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Pellet mill die and roll design

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This chapter will discuss design details specific to the pellet mill die and the rolls. In **Figure 4-1**, we see a typical pellet mill die. The particular die shown is a clamp-on type and shows a keyway cut into the backside of the die. This type of die is driven by a die-driving key mounted into the front face of the quill flange, or die-driving rim, and is held in place with a die clamp. This type of die has a reinforcing flange built into the front face of the die in order to give it strength, reduce deflection and prevent breakage.

Figure 4-1. Typical pellet mill die.

Photo courtesy of engormix.com

Another type of pellet mill die available is the bolt-on die, which uses bolts to hold it in position and drive it instead of using a clamp and a die-driving key. The bolt-on die is usually symmetrical in design and, unlike the clamp-on style, uses a removable stiffener ring mounted to the front of the die with bolts to hold it in place and give the die strength.

Die metallurgy

The basic physical properties of pellet mill die materials are controlled by the composition of the steel used and the heat-treating process. The two key elements in dies are carbon and chromium, where the carbon content in the steel determines the hardness of the material, and the chromium content of the steel affects the corrosion resistance and the wear resistance of the die.

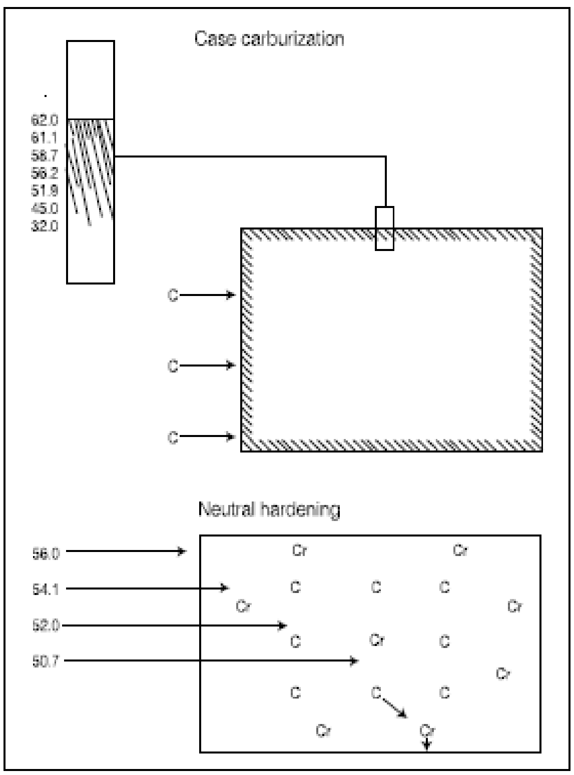
Usually, a free chromium content above 12% classifies a steel as stainless. Chromium carbides are formed during the heat-treating process through a combination of chromium and carbon atoms, increasing wear resistance. There is no such thing as a rust-free "stainless steel," as all dies oxidize when exposed to heat, moisture and acidity.

Dies are typically heat treated in two different ways—carburizing the die or neutral hardening the die. Case carburizing of dies can be done in a pit furnace or in a vacuum furnace by the addition of a carbon-rich gas such as propane. Alloy steel dies are processed in a pit furnace, whereas some types of stainless steel dies are vacuum carburized. When carbon is added into the atmosphere of either of these furnaces, it soaks into the steel to form a hard case.

Case carburized dies tend to create more friction in the pelleting chamber, usually resulting in better pellet quality due to the increased resistance of the die hole surface. Alloy dies are a medium-grade carbon steel which is case carburized for a hard outer case of 57 HRC and a soft core. Stainless steel dies are carburized in a vacuum for a hard outer case of 61 HRC and a soft core.

Neutral hardening is a process that gives the same relative hardness throughout the thickness of the die. The dies used in this process are stainless steel or those dies having a high chromium content. Due to the homogeneous hardness throughout these types of dies, they usually offer excellent die life. These types of dies also have a smoother hole surface, resulting in easier start-up. Neutral hardened stainless steel dies have a hardness of 52 HRC throughout the thickness of the die. **Figure 4-2** shows a comparison between the case carburized and the neutral hardened dies.

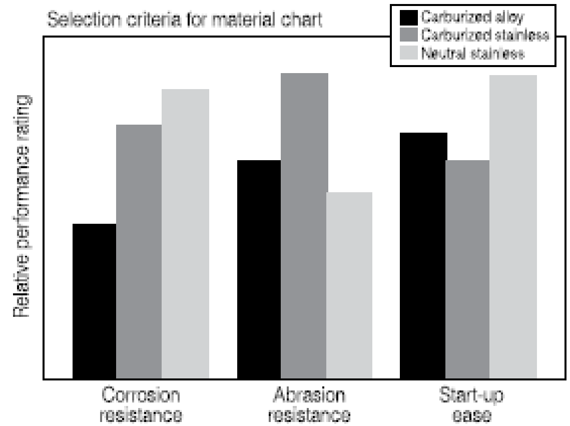
Figure 4-2. Comparison between case carburized and neutral hardened dies.



Die material application

The different die materials have characteristics that make one more desirable than another for different reasons. **Figure 4-3** compares the performance of each different die material.

Figure 4-3. Selection criteria for material chart.



Case carburized alloy dies are usually the most breakage resistant and best suited for heavy tramp metal situations. They are used in heavily-abrasive situations, such as high mineral feeds, where die life with other materials is much shorter, keeping cost-per-tonne ratios to a minimum. They are the lowest-priced dies available when compared to the stainless steel dies. Alloy is most commonly used for the large-hole or "cube" dies. They should not be used in corrosive applications.

Case carburized stainless dies can be used in mildly-corrosive applications. They are generally used where pellet quality is of prime concern; as hole and face wear occur at a much slower rate than with neutral hardened stainless dies. They work well with moderate to highly-abrasive materials, and have an extremely hard case with a soft core in order to give maximum wear life and good breakage resistance. The best wear and throughput occur with close-hole patterns and small holes. Even though it is a type of stainless steel, it is still susceptible to some corrosion. This type of die usually provides the best pellet quality over a longer period of time than the other dies mentioned.

Neutral hardened stainless dies provide high throughput and die life, but usually at the expense of pellet quality over the life of the die. They should always be used in high corrosive applications. They need to have increased effective thickness than the carburized dies in order to achieve similar pellet quality, as the hole surface in these dies does not have the frictional resistance that

the carburized dies do.
Usually the effective thickness is 6.35-12.7 mm more on these types of dies than with the carburized dies. They will perform well in some abrasive applications where pellet quality is not an issue. They are easy to start up and reach full production quickly. Because this type of die is through hardened and not case hardened, the die holes are more susceptible to wear and enlargement than the other dies mentioned; therefore, they should not be used where pellet quality is a priority and need to be maintained as long as possible.

Abrasion resistance is the ability of a material to resist frictional wear that occurs on a die face and within the holes. It usually increases in direct proportion to the hardness of the steel from which the die is made; however, as dies are hardened, reductions in structural strength and toughness may occur.

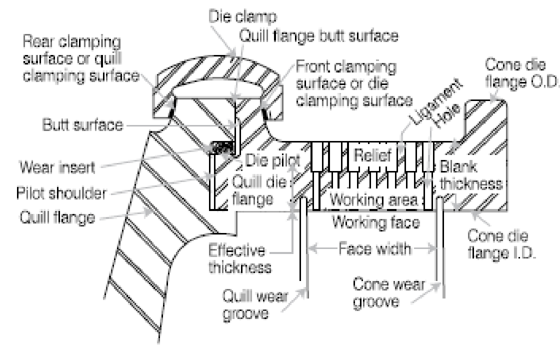
Corrosion resistance is the characteristic of the die material to resist chemical or atmospheric oxidation. Corrosion may appear as rust on the surface of a die or as pitting inside the holes. The hot, moist environment during pelleting creates an extremely active setting for corrosion to occur, especially with the intense pressure caused by the extrusion process. Stainless steel dies with a high chromium content should be used for these applications.

Breakage resistance is necessary in order to resist the tremendous stresses caused by the pelleting process. Start-up ease is important in order to help the pellet mill reach full capacity as soon as possible. Each of the different die materials requires special processing to allow it to achieve its pelleting goal. As a result, each die material has a varying rate at which it will start pelleting, with the neutral hardened stainless dies being the easiest to start up. The carburized dies take longer due to their harder, rougher surfaces taking longer to wear or polish to the point where they can achieve full capacity.

Die design features

The physical characteristics of a die determine its performance by specifying the correct blank or overall thickness, hole size, type and depth of relief. This determines the effective thickness, hole pattern and, of course, the material used. **Figure 4-4** shows a cross-section view through a typical clamp-on die.

Figure 4-4. Die cross-section view.



Die cross section view

The blank thickness determines the overall strength of the die. The thicker the die, the more it resists deflection caused by the pelleting process at the nip point between the die and the rolls. The effective thickness is the length of the pellet chamber where the pellets are being formed. It is determined by the blank thickness minus the depth of the relief. The effective thickness determines the amount of work the die will perform on a material, thereby affecting pellet quality. It also affects the amount of stress on a die caused by the extrusion process taking place in the die.

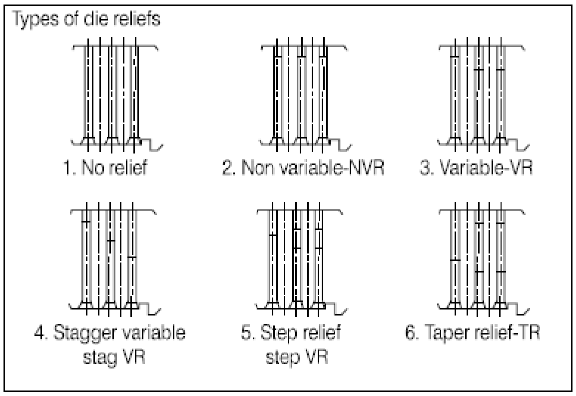
The effective thickness should be changed if the die material is changed for some reason, in order to maintain good pellet quality and production capacity. The effective thickness (the length of the hole; "L") is often compared to the hole diameter ("d") to determine the correct L/d ratio for each different application.

Die hole reliefs

Reliefs are added to the die holes to allow stronger, thicker die blanks to be used. Some of the different types of reliefs are shown in **Figure 4-5**. As shown, there are different types of reliefs that can be used, depending on the application.

No relief (NR) dies are used in applications where the blank thickness and the effective thickness are the same in order to achieve the pellet quality required. They are also used for applications such as shrimp feeds, where the length of the pellet is important and must be maintained.

Figure 4-5. Types of die relief.



Non-variable relief (NVR) dies are used where the same effective thickness must be maintained across the full width of the die working surface, so the relief is the same depth in all the holes. Variable relief (VR) dies are the normal or standard type of relief used in most dies today. The outer rows of holes are relieved deeper than the middle rows of the die, reducing the resistance in the outer rows of holes, allowing the die to pellet continuously across the full working face and prevent the outer rows of holes from plugging and reducing capacity. This type of relief also encourages the die to wear evenly across the full working face and prevent the entrance of the holes in the outer rows from being rolled over, leading to reduced capacity.

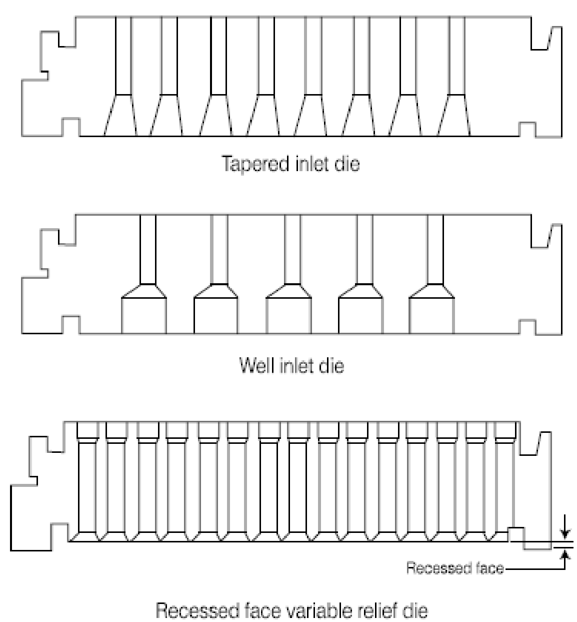
Staggered variable relief (Stag VR) dies are a variation of the standard variable relief die mentioned above. Instead of the variable relief being all the same depth in the outer rows, some of the rows of holes are drilled deeper than others to reduce the resistance even more than in the variable relief die. This type of relief is used where the outer rows of holes in a standard variable relief die stop working and cause rollover and reduced capacity. Step relief (Step VR) dies have different size holes in the relief, allowing the pelleted material to expand in the relief without dragging on the side of the relief. This type of relief is used with materials that will expand during the pelleting process as they leave the compression chamber—i.e., materials that have a lot of heat and moisture applied to them, such as high grain rations. They are also sometimes used in dies having very deep reliefs.

Taper relief (TR) dies are a variation of the step relief die, which allows the pelleted material to expand in the relief without dragging on the side of the relief. The TR is used with materials that are high in fiber and want to expand and resume some of their original identity after leaving the compression chamber. They are used for hard-running or difficult-to-pellet materials where a thick die is needed for strength, but only a short effective length is needed to create the pellet.

Die hole inlets

In addition to reliefs being added to the hole outlets, or at the outside diameter of the die, the inlet of the hole can also be tapered or have an enlarged diameter hole prior to entry into the die hole itself (see **Figure 4-6**). These tapered inlets, or well inlets, are used to act as a pre-compression chamber. They are used in order to control the overall thickness of the die blank, allowing for practical machining methods to be used and also to keep the die cost down.

Figure 4-6. Recessed face variable relief die.



Die blanks are normally limited to a maximum of 12 cm overall thickness, so if the user is producing 19.05 mm or 25.4 mm diameter pellets, sometimes referred to as "cubes," it is not possible to achieve the correct L/d ratio to produce a good quality pellet or cube. This is why a pre-compression chamber is necessary for these particular applications. These types of dies are used to produce good-quality cattle or sow cubes, and for use with high-fiber, light bulk density materials.

Recessed face dies (as shown in **Figure 4-6**) are used in easy-running applications with high grain rations such as broiler and pig feeds—which are usually conditioned extremely well and contain a lot of heat and moisture. This type of feed material wants to take the path of least resistance and will, therefore, squeeze out from between the die and rolls at the outside edges. The recessed face helps capture and hold the material onto the die face due to the wall at the outside edges, preventing the material from escaping, thus making sure that the whole die face working width is being used effectively.

The die specifications remain identical to the standard die, so pellet quality is the same in both cases. By recessing the die face; however, the inside diameter of the die is increased along with the total working face area of the die. Sometimes the hole count is increased also, helping to improve the overall performance of the die in most cases where it is used.

Die hole patterns

There are three basic types of hole patterns used in a die: standard hole pattern, heavy-duty hole pattern and close-hole pattern.

Standard hole pattern dies have a nominal hole count that is suitable for general line feed applications where many different formulas are pelleted on the same machine through the same die. This allows for the best average performance to be maintained where possible, but the production capacity and pellet quality are compromised with some of the formulas. Overall die life, measured in total tonnes, is also adversely affected, resulting in only average cost per tonne of feed produced.

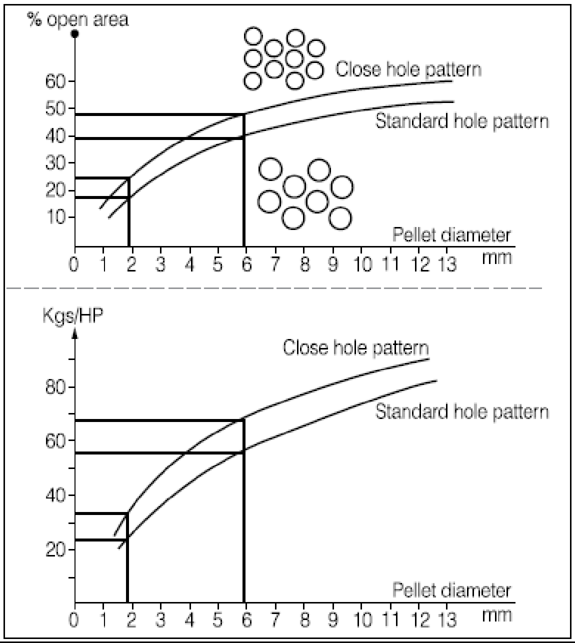
Heavy-duty hole pattern dies have fewer than normal number of holes in the die in order to increase the ligament thickness between the holes, making the die stronger. They are obviously used in all heavy-duty applications where hard-to-pellet materials are being processed, in order to prevent and eliminate early die failure. Due to the reduced hole count, production capacity is greatly reduced when using these types of dies, and die life is lower than normal and the cost per tonne of feed produced is well above average.

Close-hole pattern dies have an increased hole count over that of the standard hole pattern die—sometimes by as much as 25% or more. This means that the total "open area" in close-hole pattern dies is increased by the same amount. The "total open area" of a die is the total number of holes in a die multiplied by the cross-section area of one hole diameter. The benefits of using close-hole pattern dies are: Increased production capacity; increased pellet quality; better die face wear; easier start-up; increased die life; more efficient use of energy; and a much lower-than-average cost per tonne.

Due to the increased hole count, the ligament thickness between the holes is obviously less than with the standard hole pattern die, so it may be necessary to increase the overall blank thickness in order to make the die strong enough to prevent early die failure. This will necessitate the relief in each hole being machined deeper in order to maintain the correct effective thickness of the die and the correct L/d ratio for the material being processed.

Close-hole pattern dies should be used wherever possible due to the obvious benefits of using this type of die. **Figure 4-7** shows a comparison between a close-hole pattern die and a standard hole pattern die.

Figure 4-7. A comparison of the close-hole pattern die versus the standard hole pattern die.

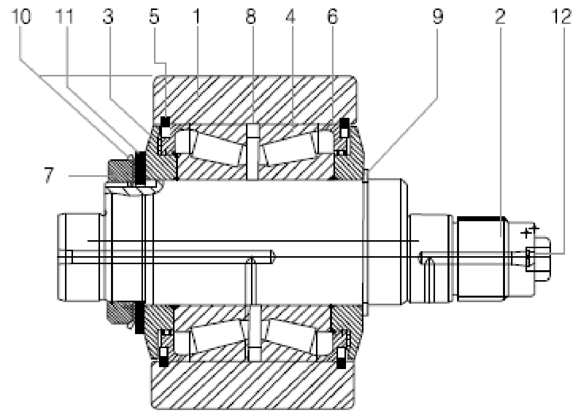


Item	Description	Qty.
1	Roller shell	1
2	Roller shaft	1
3	Roller shaft collar	2
4	Taper roller bearing	2
5	Retaining ring	2
6	Inner collar	2
7	Bearing locknut	1
8	Bearing spacer	1
9	Retaining ring	1
10	Bearing lockwasher	1
11	Keyed washer	1
12	Lube fitting	1

Pellet mill rolls

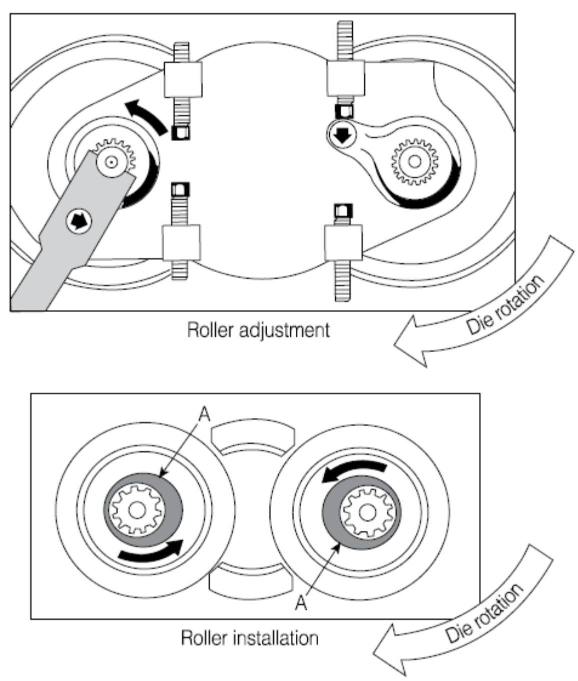
Figure 4-8 shows a sectional view of a typical pellet mill roller assembly. The shell is mounted on two opposed heavy-duty tapered roller bearings and held in place on the shaft with an arrangement of collars and locknuts. The seals are the metal labyrinth type, which retain the grease inside the roller assembly, but there is enough clearance between the seals and the shaft to allow some grease to escape if over-greasing occurs. This is because the roller assemblies are greased from the rear of the pellet mill while it is in operation. The roller shaft has an eccentric built into its design, which allows the rolls to be adjusted and maintain the correct clearance between the die and the rolls.

Figure 4-8. Pellet mill roller assembly.



In **Figure 4-9** you can see the correct method of installing and adjusting the rolls. The eccentric shafts "A" are rotated to move the rolls toward or away from the die surface in order to maintain the correct running clearance between the die face and the rolls. As shown, the rolls should always be adjusted in the opposite direction to the die rotation in order to prevent any possible damage to the die face, such as roll-over of the holes.

Figure 4-9. Correct method of installing and adjusting rolls.



The rolls should be adjusted to allow a minimum clearance of approximately 0.051 cm between the rolls and the die face at all times. There should never be any metal-to-metal contact between the die and rolls, other than a skip-touch when a new die is installed. A skip-touch is due to the eccentricity of the die face caused by the heat-treatment process. This is probably the most critical adjustment made to the pellet mill to allow for correct operation and maximum performance and avoid damaging the die and rolls.

Roller shells

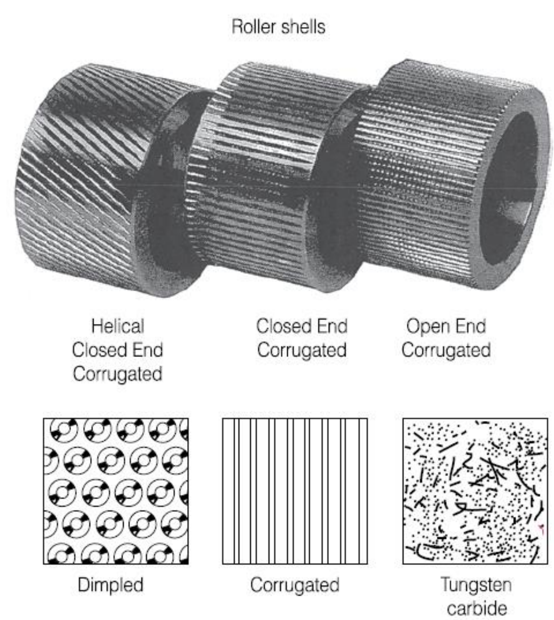
Roller shells are typically manufactured from a Timken-grade bearing steel that is heat-treated and through hardened to a Rockwell hardness of 60 to 62 Rc. Roller shells come in many different configurations (see **Figure 4-10**), and the correct design must be chosen to suit a particular application if maximum performance is to be expected. Each geometric design is engineered to provide maximum production of feed through a die, while ensuring reliable traction on the die face. Several geometric variations are available to suit the requirements of each different application.

Open-end corrugated shells feature narrow corrugations which run horizontally across the roller shell face. They have more corrugations than any other shell, making it ideal for some applications that suffer from chronic roll slip, but they are generally used with high-fiber materials such as dairy and cattle feeds. Closed-end corrugated shells have a gently sloping corrugation shape that is closed off at the shell edges to promote effective use of the outside rows of holes in the die. The closed ends keep the feed material trapped on the die face to prevent well-conditioned materials that contain a lot of moisture from escaping at the outside edges. By retarding the natural tendency of some feed formulations to work towards the grooves on each side of the die working face, the closed-end roller shell assists in promoting more even die face wear.

These shells are available in different corrugated widths and depths to suit different applications. This type of roller shell is generally used for well-conditioned, high grain rations such as poultry and pig formulas as they provide excellent traction. However, they are probably the most commonly-used shell today, and are used in a multiple of different applications due to their excellent all-around performance.

Helical closed-end corrugated shells feature two helices which can be used either as a pair in tandem by using one of either helix to create a natural opposition. The helix design tends to push the feed material across the die face towards the outer edges, so they are especially useful in assisting dies that are experiencing feed distribution problems or uneven wear across the die face. Due to being cut at a helical angle, the corrugations partially pass around the contour of the roller shell face in the form of a curve, which ensures that a multiple of corrugations are in close contact with the die face at the same time, resulting in a smoother operation than with the straight corrugated shells. These shells can be used in similar applications to the straight closed-end corrugated shells.

Figure 4-10. Roller shells in various configurations.



Dimpled shells have a series of specially-designed holes machined into the roller face surface. These shells are available with a shallow or a deep dimple, depending on the application. They have excellent wear characteristics due to the increased surface area of metal as compared to the corrugated shell.

They do not provide as much traction as the corrugated shell. However, they are susceptible to roll slip with certain feed materials. They are generally used for applications such as high mineral cattle feed concentrates or supplements, and are also used for some high-fiber, abrasive-type materials applications.

Tungsten carbide shells are created by using the same steel as the other shells, except that tungsten carbide particles are deposited into a molten bed of welding material that is being simultaneously deposited onto the roller shell surface. The molten material then solidifies and captures the tungsten carbide particles and holds them in place. These shells are used in extremely abrasive applications, where the other types of shells discussed here would wear out too quickly. These shells normally have long life and superior wear-resistance qualities. They are used to pellet materials that contain low-ground crops, which contain sand and dirt, or with high mineral cattle feeds. Extreme care should be taken when adjusting rolls that have this type of shell fitted. If the roll is adjusted too tight against the die face, the tungsten carbide surface of the roller shells will grind the die face and cause damage and rapid wear to occur.

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