Design and Performance of Pasta Dies

Extrusion dies are used to extrude products in many different shapes and sizes. More than 250 configurations are possible, including dies for snacks, cereal, and animal feed. In a broader sense, extrusion dies can be used for metal and plastic products. This article traces the development of present-day dies and discusses considerations in designing dies for pasta production and some factors affecting die performance.

History of Pasta Dies in the United States

In the early days of the pasta industry in the United States, there was a conspicuous absence of mechanized equipment. Dies were manufactured entirely by primitive hand methods. The first pasta dies in the United States were made of copper because of its physical properties bowed to human strength. Holes were hand-punched through a maximum thickness of 1 inch, and the outside diameter of the die was obtained by chiseling the excess metal and filing. These manual methods required a malleable material soft enough to yield to hand-punching. Hand-punching methods were subsequently replaced by hand-driven drill presses, and two years later power-driven drill presses and lathes were drafted into service.

With mechanization came the need for increased production by past manufacturers. Higher production was achieved by increasing the pressures in extruders. Copper, because of its malleability, was unable to withstand the greater pressures developed by the improved extruders. The problem, then, was to find a material that was not too difficult to machine yet strong enough to withstand the factors associated with the increased production. This problem was solved by the selection of a bronze alloy.

Profit-minded manufacturers, however, demanded a still better material with a higher yield point to prevent bowing under the higher pressures and number 303 stainless was selected. Stainless steel is more wear resistant than is bronze but has the distinct disadvantage of a low coefficient of thermal conductivity. Thus, stainless steel dies with bronze alloy or Teflon inserts were developed. These materials were satisfactory until the production output of extruders was steadily increased to 4,000-8,000 lb per hour. The problem of die bowing was magnified by the fact that the European extruder manufacturers had no support under the die during operation. This problem was solved by the discovery of number 450 stainless steel, with an approximate yield strength of 177,000 psi. The maximum yield strength of aluminum bronze is approximately 40,000-45,000 psi, which is roughly comparable to that of number 303 stainless steel. Initially, all dies were manufactured from solid pieces of material, i.e., the outlets were machined in the solid piece itself. As dies became larger in response to greater production needs, weight and bulk became a decided factor in the development of inserts. Inserts can be described as miniature dies that are fitted into a support (or holder) that can accommodate a number of inserts. Inserts with the required outlet configuration can be manufactured and installed into a drilled support or holder. One advantage of the inserts is that they can be changed at the plant location, therefore eliminating the need for returning the weighty support back to the manufacturer. However, problems may be encountered should the chambers or holes in the support be distorted through die warping. Forcing the insert in the die might close the extruding outlets or distort the insert. If the insert does not fit properly, dough leakage can invariably change the outlet specifications. If the insert protrudes slightly, knife breakage occurs. If the insert is recessed, poor product cut results. Should the die be bowed or bent, a number of the above difficulties might be encountered. The extruding surface of the die might be damaged by knife action or during handling, and this condition must be corrected.

Depending on the extrudate and the process, cereal and snack dies are generally manufactured using stainless steel and bronze alloy inserts to reduce the effect of wear; Teflon inserts are extensively used for pasta dies.

Matching Dies to Production Requirements

In determining the specifications for a new die and/or product, calculations must take into consideration all pertinent factors that affect the final product. The first decision is the selection of the material to be used. This selection is dependent on the product itself, method of packaging, product appearance desired, and rate of production. The selection of the most suitable material for a given application is highly important and often difficult-many factors must be considered and balanced. In keeping with today's technological improvements and high-volume production, the basic material must be strong enough to stand up under a design that will provide maximum output. This usually means more outlets per die. The overall physical properties of the metal must be considered, with machine ability as a primary factor. General properties will include resistance to the flow of dough, and wear ability.

The following example illustrates the series of steps required for drawing up specifications of a spaghetti die. One common practice today is to submit samples with the order. The samples are carefully measured. Several measurements are taken over the entire length of the strand because the measurements at different points on a single strand will vary. Such variations may be caused by moisture content of the mixture, stretching during extrusion, drying, and condition of the die outlet. From these measurements on the dry product, an average figure is computed.

The next step-- and a truly important one--is to determine the dehydration or shrinkage factor for the product. This factor must be based on past experience and performance, for it varies with each manufacturer. Thus, it becomes a variable factor dependent on the method of production used and outlet material. For example, the use of Teflon will often necessitate a higher shrinkage factor over that for metal. This factor is added to the basic sample size to arrive at the final outlet size.

The next calculation, which often presents a problem, is the determination of the number of outlets per die.

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On one hand the extruder manufacturer has already set the rate of production for equipment and wants the die manufactured with as many holes as possible. The pasta manufacturer, on the other hand, expects a perfect product from the die. What are the problems? If the die is designed with too many outlets, the following scenarios are possible: 1) the die may be too weak, reach its yield point, and bend under pressure; 2) the dough may not have the opportunity to properly amalgamate before extrusion, which may result in a weak, low-density product; 3) the operator may think that the extrusion rate is too great and make the mixture a little harder (greater viscosity) with subsequent damage to the die; and 4) the strands may overlap too much and consequently be difficult to dry properly.

If the die is designed with too few outlets, too much back pressure can develop with possible damage to either the die, the extruder, or both. In this respect, collaboration with the pasta manufacturer is essential so that the requirements may be satisfied.

The die with a pin presents additional problems, for wall thickness must be considered. Shrinkage occurs on both the outside and the inside diameters. The shrinkage factor is greater for the outside diameter than it is for the inside diameter, and extreme care must be exercises in drawing up the specifications. This particular characteristic must be given close attention or wall thickness will be either too thick or too thin, which will present subsequent difficulties in drying , packaging, and cooking.

The trend today is toward more exotic shapes, including those that appeal to children. Difficult configurations are now designed using computer technology. Complicated configurations must be given special attention--the extruding pressure on each outlet must be adjusted to extrude a product that will have a uniform thickness after cutting at the die.

On the subject of cereals and snacks, shrinkage or expansion of the finished product cannot be determined empirically because of the many different processes and raw materials used.

Factors Affecting Die Performance

One of our more serious concerns today is die wear. Under normal circumstances, die wear becomes apparent through the warning signals associated with packaging. Too heavy a product yields less volume per unit weight, which results in too much slack in packages. This applies predominantly to solid and tubular products, in which gradual war can seldom be detected by visual inspection of the product but instead must be determined by actual measurement. The more elaborately shaped products generally give some indication of wear by a change in physical appearance. For example, sea shells tend to show greater curvature, mafalda shows a more pronounced wave, and rotini and twists show a tighter curl.

In a sea shell production, the flow of dough is at its maximum at the center of the shell, making this point more susceptible to wear than are the ends. As wear increases, the dough flows faster at the center, thereby increasing curvature. Today, the most common warning of wear in shell dies comes in the form of checking either during or after drying.

Checking can be described as minute cracks in the finished product as a result of improper drying or dehydration of the product. This may be a consequence of a heavy wall or improper diameter product (possible result of die wear) with no correction in the drying process. This checking can be attributed directly to die wear and can be eliminated by reducing the thickness of the die outlet.

In the wavy products, such as mafalda and rippled lasagna, die wear becomes evident visually by a more pronounced or closer-curled wave. A cross section of these products should present a flat, noodle-type appearance. The wave is the result of a greater flow of dough on the ends of the slots in the die, making the ends the points of greatest wear. An increase in wear is accompanied by an increased flow of dough, resulting in a more pronounced wave. A cross section of the product after wear made with a die exhibiting signs of wear appears as a flat noodle in the center with a spaghetti-like effect at the ends. This condition presents both drying and packaging problems and can be eliminated by proper die maintenance.

The rotini and twist products present cross sections analogous to those of lasagna--a cross section of the product before wear is a noodle type product whereas after wear, the ends (at the circumference) develop a heavier, spaghetti-like appearance. The increase in the flow of dough at these points results in a tighter curl or a greater degree of twisting.

Elbow macaroni is tricky because wear occurs at several points, and certain dimensional proportions must be maintained to obtain a standard product curvature. Wear takes place at the outlet, at the pin tip, at the base of the notch (where applicable), and, in the case of brass pins, at the pin stem between the notch and the tip of the pin. Many have been plagued with product splits on short-cut products and splits or weird distortions on long products. The cause, though not immediately detectable by visual inspection, can generally be traced to grit in the raw material. In the case of splits, the grit lodges between the pin and the outlet (the grit is too large to be pushed out) and results in a definite split in the extruded product. (A split is a term used in the pasta industry to describe a break in a tubular product in which the cross section looks like a split ring.) In the case of the weird distortions of long tubular products, the grit is forced through the die but in the process forces the pin to one side. Thus, off-center pins--directly attributable to grit--are the base cause.

A rather mystifying condition is presented by uneven wall thickness in short-cut products in which grit definitely does note enter picture.

When proper and standard operational procedures are not carefully adhered to, the die yields during production. This bending follows an elliptical pattern tending to distort the outlets and disturb the concentricity of pin and outlet. The result is uneven wall extrusions.

In these days of high-volume extrusion operations, a major complaint is wear vs. number of hours production. Number of production hours can no longer be used as a yardstick for wear. Statistics must be based on tonnage pushed through the die, which will give a more realistic basis for rate of wear.

How often should dies be returned for repairs and reconditioning? Every three months? Every six months? The answer depends on a number of production and handling factors. A die in a continuous production system must be repaired more often than must a die in limited production. The responsibility of setting tolerances for the product sizes rests with the manufacturer. Once these tolerances have been set for the various products, it is easy to determine wear on the die. This task may be facilitated by the use of gauges within the specified tolerances on the die or by enlisting the aid of quality control on the product. In view of the many variables that influence final product size, it may be beneficial to work out some program involving die wear, although it most certainly will be more practical to work on product tolerances, which may result in a colossal headache.

All difficulties are not the result of die wear. Improper maintenance will result in serious problems. For example, a die not properly cleaned will have a thin crust of dough left on the outlet. This will affect both product size and appearance. Pressures may have a decided effect on the extruded product. One problem that has gained prominence is the noodle with a slight twist. A die extruding 1,000 lb per hour manufactured to identical specifications as a die extruding 3,000 lb per hour will not give the same twist as the latter die as a result of different extruding pressures. The twist will be in direct proportion to pressure. Similarly, pressure may affect the wall thickness of the product. The same things apply to all products that curve or twist, such as elbows, rotini, and sea shells.

Among the factors affecting the quality and appearance of the extruded product are raw material, moisture content, pressure, die outlet finish, number of outlets in die, material of die, and drying procedures.