The Effect of Dies on Rotary Moulded Products and Productivity

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About the Author

Sam Pallottini has been with Baker Perkins for 22 years in a wide-ranging engineering career that has included positions in design, manufacturing, project management and field service. For the last ten years Sam has been involved in the design and manufacture of dies, initially as a product manager, then moving over to manage the die business as a whole.

During this time Baker Perkins has introduced a number of innovations to the die product range including ceramic coatings and plastic inserts. Sam has also overseen a significant expansion of Baker Perkins’ design and manufacturing facilities with the installation of multi-spindle engraving machines and a new coating facility.

Sam and his colleagues spend a great deal of time with customers using Baker Perkins’ collective experience of die design and engineering to advise on best practice in die construction and materials. Typical projects involve new product development and process trouble-shooting as well as die design and supply.
**Introduction**

In a typical rotary moulder line the die has more impact on the properties of the finished product and, arguably, on the efficiency of the line itself, than any other single piece of equipment. The direct effect that the die has on the appearance of the finished product is obvious but there are more subtle effects too: inaccurate weight control leads to waste, giveaway and packaging problems; poor release results in excessive extraction pressure causing wedging and tailing; incorrect choice of coating materials and finishes means rapid wear and frequent stops for cleaning because of plugging.

All these problems can be avoided by good design and manufacture but there is a lot more to achieving this than meets the eye. This paper examines the various options open to biscuit manufacturers when specifying a new die and considers the impact of each on performance and quality.

**The Rotary Moulding Process**

Dough that can be rotary moulded is pliable and crumbly. It is usually rich in fat and sugar which give it the key characteristics of being easy to form into stable shapes with sufficient lubrication to promote clean extraction. Factors such as differences in flour quality, ingredient temperatures, mixing time and standing time all affect the final dough quality and careful attention to these is required if a rotary moulding line is to perform consistently. Dough is normally mixed in batches that are fed into the moulder by some kind of dough feed system. Typically these break up or “kibble” the dough into small pieces that are metered into the moulder hopper and are able to flow evenly across the die roll. On smaller lines the dough can be hand fed directly into the moulder hopper.

The rotary moulder is made up of three important rolls: the die roll, forcing or feed roll and a rubber-covered extraction roll. The other key components are the knife and extraction belt.
As the dough enters the rotary hopper it falls between the forcing and die rolls. The rolls rotate towards one another pulling the dough into the gap which forms a blanket on the forcing roll and then starts to fill the cavities of the die. The knife is used to shear off the dough leaving the cavity filled. As the die cavity rotates around, it comes into contact with an extraction belt sandwiched between the rubber and die rolls. There is just enough pressure for the product to be extracted from the die cavity onto the belt. The extraction belt takes the newly formed product (i.e. biscuit) away and toward the oven.

A balance must be achieved between these various components to obtain the best results for specific doughs. There are several important variables with each item. Forcing roll speed, gap, as well as design effect how well the cavities are filled while the shape and position of the knife may be varied to suit different types of dough. The pressure between the die and rubber roll is vital in ensuring good extraction but too much pressure results in tailings. Either single or dual durometer rubber rolls can be used to help with this. The belt can be either synthetic or cotton or a combination, such a poly-cotton blend.

**Why the Die Roll / Cavity Design is Important**

How many of these variables are fixed at the design stage and how many are adjustable depends on the speed and flexibility required of the rotary moulder. Standard machines tend to have a single motor driving the forcing and die rolls while the belt is driven by the pressure created between the rubber and die rolls. However, all three rolls can have separate drives with independent speed control. A separately driven rubber roll helps with extraction, particularly at high speeds while driving the forcing roll faster than the die roll, is useful when filling large die cavities. There are also options for the forcing roll gap to be adjustable to accommodate higher dough flow rates.

Although the ability to adjust these variables may make the process more forgiving, they can do little more than fine tune the performance of a rotary product; they cannot compensate for poor die design. The majority of rotary moulders have only a few adjustments, which makes the design of the die all the more critical. Thus it is important that the design of the cavity allows the moulder to operate optimally within its capabilities and cope with the day-to-day variability commonly found in food manufacturing environments.

**Anatomy of a Die Roll**

The die roll itself is made up of three key items: end hubs, shaft and a bronze tube. End hubs can be manufactured from either a casting or mild steel. The hubs are press-fitted into the ends of the bronze tubing and utilized to hold the shaft. The shaft is normally manufactured from mild steel and can be fitted with setscrews, lock nuts or ringfeders.

![Die Roll Anatomy Diagram]
The bronze tubing is the key to a successful die. The tubing must be concentric to achieve the desired run-out while the correct thickness is required to keep the die from flexing in the center to avoid weight variations or excessive tailing. A harder bronze material will extend the life of the die and ensure that any coating adheres properly to the roll while the wrong choice of bronze can cause black streaks in light colored dough.

The shaft has to be easy to remove for coating and repair and, if hopper seating grooves are required they have to be correctly positioned and accurately machined to minimize dough leakage. Another item to consider is the size of the roll which is determined by the design of the rotary moulder. Most utilize a standard 10” diameter die whereas machines intended to process tough dough including low fat, no fat and petfood products, or run at high production speeds, require a larger diameter die.

Another note to consider is the number of times a die roll can be re-engraved or repaired. Thick-walled bronze tubing can be re-engraved three times before the die is recycled, depending on the wear and damage. One area that is attracting more attention is the use of water-cored dies and forcing rolls. These are used to help control dough temperature and improve extraction.

All the items discussed above are helpful but, in short, it is critical that the die has a smooth finish, meets stringent tolerances for engraving and runs concentrically. These last two features will dictate the weight control of the cavities across and around the die. If the roll does not run true, the weight consistency of dough pieces will be adversely affected. Furthermore an unbalanced die will result in undue wear on the rubber roll, bearings and knife.

**Die Design for a Green Environment**

A well designed die roll will have the complete life cycle in mind. Bronze is the most significant cost driver in manufacturing die rolls. Recyclers will pay well for these bronze tubes so it is advantageous to design the roll so that it can easily be taken apart while retaining its strength and integrity. In order to get a maximum return, the bronze has to be pure with no foreign materials such as plastic inserts or mild steel components. A good supplier will relieve the customer of this task by taking rolls back and offering discounts on their new die order.

**Cavity Design**

The process for designing a cavity starts with a customer’s idea or concept. This is given to a design engineer who creates an engineering model with the required visual appearance and physical specifications such as size and weight. A model is then rendered as a drawing; 2-D if the shape is very simple and straightforward or 3-D if the shape is more complex.
The customer reviews the drawing to decide if it matches their concept. The next recommended step is a small flat master or a hand mould. The drawing is programmed into machine code which is used to engrave the cavity into a small, clear plastic, flat plate or a flat, bronze plate. A hand sample enables the customer to visually assess the engraved cavity and run some product samples to determine how the product bakes out.

If everything looks good, the next step is a small test sleeve that can either be run on a small lab rotary machine or on a test roll in a production environment. The test sleeve shows how the dough and cavity react in a dynamic environment. This step may highlight problems such as checking, blistering, plugging, breakage, inaccurate product weights, and uneven bake out to just name but a few.

If the cavity survives the process, the next step is to purchase the production roll. If not, the cavity concept can go back to any of the previous steps and start over. The production step is not the final step: we always recommend running the product for an extended period of time to ensure no packaging or process problems that were not flushed out during the test stage have been raised. It is a good practice to purchase a back-up roll to ensure that production continues in the event of damage, recoating or wear.

The above outlines the basic steps required to move a cavity from concept to production. Along the way there are several engineering factors to be taken into account:

1) Release angles are important for extracting the product from the cavity. For thinner products, such as sandwich biscuits with a lot of detail, a shallow angle helps release the dough from the cavity. Bigger products such as dog biscuits will require a steeper angle to retain the biscuit in the cavity.

2) Docker pins are normally used to help dry or bake the product as well as minimize the problems with checking, gas pockets, and blistering. A docker pin also helps hold the product in the cavity. The customer will need to decide if a through hole or a partial hole is acceptable in the product. In almost all cases baking on a solid band will require some type of docker, whereas baking thin products on a mesh may not.

3) As mentioned earlier, the design could be created as a 2-D or 3-D concept. 2-D is really about flat surfaces whereas a 3-D cavity has rounded or curved surfaces. There is a substantial price difference between 2-D and 3-D as the latter requires a manufacturing process called contouring. Contouring shapes the product by enabling the engraving machine to work several different axes at the same time. The programming, engineering and engraving processes takes longer to implement for a 3-D cavity. There are several techniques that have been created utilizing 2-D shapes to give a more pronounced look or 3-D appeal. One is using undercuts around lettering and details. Also, adding several different flat surface layers to the cavity gives depth to the shape and creates a 3-D appearance. This technique is commonly used on animal shapes.
Manufacturing

Manufacturing a die roll for a rotary molded product requires special equipment including multi-axis spindle engravers, mills, lathes, comparators and tool sharpeners. The initial process for manufacturing a die roll starts with the construction of the blank roll. As noted above, the die roll is made up of four basic elements: bronze tubing, end hubs, shaft and items to attach the shaft such as bearings and gears. The lathe is used to turn the tube and shaft as well as finish machining the assembled roll. The mill is used to machine the keyways in the shaft and hubs.

A die should be turned on centers (machined tapers at end of shafts) to ensure the run-out for the bearing journals and surface of the bronze tube meet stringent tolerances. Any run-out will lead to variations in the depth of the cavities during the engraving process and adversely affect weight control.

Another critical item to ensure consistent weights for the products is the tooling the engravers use. Normally “D” cutters are utilized in the spindles. Tool sharpeners and a comparator are used to check that all tooling is within a very tight tolerance. A tool outside specification will produce cavities that are either too small or too large. Tool sharpeners are used to shape the tool to the proper angle, shape, cutting edge and relief. Comparators are used to magnify the tooling to verify it meets specification. In short, special purpose equipment and skills are required as well as stringent attention to detail in order to produce accurate, high-quality cavities on the production roll.

Coating

Another key item a die manufacturer should possess is an oven for applying non-stick, food-grade coatings to their die rolls. Coatings have been utilized for years to assist in the product release from the cavity and are usually one of two types: PTFE or ceramic. The main trade names for PTFE coatings are Teflon or Xylan and both offer good release but limited wear resistance. Ceramic coatings are harder and normally require a primer. A simple rule of thumb is that the harder the coating the lower the release characteristics.

To prepare the roll for coating or recoating the shaft is removed and the tube baked at 800 degrees then blasted to remove all the surface contaminants. This step also roughs up the surface of the bronze to make sure the coating will adhere properly. The coating is applied via a spray gun after which the tube goes into the oven for curing.

After the roll is coated, the shaft is reinstalled in the tube and the run-out checked to ensure that it remains in tolerance. As mentioned earlier, a tight run-out is important to avoid undue stress and wear on the rubber roll and knife to avoid extraction problems. Once assembled, the coating is polished off the outer surface of the roll, leaving the coating only in the cavities.
Choosing the proper coating is through a process of trial and error as well as experience. There are many variables that affect the release of the product including: dough temperature, flour, formula, etc. Unfortunately there are no hard and fast rules. Two apparently similar doughs respond differently to a particular coating so there is no better way to find the ideal coating than through experimentation. Normally, once a customer has found a coating that meets their expectations they stay with it.

When is it time to recoat? The simple answer is when the dough does not easily come out of the die anymore. Some customers will time the coating. When they reach a specific number of run-time hours, they will send the die out for a recoat. Others will wait until they have exhausted all other process variables such as increasing the rubber roll pressure or adding water to the dough. A water-cored die and forcing roll allow the temperature of the dough to be manipulated to extend the coating interval. A general rule is that a warmer roll works better for butter-based products whereas cooler temperatures work better for lard-based products.

As indicated above, it is highly desirable for a customer to choose a supplier with an in-house process to apply the coatings to their rolls. The supplier can make sure the roll is taken apart correctly, coating is applied properly and the roll reassembled to the correct run-out requirements.

**Plastic Inserts**

Plastic inserts were first used in Europe on low-speed equipment but as their durability has improved they have become a popular option in the North American market. A plastic insert die is made by machining or engraving a pocket in the bronze before pressing, injecting or mating the plastic into it. The plastic is then engraved in the normal way to ensure the depths of the cavities are all within tolerance, which is the main variable for controlling the weights across and around the die. Beware of suppliers who press in a finished plastic cavity. There are many variables involved which make it very difficult, if not impossible, for the supplier to hold the expected depths.

The right time to use plastic inserts is when it saves your company money. The answer sounds simple but it is not. The objective of plastic inserts is to eliminate the need for coating and, crucially, recoating. For dies that have to be recoated several times over their life cycle, a plastic insert die might be the answer. The problem that has arisen is the length of time the plastic lasts before it needs to be replaced or re-engraved. Several suppliers offer plastic inserts that are manufactured from Delrin or Acetal. These plastics can be too soft and, in some cases, will only last a short period, or effectively as long as a typical coating would last.
Some suppliers offer different types of plastic to help increase the wear resistance of the insert. These are highly engineered plastics that add significantly to the cost of the die roll. These plastics may be hard enough in some circumstances to last long enough to justify the extra expense. The other problem noted with plastic inserts is when docker pins are needed to help control blistering. Plastic docker pins are not as strong as bronze and, if they break off, they will not be caught by the metal detector.

In short, plastic inserts are an option to consider when purchasing a new die. The plastic inserts will eliminate the need for coating but may not be hard-wearing enough to provide a cost saving or a payback to justify. Harder plastics may be an option but their release properties may not be good enough to provide a realistic alternative to coatings. Customers need to be aware of how the plastic inserted die is manufactured to ensure they obtain the required weight control. Also, the plastic inserts may not have a long enough life to provide a payback compared with coated rolls, even once the cost of recoating is taken into account. An experienced die supplier can help you navigate through the decisions required on a plastic insert die roll to ensure you are actually reducing your overall production cost.

One final note, almost all plastic can and will swell due to moisture in the product. If the sides of the cavity are plastic, the top of the inserts may be shaved off by the knife. Once the roll is taken out of production and allowed to dry out, the plastic will be below the roll surface, causing tails. A good supplier ensures that the plastic is recessed from the top of the cavity so the shaving does not occur.

**Trouble Shooting**

Clearly, the die is a critical item in the process of manufacturing biscuits. Although both the formula and machine are major players in the process, the die controls the shape, weight, detail and overall appearance of the final product. Following are several items most biscuit manufacturers deal with when running products on a rotary moulder:

**Tailing**

Tailing is simply a streak of dough that follows the biscuit on the extraction belt. This is normally caused by the product falling out of the cavity and then reforming as the die rotates around on the rubber roll and extraction belt. The product falls out of the cavity because there is not enough friction to hold it in place. It is usually a problem for larger size biscuits where the weight of the biscuit causes it to fall. There are several ways to correct this problem. The first suggestion is to increase the friction in the cavity. This can be accomplished by changing coatings, frosting the coating (i.e. rough up the surface), eliminating the coating, adding docker pins or changing to a steeper release angle. Other non-die changes may include altering the moisture in the dough, adjusting the knife settings or controlling the dough temperature. It can be easier to manipulate the variables with a coated bronze roll than a plastic insert die.

There are other causes of tailing such as over feeding the cavity (i.e. forcing roll running too fast) or running too much pressure on the rubber roll which forces the product out of the cavity. Another way is having too soft a rubber on the extraction roll, which allows it to sink into the cavity, forcing out the dough. Tailing can also indicate a need to recoat the die. Normally operators will increase the pressure of the rubber roll to get the extraction they need. This causes the rubber roll to sink into the cavities and thus the weight of the product decreases and the tailing increases. Tailing is one indication of waste.
Incorrect Weights
The depth of the die’s cavity is key to determining the weight of the biscuit. It is important that all the cavities maintain the same depth to ensure consistent biscuit weights across and around the die roll. When engraving a roll, manufacturers need to keep in mind how much depth they lose because of the thickness of the coating. It is a good practice to be too deep than too shallow on the cavity’s depth as it is easier to manipulate the die roll to lower the weights than increase them by skimming a the roll’s diameter on a lathe. If the biscuits are too light, the only technique would be to over-feed the cavity which can be accomplished by running the forcing roll faster or positioning the knife in a position higher on the roll. A dull knife will also help in over-feeding the dough as a sharp knife provides a better cut and cleaner feed to the cavity. If these machine adjustments do not increase the biscuit weight enough, then the only course of action to rectify is a re-engrave.

It is very important to have a roll with a good run-out because it enables the multi-spindle engraver to machine each cavity to a consistent depth. Repetitive product depths across and around the roll will help provide an even bake which will help surpass quality requirements on the end product and minimize any give away on the packaging line.

Wedging
Wedging is caused when the dough is pushed towards the back of the cavity creating a wedge-like effect in the final product. This is commonly seen on products with soft dough that have large or long cavities. This can be countered by a design known as anti-doming. Anti-doming is a 3-D shaped product where the cavity was designed with an opposite wedge to counter the wedging that occurs in the production setting. It is difficult to design the exact dome to eliminate the wedge. This step takes some trial and error to get it exact.

Both the knife or knife setting and rubber roll can have an impact on wedging. Ideally you would use a sharp knife and a dual durometer rubber roll. Dual durometer means the roll has a very hard rubber outer surface and a very soft inside surface. This design enables the roll to better form to the surface of the die without sinking into the cavity. Dual durometer rolls work well for all products but it becomes very important on larger cavities. Single durometer rolls are quite common but have their limitations. If it is too hard, the roll will not have enough surface area in contact with the dough for proper extraction. If it is too soft, the rubber roll sinks into the cavity and may cause tailing.

Plugging
Plugging is where a coin-edge or florets fill with dough that does not come out during a production run. This leads to incomplete and/or lightweight biscuits. Products that have a lot of detail, such as sandwich base cakes, are particularly susceptible to this problem. To eliminate plugging during a production run customers normally blow out the cavities with air but this is only a temporary solution and the plugging usually becomes progressively worse. Once it reaches a critical point, the die has to be removed from the machine and washed.

Plugging is a difficult problem to solve and seems to be worse on products that contain cocoa. The best solution is for the die to have a very smooth, high-release surface. Plugging seems to be minimal on fresh recoats or new rolls. It also becomes less of a problem for plastic insert cavities that have worn from hours of running because the edges are not as sharp or crisp which gives it a smoother, rounder surface for extraction.

Wash Boarding
Wash boarding is relatively a new problem that is showing up in the plastic insert dies. On coated or uncoated dies the diameter of the roll wears before the cavity because of the action of the knife on its surface. Over time the diameter wears enough that the product becomes too light and the roll has to be re-engraved. Plastic inserts are softer than the bronze roll and can wear out more
quickly and, although the product would stay within specification longer, the detail would become less pronounced. When the wear is so bad it gives the appearance of a wash board.

Once the detail does not meet quality inspection, the die has to be scrapped or re-engraved. Most die suppliers provide only one kind of plastic (Acetal) because of price. In order to combat this problem, it often pays to look at other types that are harder yet have the same release characteristics. The harder plastics extend the life of the die, especially on tough and abrasive dough, although they do cost more.

**Checking or Cracking**
Checking or cracking can occur for either of two reasons: heat and stress. Heat generates steam and other gases which need to find ways of escaping as they can prevent the product from baking properly and lead to cracking as it cools. The best solution is a series of well-placed docker pins in the cavity which create holes in the product and allow the gases to escape.

Stress, on the other hand usually shows up in the product around the embossing lines (e.g. product or company names). The name is usually created by a sharp corner or embossing edge. As the product cools, the embossing can create a stress point that is susceptible to cracking. The solution is to place the embossing edge in an area that does not create any stresses as it goes over rollers or nosebars. It might be as simple as rotating the cavities so the embossing is running perpendicular to the roller.

**Poor Release or Tearing**
Poor release or tearing of the product can be caused by either bad coating or burring. Bad coatings can be removed and redone. Burring is normally caused by the knife being set incorrectly or the bronze material being too soft. Using a finger nail on the leading edge of the cavity it is possible to feel the burr where the knife has shaved the surface of the roll and pushed it into the cavities. This can be corrected by scraping the edge of the cavity (de-burring). It is critical that the die is cleaned and the knife set correctly before going back into production.

**Corrective Actions**
Over time, every die will have to be repaired because of wear or damage. The main repair functions are de-burring, welding, hand grinding, recoating and re-engraving.

The surface of the die may become damaged over time by foreign material running through the machine during operation. In order to repair the die, the open areas are welded or brazed then dressed by hand with a small tool grinder. Cavity side walls can be blended in and made to look like new but if the damage extends to the bottom of the cavity it might be better to re-engrave the roll. Welding on the die does leave a noticeable, but harmless, blemish.

Recoating is simply removing the old coating as well as any contamination via a bake and blast operation as mentioned earlier.

Re-engraving is returning the die to its original state, albeit with a smaller diameter. The first step is to remove the old coating from the cavities by blasting followed by turning on a lathe to clean up the die and get the desired run-out. Afterwards the die is set back on the engraver where it is machined with the original programs. A well kept die can be re-engraved up to three times. A good rule of thumb for rotary dies that have outside grooves is that when the groove is gone, the die is scrap but you can return it for a discount on a new die. Normally the limiting factor is the thickness of the blanket of the forcing roll. If the gap is too big because the diameter is smaller, the blanket will become too heavy and fall off.
Care & Maintenance

Both the rotary moulder and rotary die require proper care and maintenance. The rotary moulder knife should be regularly inspected for any gouges, wear or damage. A damaged knife will damage the die roll and shorten its life. The rubber roll should also be inspected on a regular basis for wear or hard spots that make it difficult to properly extract the product from the cavities and lead to more pressure being required to extract the product and thus more wear and tear on shafts and bearings. The extraction belt is another item that will wear over time. Again more pressure from the rubber roll is added in order to obtain the desired extraction.

Taking the die roll out of the rotary moulder requires the proper lifting mechanism. It is also desirable to have a good cart or storage rack that keeps the die out of harms way. The die should be thoroughly washed. Once cleaned, it should be stored in an area that is at room temperature and covered to keep dust off it. Washing down the die with hot water prior to running it should be avoided as the bronze will expand leading to increased wear. The bearings and shaft of the die should be inspected daily to make sure the bearings have not become frozen. A damaged shaft makes it very difficult for the die to run properly as it will require more force from the rubber roll in order to get extraction across the length of the belt. Finally the gear should be frequently lubricated so it fits and runs smoothly with the drive gear of the rotary moulder.

Summary

A die is the most critical component in the operational success of a rotary moulded product. There are many things in the design, manufacture and operation of the die that can adversely affect performance and it is important that customers take the time to discuss these with potential suppliers. The following is a list of items that should be considered when specifying a die:

1) Chose a die manufacturer who thoroughly understands how the rotary moulder operates. They will have a better grasp of how to design your cavity for optimal efficiency.
2) A rotary moulder with multiple adjustments such as gap, separate drives on forcing, rubber & die rolls, knife locations, etc. are designed to improve performance of the machine but are not a substitute for a properly designed cavity/roll.
3) Understand the total lifecycle cost of the different materials available. The cheapest die may not turn out to be the lowest cost in the long run.
4) Recoating involves re-engineering of the die roll and should be done by a specialist die manufacturer rather than a coating company.
5) A good die supplier can help solve or even avoid problems with tailing, wedging, plugging, black streaks, wash boarding and checking by making adjustments to the design of the die cavity.
6) A well designed die roll has both the beginning and end of its life cycle in mind. Bronze is the number one cost driver for die rolls so building rolls with recycling in mind should be considered up front.
7) A damaged die can be saved by de-burring, welding, hand grinding, recoating and/or re-engraving. A well built die roll can be re-engraved several times before it has to be scrapped.

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