instance — come in contact. At the point of contact, extremely high stresses are formed, causing the surfaces to momentarily weld together and then immediately fracture. This normally leaves the surfaces rough and pitted. Metal fragments then become suspended in the resin to cause additional abrasive wear. To minimize metal-to-metal contact, it is critical that all components are straight and properly aligned, according to the manufacturer's specification.

CORROSION

Corrosion is sometimes classified as a wear mechanism, but technically it is a phenomenon that changes the metal surface even when the machine is not in operation. In most cases it breaks down the metal surface and renders it more susceptible to the mechanisms of mechanical wear. Resins that have chlorinated and fluorinated components, such as PVC and PTFE, are very corrosive and will attack any component that has a high iron matrix. Even a material that normally is not corrosive by nature, can degrade under improper screw-design and processing conditions, producing a corrosive environment. The best defense against corrosion is proper component material selection and the use of corrosion-resistant coatings.

WHAT OPTIONS EXIST TO EXTEND SCREW LIFE:

There are more material options today than there were ten years ago, and the number will certainly continue to increase. Success depends on identifying the type of wear mechanism involved, and selecting the right material for the application.

Generally speaking, there are several different approaches that can be taken to extend the life of a screw. The simplest is to treat the steel's surface to improve its hardness and wear resistance. Another technique involves welding special abrasion- and corrosion-resistant metals onto wear-prone areas, such as the screw-flight surfaces. And the third approach is to cover the entire screw with a protective coating.

The decision as to which approach is right for you is likely to be complex, requiring analysis not only of the materials being processed but also the size of the screw and the long-term economics of the application. This analysis is best done with the assistance of a knowledgeable screw manufacturer.

One of the first things to decide is what the screw itself will be made of (see Table I). This is important because, naturally, some metals are inherently more durable than others. In addition, some of the coatings and treatments that can be applied later are limited in their compatibility with certain metals. And, of course, some steels cost more or less than others.

For example, smaller diameter screws can be made out of a high-grade tool steel and heat treated and ion nitrided to improve wear resistance even further. The initial material cost is 20 times greater than a conventional AISI 4140 or AISI 4340, and manufacturing costs are higher too, but a tool steel screw will last about 50% longer. In a screw that is 2-1/2 inches in diameter or smaller, the material cost is relatively small, compared to the other costs involved.

Conversely, screws that are made out of less expensive materials can usually be rebuilt at a fraction of the cost of a new screw. So, while the original screw may not last as long, it normally can accept two to three rebuilds before going on the scrap heap. Tool steel screws normally cannot be reconditioned. But remember that you also have to take into account the machine down time while the screw is being pulled and remanufactured.

SCREW SURFACE TREATMENT

Table II lists some common steel surface treatments that can be used to improve wear resistance. The most common technique is flame treatment or flame hardening and it probably represents the minimum that can be done to improve wear resistance. Normally applied to AISI 4140 or 4340 steels, it really offers very little wear protection and no additional corrosion protection. Flame treated screws are the least expensive. Induction hardening is a similar technique that can be applied to smaller screws.

A more effective hardening technique, nitriding involves placing the screw in a vacuum vessel containing ammonia gas. At temperatures between 750F to 1100F, depending on the manufacturer, the surface of the steel reacts with the gas to form hard nitrides. The hardness and depth of case depends on the grade of material and the time it is exposed to nitriding conditions, but typical case hardening depths are between 0.010 to 0.030 inch. The advantages of nitriding are

Table I. Typical Screw Materials

Material	Hardness as Machined (Rc)	As-Treated Hardness (Rc)	Can be Rebuilt	Corrosion Resistance	Wear Resistance	Price per Pound ($)
4140	28-32	50-55	Yes	Poor	Poor	.70
4340	28-32	48-50	Yes	Poor	Poor	1.50
Nitralloy-135-M	30-35	58-62	Yes	Poor	Good	1.75
17-4 PH Stainless	30-35	50-55	Yes	Good	Poor	3.00
CPM-9V*	23-25	52-55	No	Fair	Good	15.00
CPM-T440V* Stainless	23-25	56-58	No	Good	Good	15.00
D-2	96 Rb	58-62	No	Fair	Good	4.50
H-13	96 Rb	55-60	No	Poor	Good	4.00
Duranickel	30-38	38	Yes	Good	Poor	25.00
Hastelloy C-276**	86 Rb	38	Yes	Good	Poor	25.00

*Product of Crucible Materials Corp.

**Product of Haynes International.

Table II. Wear Resistant Surface Treatments			
Treatment	Hardness (Rc)	Treatment Depth (in.)	Application Notes
Flame Treatment	50 - 55	Up to 0.020	Used to improve hardness in localized areas like flights. Treatment depth depends on base material. Mainly for use with non-abrasive materials or to cut costs.
Induction Hardening	50 - 55	Up to 0.020	Uses electric heat to achieve same effect as flame. Normally used for small screws or to treat limited areas.
Ion Nitriding	60 - 64	0.005 – 0.025	Provides significant improvement in wear resistance vs. flame. Some corrosion resistance. Best applied to nitriding steels like Nitralloy-135-M. Protects entire screw surface.

improved surface hardness of the root and sides of the flights, which provides good protection against abrasive wear. Some improvement against corrosion is achieved but this is normally not the primary objective with nitriding.

WELDED-ON MATERIALS

For maximum resistance to all forms of wear, particularly on the flight OD, the materials listed in Table III can be welded onto wear-prone surfaces. There are several suppliers of hardfacing material and each offers similar grades. The main differences will be seen in the size, shape and amount of the carbide particles in the matrix. Other differences may include the way they are applied. Some materials are more intended for Plasma Transfer Arc (PTA) welding while others require an oxygen acetylene torch.

In hardfacing materials, manufacturing ease and hardness are directly related. The harder the welded material the more time it will take to finish. For instance, cobalt-based alloys, like those made by Stellite, are somewhat easier to machine than the nickel-based alloys like Colmonoy, products of Wall Colmonoy Corp. But the trade-off is that softer materials offer less resistance to wear and have a greater tendency to gall when run in combination with hard bimetallic barrels

Nickel based alloys, particularly products like Colmonoy #56 and #86, are favored for abrasive wear resistance and are compatible with a greater number of barrel liner materials. If corrosion resistance is required, Stellite #12 or a comparable alloy may be the best choice. In any line of hardfacing alloys, there will be a range of grades containing greater or lesser amounts of tungsten carbide for increased wear resistance. As always, it is a good idea to consult with a good screw manufacturer, since they will be able to recommend a material that has the right performance characteristics and with which they are most comfortable working.

SCREW COATING MATERIALS

Table IV lists several processes and/or materials used to provide a protective coating to the surface of the screw. Generally, coatings are not designed to protect the flight OD against wear because they can't stand up to the high stresses between the screw flight and barrel.

Table III. Welded-On Hardfacing Materials			
Material	Finished Hardness (Rc)	Base Matrix	Comments
Stellite* #6	43-45	Cobalt	Corrosion resistance. Fair wear resistance but tends to gall. Not used very much.
Stellite #12	43-48	Cobalt	8% Tungsten Carbide. Good corrosion and wear resistance. Very popular material.
Colmonoy** #5	45-50	Nickel	Good wear resistance
Colmonoy #56	50-55	Nickel	Industry standard for wear resistance. More brittle than cobalt material.
Colmonoy #86	50-53	Nickel	Less crack sensitive than #56.
Colmonoy #88	55-58	Nickel	17% Tungsten Carbide
Colmomoy #83	59-64	Nickel	34% Tungsten Carbide. High hardness. Most wear resistant. Costs 1.5 times #56

*Stellite is a trademark of Stellite Inc. These products listed are typical of most cobalt-based hardfacing materials.
**Colmonoy is a trademark of Wall Colmonoy Corp. These products listed are typical of most nickel-based hardfacing materials.

Rather, their purpose is to protect the sides of the flights and the root of the screw, and to reduce the tendency for the melt to stick to the screw. Therefore, they are frequently used in combination with various other treatments and welded hardfacing.

Coating materials tend to be quite hard and, consequently, quite brittle. With some exceptions, these coatings tend to have a relatively weak bond to the base screw material, which makes them prone to cracking and delamination. A notable exception is the tungsten carbide coating marketed by Union Carbide Corp. Applied under explosive conditions using a special deposition gun, the tungsten carbide coating is literally blasted into the base material, creating a strong, metallurgical bond.

Generally, the quality and performance of a screw coating or plating material will depend on base screw material. Chrome, in particular, picks up any flaws or imperfections in the base material. And, because it is quite brittle, it should be applied to a relatively hard screw material or else the ductility of the base metal can cause the chrome to crack and flake off. A proprietary version of standard chrome plating, Armoloy is somewhat harder and less porous than industrial chrome, which offers more corrosion resistance

Chrome usually achieves a better bond than does electroless nickel plating. The nickel coating, however, provides better corrosion resistance. Poly-Ond is a proprietary electroless nickel coating, which incorporates PTFE for better lubricity and material release.

The PVD (Physical Vapor Deposition) process is used to apply some of the hardest surface coatings available. Diamond Black, a product of Diamond Black Technologies, Inc., is an extremely hard (93 to 95 Rc) ceramic layer that is applied to the surface of the screw. Depending on the specific grade selected, it can be both highly abrasion and corrosion resistant. Diamond Black coatings are applied at relatively low temperatures (about 250F), which minimizes the potential

Table IV. Screw Coating Materials			
Treatment	Hardness (Rc)	Thickness	Application
Chrome Plating	68-70	.00075 - .0015	Minimum resistance to wear, Aids in material release, Corrosion resistance
Armoloy[1]	72	.0001 - .0002	Improved corrosion resistance, Minimum resistance to wear.
Electroless Nickel	60	.0005-.001	Improved wear resistance. Reduces friction. Corrosion resistance.
Poly-Ond[2]	50 - 68	0.00002	After coating, screw is baked for increased hardness. PTFE wears away over time.
Titanium Nitride	85	.000001-.000004	Improved wear resistance. Reduces friction.
Diamond Black[3]	93-95	.00008	Boron carbide ceramic coating goes on very thin; offers good corrosion and abrasion protection.
Tungsten Carbide D-gun[4]	90 Rc	.001 - .002	High resistance to wear. Minimum resistance to corrosion

[1]Supplied by Armoloy Corp.
[2]Product of Poly-Plating, Inc.
[3]Supplied by Diamond Black Technologies, Inc
[4]Product of Union Carbide Corp.

for the dimensional distortion that can occur with other types of coatings. Another PVD process, Titanium Nitride (TiN), develops a very hard, thin layer of titanium nitrides to resist abrasion.

Both PVD coatings are limited by the fact that treatment takes place in a sealed vacuum chamber. Although attempts are being made to extend their application to larger feed-screws, these coating are currently only available for small (up to 30 in. long) components.

WHAT DOES THE FUTURE HOLD?

Just pick up any trade magazine and it is evident that the plastic industry is very dynamic. Resin companies are continually producing new materials with greater amounts of filler additives for improved performance and strength. This has forced steel suppliers and screw manufacturers to look at new materials and processes that will stand up to the increased demand. What once was considered “space age” technology is now common practice in the metalworking industry.

These new advances in metallurgy and coating technology give the processor more options than ever to reduce the risk of wear. In many situations, though, wear is caused by a combination of mechanisms that, together, act to reduce the performance of the machine. By correctly identifying the type of wear, and consulting a knowledgeable screw manufacturer, you can select the right metallurgical combination that will reduce wear and increase machine up-time.

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