...blank affects the temperature of the ... at the moment that melt flow be... At faster press closing speeds less ... will be lost, and flow and appearance ... to improve.

... mechanical and hydraulic presses ... Mechanical presses close rapidly ... full pressure within a fraction ... after pressure is first applied. ... decays as the part cools and ... Mechanical presses may require ... modification to maintain dwell ... pressure. Hydraulic presses gener... and build up pressure more ... than mechanical presses, but con... pressure is held throughout the ... period, and no modification is ...

Pressure is maintained until the part ... sufficiently for removal from ... Dwell time ranges from 10 to 30 ... with thicker parts requiring longer ... Total cycle time, which also in... time needed to open and close the ... to remove finished parts, and ... the heated blank, generally is ... 20 and 45 sec.

... temperature is controlled to opti... melt flow, rate of cooling, and prop... of the stamped part. Positive dies ... used, i.e., all of the press pressure is ... to the material being formed and ... to the die. The vertical flash, or tele... shear edge, should have a clear... of 0.0015 to 0.002 in. and be about ... in. long.

Because the heated blank covers a large ... of the stamping tool, relatively little ... flow is needed to fill the die. Large, ... parts as well as very thick parts ... can be formed with relative ease, ... bosses and ribs of all sizes.

...id phase stamping

... solid phase stamping, the thermo... sheet is formed at a temperature ... C. or more below its crystalline melt... point. This process results in orienta... of the polymer chain, thus enhancing ...chanical properties in the direction of ...entation. Die design must make allow... for elastic recovery which can ... distortion after the forming pres... is removed. The solid phase forming ...chanism is one of deformation rather ... flow. As a result, wall thickness will ... substantially uniform, and abrupt ... in cross section cannot be formed. ... unfilled and filled thermoplastics ... be used for solid phase stamping. ...ypropylene and high density poly... are most commonly used. Other ...moplastics such as nylon-6, PVC, and ... also can be used. Fiber-reinforced ...ulations are very difficult to form and ... not normally used.

...ermoplastic forging

...orging of thermoplastics, like stamping, ... be carried out either below or above ... melting point. Reinforced or filled ... are used for hot forging, whereas ...filled billets normally are used for solid ... forging. Polymer orientation is sim...ilarly affected by forming temperature in ... forging and stamping.

Forging pressure is much higher for solid phase forging than for melt flow forging. For the lower-temperature process, the required pressure is reported to be between 4000 and 10,000 p.s.i. For hot forging, the pressures are in the same range as for melt flow stamping, i.e., 500 to 2000 p.s.i.

Billets for forging are very much thicker than the sheets used in stamping. Heating of billets to avoid surface degradation and assure temperature uniformity is therefore more difficult, and control of the process is more critical. Infrared and circulating hot-air ovens as well as direct contact-heated plates or rolls are used to heat the billets.

Polypropylene, polyethylene, and ABS are the thermoplastics most commonly used for forging. Forging can also be used to form some materials, such as ultra-high-molecular-weight polyethylene, which are difficult to form by other methods.

Applications

Melt-flow stamped thermoplastics are currently used in numerous applications. Automotive end uses, in production or in prototype testing, include front end fascia supports, fender liners, oil pans, seat components, and battery trays. Stamped shrouds and baffles are being made for lawnmowers. Stamped gear shift covers are being used on garden tractors. A variety of containers are being stamped.

A stamped automotive engine oil pan is an example of the cost/performance effectiveness potential of thermoplastic stamping. Stamped from reinforced nylon-6 sheet, such an oil pan provides creep resistance to maintain oil-tight seals against the engine block, rigidity to support the engine weight during assembly and maintenance, impact and abrasion resistance to withstand over-the-road use, and hot hydrocarbon resistance necessary to contain oil at engine operating temperatures. This complex, deep-draw part can be formed rapidly at moderate pressure resulting in low operating costs and low tooling and press investment.

Automotive seat components require rigidity and impact resistance, a combination readily achieved with long glass-fiber-reinforced thermoplastics. Some of these components, e.g., the back of a bus seat, are large, flat, thin parts which can be stamped in a short cycle at moderate pressure, but would be difficult to form by other processes.

Automotive fender liners are currently made by a solid phase stamping process. These parts are formed in a very short cycle, thereby minimizing forming costs and capital investment.

Forged thermoplastics are used for parts with heavy cross sections such as pipe flanges and gears.

Mixing and compounding

Continuous compounding

By W.A. Mack

The continuous compounding and mixing of polymers is accomplished by a variety of mechanisms ranging from single-screw to twin-screw extruders with variations in design and additional equipment to achieve a range of end products. The type of compounder or mixer chosen depends upon the specifications and properties required of the end product, volume requirements, overall economics, and whether the compounding is done in-house or by a custom compounder.

The basic functions of any compounding extruder are to melt the plastic and to introduce a closely controlled amount of shear energy into the melt to properly disperse and distribute additives or fillers.

Such properties as color, flame retardance, impact and tensile strength, lubricity, and UV stabilization are obtained through the addition of one or more additives to the basic polymer. A uniform distribution in the polymer mix is necessary for a well-stabilized product and to reduce or eliminate degradation. Multipurpose or multi-additive concentrates were developed to produce many characteristics, and to properly incorporate these into the base polymer. The choice of compounding method and process is important.

There are various types of degradation: thermal, mechanical, chemical, and environmental. When polymers are mechanically degraded, a reduction of molecular weight occurs. This is a function of mechanical shear and the time exposed to that shear.

Viscosity difference between the polymer matrix and the additives can be a problem with conventional compounding equipment, where conveyance in the solids conveying zone is primarily dependent on frictional forces between the solids and the barrel and screw. Because of the lubricity effect of the additives, viscous heat generation is minimized toward the melting zone, which can lead to a nonhomogeneous product unless modifications are made to obtain the desired material. With more sophisticated machinery, conveyance is nearly independent of frictional forces and melting can be adjusted to cope with the viscosity differences.

A single-screw extruder may be used for compounding colorants, masterbatch, and other additives to the resin when cost is a major factor and when a relatively simple design is an important considera-

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tion. Single-screw sizes may range from 2½ in. to 8 in. in diameter with lengths of 20 to 42 L/D. One of the disadvantages of the single-screw is the difficulty of mixing partially melted polymer. Difference in heat history often can lead to nonuniformity of the product, and the time required for cleaning screws also can increase costs.

Very little mixing occurs inside the channel in single-screw equipment. To overcome this defect, mixing devices have been installed to shift the point of zero stress to various locations in the screw channel so as to achieve an adequate mix. This requires that the equipment have sufficient processing length to accomplish the desired degree of mixing. A number of improved mixing devices are available, including the EVK, the Maillefer type, and the fluted screw.

A further advance in technology is the precompounding of additives as concentrates, which allows their introduction in conventional equipment, with improved compatibility of the additives and the matrix. Direct addition of additives is widely used; however, there are drawbacks which can be overcome by the use of concentrates. For example, concentrates eliminate some problems of dispersi[on] caused by additives which are liquid [at] room temperature. It is important, h[ow]ever, that the concentrate level be wit[hin] the range of the capability of the proc[ess]ing equipment to avoid problems of l[et]down with high levels of concentratio[n]. Such concentrates as slip-antiblock-antioxidant can be prepared in concen[tra]tions of 50% or more, but since the fin[al] concentration required is usually belo[w] 2%, a concentration of 20 to 30% woul[d] be more feasible for proper dispersion [us]ing single-screw equipment.

The problem of poor stress distribu[tion] in the channel has largely been minimi[zed] by advances in twin-screw extruder design. These extruders are available in a variety of designs, including co-rotating and counter-rotating systems with man[y] variations. The twin-screws offer positi[ve] conveyance of the material. Co- and counter-rotating screw designs can be either intermeshing or nonintermeshing. When they are intermeshing, they can be made self-wiping, which is advantageous to the operational economics as the screws require much less downtime for cleaning.

While both counter-rotating and co-rotating screw designs offer positive conveyance, the pattern of conveyance differs. In a co-rotating arrangement, the material is conveyed in a figure 8-shaped pattern from one screw to the other, thus increasing the degree of mixing.

Nonintermeshing screws are always open both lengthwise and crosswise. The design of intermeshing screws, however, includes variations in lengthwise and crosswise open and closed positions, which directly affect the conveying conditions, the mixing action, and the pressure build-up capacity of the screw system. Co-rotating twin-screws can operate at higher speeds than counter-rotating. Counter-rotating screws tend to cause a proportionate increase in wear of the screws because of their pressure and velocity distribution. Counter-rotating systems have a maximum diameter of about 170 mm., and they are used primarily for profile extrusion at lower screw speeds.

Co-rotating screws can be operated at higher screw speeds with greater throughput, with less wear than can counter-rotating screws, because there is no calendering effect between the crest and flank of the screws. A co-rotating, self-wiping twin-screw extruder with 300 mm.-diameter screws can process up to 35,000 lb./hr. of HDPE at 160 r.p.m. screw speed. In addition, there is more uniform heat and shear history and more efficient self-cleaning action.

Improvements in the design of counter- and co-rotating twin-screw machines have been made to improve the degree of dispersion and stress distribution. Interrupted flights/channels have been incorporated in counter-rotating machines to break the material and reorient the layers. Among the variations possible for co-rotating machines, kneading disks are available with the same cross section as the corresponding screws, to achieve a higher degree of plastication. Disks with various widths and staggered angles can

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be arranged along the screw shaft. Right- and left-handed screw elements also can be included to accommodate varying processing requirements and to assure complete melting in short distances.

Various feed arrangements for additives can be incorporated, including side and vertical inlets. Vertical feeders offer advantages for feeding materials such as glass fibers, chopped glass, and glass beads which are highly abrasive and cause considerable wear. Wear is minimized by feeding abrasive fillers into the extruder, where the base polymer is already in a molten stage. A higher feed capacity possible with the vertical feeder allows a reduction in r.p.m. and a considerable reduction in wear. The vertical feeder normally is used in conjunction with a metering system, either a weigh belt feeder or a metering screw.

The removal of volatiles from polymers is an important factor in extrusion technology. There is a deterioration of conveying capabilities as single-screw diameters increase, because the conveyance in devolatilization zones must be at or below atmospheric pressure to prevent vent flow. The conveying capabilities of the twin screws and the renewal of surfaces by product transfer from one screw to the other help to achieve steady-state, efficient venting. A major advantage of intermeshing self-wiping twin-screw systems is the elimination of material hang-up in the screw channels in a vent area, which prevents material degradation.

For compounding PVC and other heat- and shear-sensitive materials, two-stage systems have been developed. The use of twin-screw extruders followed by single-screw has proved highly effective, by separating the mixing and compounding operation from the pumping, conveying, and extruding function. Interchangeable screw and kneading elements in the twin-screw extruder can be used to vary the length of kneading zones to maintain correct heat levels for dispersion of additives without degradation of the additives or the polymer.

Another system combines a twin-screw feed section with a large rotating cone for imparting high shear and a single-screw extruder for final extrusion through a pelletizing die. This system is designed for the compounding and pelletizing of flexible PVC formulations. Material, usually a premix from a ribbon blender, is fed into an agitated hopper and then to a short twin-screw extruder for pulsation-free conveying to the shear cone. The shear cone is a ribbed conical screw that rotates in a corresponding conical housing or barrel. The diameter of the cone increases in the direction of material flow and the space between the cone and the housing can be varied from 0.3 to 6.0 mm. during operation.

When the material is forced between the cone and housing, it is plasticated, gelled, and homogenized. No additional energy is required to melt the material because of the high shear force generated by the rotating cone. Even temperature distribution is obtained because of the relatively small material cross-section.

Pelletizing

There is a wide variety of commercial pelletizing systems available today. They fall into two general categories: hot die face cutting and cold cutting systems. The basic processing steps involved with hot die face cutting are:

1) Extrusion of the plasticated material through a die plate.

2) Immediate cutting of the strands of melt by rotating knives.

3) Transportation of the pellets out of the pelletizer hood.

4) Cooling or quenching of the pellets in air and/or water.

5) Drying of the pellets.

Cold cutting involves:

1) Extrusion of the plasticated medium through a strand or strip die.

2) Transportation of the extruded strands or strips (band or ribbon) through a cooling medium to the cutting apparatus.

3) Cutting of the cooled strands or strips in granulators.

4) Drying of the pellets.

The strands or strips also can be dried

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before they are cut by means of an air knife.

The shape of the pellet required for specific applications has a direct bearing on the cutting method selected. Final processing efficiency and throughput rates are directly affected by pellet characteristics such as bulk density, pellet uniformity, surface structure, and surface moisture.

Strand cutting is the most efficient and economical method for many polymers at rates of up to 4000 lb./hr. Strip dicing systems are available which can accommodate rates up to 11,000 lb./hr. and, where cube-shaped pellets are required, the process offers advantages.

A unique cold cutting system is a self-stranding forced conveyance pelletizer for difficult-to-strand materials which eliminates stoppage and binding which are common for certain plastics. This is accomplished by forced conveyance through the water bath in an up-and-down path.

Throughput ranges between 2000 and 15,000 lb./hr. are possible for many different materials, with hot die face cutters. The water ring pelletizer is effective for production rates of 7000 to 15,000 lb./hr.

The water ring pelletizer can be used effectively for almost any thermoplastic, including all olefin homopolymers and copolymers, PS, ABS, PMMA, and PC. It is also reliable with the difficult-to-handle highly filled thermoplastics. In water ring pelletizing, the extruded polymer is cut immediately after discharge by rotating cutting blades. The freshly cut hot pellets are thrown into a spirally rotating water stream of approximately ½-in. depth. They are then quenched and spirally conveyed through the pelletizer hood, and after rotation are discharged into a water pre-separator and then to a subsequent drying operation.

For higher-volume polymer production, new developments in underwater pelletizing systems have allowed higher throughput rates with the main application being the polyolefins. Cutting techniques have been developed for relatively low-viscosity polymers such as polyamide, PC, and PMMA. The basic design difference in underwater pelletizing systems is the arrangement of the die plate and water chamber. A split die plate design provides insulation to prevent freeze-up of the polymer in the nozzle and minimizes heat loss in the die plate.

Discontinuous compounding

By J.K.L. Bajaj

In the plastics processing industry, batch or discontinuous mixers are extensively used at various stages of operation. In many instances they are used as part of a continuous system.

Blender types

Ribbon blenders are used for the mixing of powders, pastes, and liquids. They are workhorses for PVC compounding, cooling, standardization, color blending, and reclaim scrap blending.

Nominal capacities range from about 1 to 2500 cu. ft. Typically a ribbon blender consists of outer and inner spiral ribbons supported on a shaft which runs longitudinally through the center of the blender tank. The arrangement of these ribbons provides a triple mixing action. First, as the agitators rotate, the material is tumbled and carried radially around the inside of the blender. Second, the pitch of the outer ribbon moves the material towards the discharge opening. Third, the inner ribbon which has an opposing pitch moves the material away from the discharge opening. Widths of the inner and outer ribbons are carefully balanced to provide an even movement of material in both directions and to prevent the load from building up at any spot in the blender.

Different types and designs and even different numbers of agitator blades are used for various applications. Two or more agitators in the same tank are normally used for unusually large capacities.

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Conical mixer with orbiting screw is ideal for solid/solid blending and paste dispersion. It is very effective for intimate blending of materials of widely varying densities, shapes, and particle sizes. Large batches can be handled and precision additions can be made—as little as 50 parts per million. Typical capacities range from about 1 to 1450 cu. ft.

Three distinct mixing actions are involved. A screw agitator turning on its axis produces a lifting action as it spirals the materials in an upward flow in the tank. At the same time, while orbiting the tank, the screw removes material away from the wall and deflects it into the center of the tank, setting up a second, wider spiral current throughout the batch. Material lifted upward by the screw moves downward, thoroughly intermixing with the material being spiraled upward. These three actions in one screw result in the most intimate and thorough intermingling of all ingredients.

Horizontal stationary cylindrical mixers have mixing elements attached to arms on a shaft centrally mounted in the mixing container. The mixing elements impart intensive axial and radial movement to the material. Extremely fast lateral movement causes the mass of material to be propelled from one end of the tank to the other, setting up strong impact currents, violent collisions, and particle interaction at the center of the vessel. This is ideally suited for blending dry powders, moist solids, solids and liquids, together with pasty substances up to and including high-viscosity dough masses.

Some of the application areas are admixing of trace elements; rapid kneading of highly filled PVC pastes and pressure-sensitive hot-melt adhesives; dissolving polyurethane, natural and synthetic rubbers; and preparation of bulk molding compound, and PVC dryblends.

These machines are commonly available up to about 700 cu. ft. in size.

Double-arm mixers are characterized as medium-to-high energy processing machines. Two interacting heavy duty agitators do the intense shearing, stretching, kneading, and folding in a trough-shaped chamber. This machine is widely used for compounding a wide range of heavy pastes, mastics, caulks, and other hard-to-mix highly viscous materials such as silicone elastomers, filled epoxies, rubbers, hot-melts, and bulk molding compounds. The materials can be fed in sheets or chunks to the machine. Different types of agitators are employed, depending upon the application. The sigma-type agitator blade is best for all-around use. It may be used either with tangential or overlapping action. These machines are available up to 1000 gal. capacity.

Banbury-type mixers utilize two horizontal, spiral-shaped agitators rotating in opposite direction at a differential speed, and working together with vertical ram to develop very high shear. Prime applications are for rubber and PVC compounding. These machines are also being used for processing polyolefins, ABS, and polystyrene, along with thermosets such as melamines and urea. Maximum capacity is about 1000 lb./batch, and depending upon material the production rates can be as high as 40 batches/hr.

Physical states of mixes

In *solid-solid mixing*, where product is dry and flowable, some of the more important properties of solids that affect mixing performance are specific gravity and bulk density, surface area, interparticle friction, angle of repose, and cohesion of fine powders and granules.

Three mechanisms postulated for mixing of dry solids are diffusive mixing, shear mixing, and convective mixing. Different types of mixers have one, two, or all three mechanisms effective at one time. The differences in particle size, density, shape, electrostatic properties, and resilience are the properties of material that cause segregation. When pigment particles are mixed with plastic pellets the very fine pigment will usually adhere and form a coating on the pellets. Hence, there will not be any segregation during and after mixing.

Ribbon blenders, vertical cone mixers with an orbiting screw, and air mixers have been termed nonsegregative because they rely mainly on convection currents.

Rotating drums and mixers which rely on tumbling and stirring, such as double-cone and twin-shell mixers, are segregative because in these machines the mixing mechanism is predominately diffusive or shear mixing. For segregating types of materials, discharge, conveying, and storage should be looked into closely after the products have been mixed.

Liquid-solid mixing and dispersion,

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where the product is a liquid. The factors affecting mixing-dispersion here are the turbulence, interparticle attraction, the viscosity and density of liquids, and their natural affinity to solids. The viscosity parameter is important for most plastics processed because it is not only affected by temperature but by shear rate. Circulation of the liquids is absolutely essential for satisfactory performance. To obtain a good mix it is necessary to disperse the solids so that all surfaces of the particles are coated with the liquid. Plastisols and sheet molding compound premixes are two of the many areas where liquids are mixed with solids and where the final product also is a pourable liquid. High-speed dispersers, ribbon blenders, and conical mixers with an orbiting screw and top entering dissolver are being used for such applications.

Liquid-solid mixing where the product is dry. In PVC compounding the liquid plasticizer is absorbed by the resin, resulting in a dry product. Medium-intensity vertical mixers and jacketed ribbon blenders are all used.

Paste mixing. In a paste the physical properties of the mixture are quite different from that of its solid and liquid constituents. Internal dynamic shear is the method used for good dispersion.

When mixing high solids-low liquids, the stiffer the paste the greater the internal dynamic shear. Diffusion is an important process in the early stages of dispersing a solid phase in a liquid medium. Machines for this dispersion are characterized by high power requirements and low speed, and the mixer is designed for slow, large-scale distributive movement of the mixture as well as intense local mechanical action. Preparation of bulk molding compound, high viscosity mastics, and some plastisols fall in this category.

Fluxing of compounded polymer systems. Fluxing results in an extreme intimate blend of the additives with the mass to produce a semimolten compounded polymer as a finished product.

Color concentrates and PVC compounds are fluxed prior to further processing. The Banbury type, high-speed fluxing mixer, and the double-arm mixer-extruder are all used for such applications.

Mixer selection

When selecting a mixer, careful consideration should be given to the size of the unit required. The full cost per pound at the maximum daily or hourly production rate must be established to determine a suitable batch size. Use of several small mixers rather than one large unit usually will increase labor costs and initial investment.

The need to control or change the temperature and pressure during processing should also be considered. Some types of equipment are not suited to use heating or cooling devices and others may not be operated under vacuum or with internal pressure. Purchase of a light-duty mixer should not be overlooked if the material will be dispersed at a high temperature.

Also, thought should be given to the materials which will come in contact with the final product. Although a product may not be contaminated by plain steel, a polished stainless steel unit is easier to clean. Labor that is saved may more than justify the additional cost of a stainless steel unit. Other constructions such as the use of high manganese steel and chrome plating may be considered.

The flexibility of the unit is also worth a long look. Can the mixer be readily cleaned to change from one product to another and adapt to future production demands? Or, if another piece of equipment in the plant breaks down, can the mixer be pressed into temporary service?

Pretesting pilot-scale equipment is an extremely useful way of evaluating the various dispersers available.

Motionless mixers

By Annette Comeau

Any stationary baffle installed in a pipe will utilize the energy of the flowing fluid to produce mixing. The baffle represents a simple motionless mixer. Industrial motionless mixers have programmed flow patterns that create progressive mixing action by: 1) flow division, and exponential increase in the number of flow striations, and 2) radial circulation of the processed fluid around its own hydraulic center. Energy required to promote mixing is simply the differential pressure drop between product inlet and outlet.

Motionless mixers are designed to produce a melt having almost no random character in viscosity, temperature, or mass. In essence, they are processing aids that eliminate melt nonuniformities in critical tolerance or appearance applications and where a machine, even under optimum conditions, cannot meet product quality requirements.

Types of processing

Motionless mixers have a place in all areas of *extrusion*: wire and cable coating, blow molding, foam sheet, sheet, pipe and profile, and extrusion coating. Mixer units come complete with hardened tool-steel housings, mating flanges, heater bands, and transition pieces for adaptation to the extruder barrel and die. Mixer installation in extrusion processes assures near perfect color/additive distributive mixing and uniform melt temperatures for thermoplastics, including nylon, polyethylene, polystyrene, acrylic, cellulosic, and vinyl resins.

The motionless mixer will virtually eliminate melt stream temperature gradients created either by the extruder or

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other process equipment. A thermally homogenized melt stream with no radial temperature gradients provides uniform viscosity, precise gage control, and increased output. Specifically, in-line units have been found to:

1) Virtually eliminate position-dependent variations as well as effect up to a 10 to 20% improvement in short-term, time-dependent variations before melt reaches the die.

2) Allow the screw to be run at higher r.p.m., meaning greater output without sacrifice in product quality.

3) Save resin by reducing thickness variations in both machine and transverse directions.

4) Increase output matched by improvements in gage control.

5) Reduce additive loadings, up to 25% in some types of colorants, facilitate rapid color changes, and provide improved surface gloss.

6) Assure uniform distribution in the melt of a primary blowing agent.

Motionless mixers installed on an *injection molding* machine will eliminate color nonuniformities and reduce temperature variations in the melt stream.

Incorporation of a motionless mixer will prevent over or under loadings in the molded part, eliminate color streaking and therefore save concentrates or dry color. Resin savings are possible, since better flow means less packing of the mold.

The mixing nozzles are designed to replace standard nozzles on all existing injection equipment. Mixers come with standard removable tips, either of a nylon or general-purpose design. Maximum operating pressure is approximately 20,000 p.s.i. at 600° F. Unlike so-called dispersion nozzles which create thousands of pounds of back pressure, a standard motionless mixer nozzle operates with a differential pressure drop in the range of 200 to 500 p.s.i.

Computer color matching

By D.L. Alston

A typical computer color matching system, in addition to the main computer, includes a spectrophotometer and peripheral devices such as line printers for hard copy records of computer output and video screens for rapid visual display of output.

Essential to the operation of the system is the spectrophotometer, which supplies color information to the computer on the color standard. The instrument scans the visible spectrum (rainbow colors) to determine the spectral curve, i.e., the quantity of each spectrum color in the measured sample. Utilizing this information, the computer mathematically calculates the amounts to be selected of each pigment to provide the best match to a color standard. Some systems allow many pigments to be considered to provide the least costly, least metameric match.

The data on pigments which the computer uses in its calculations usually is stored on some type of bulk storage device for easy access to the system. These devices generally incorporate a magnetic medium similar to a tape recorder and vary in capacity from small to almost infinite depending on the specific need.

Curve plotters also may be interfaced with a color control system to automatically plot spectral curves, or the spectral curve may be displayed on video terminal screens with graphics capabilities.

In a typical color matching routine, a system operator instructs the computer to run a color match program. The operator then answers questions concerning pigment selection, match criteria, etc., and presents the color standard to the spectrophotometer for measurement. After measurement, the match program considers all the pigments entered and gives all formulas which meet the specified color criteria.

Present technology has developed to the point where computer systems can control not only the matching and correction of colors but the actual dispensing of liquid colorants.

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Plastisol processing

By G.R. Crane

A vinyl plastisol is a dispersion of PVC resin in a liquid plasticizer. Since it is a fluid, it can be formed by dipping, rotational casting, spreading, or spraying to produce a wide variety of molded items or coated goods. As heat is applied, the plastisol compound gels and subsequently fuses to become a homogeneous melt. Upon cooling, it becomes a solid with good physical properties and chemical resistance. Since the liquid plasticizer becomes part of the final fused compound, plastisols are considered to be 100% solids systems.

At times, to achieve lower viscosity or to work at a very low plasticizer level, volatile organic thinners may be incorporated. Such compounds are known as organosols. While this technique aids in producing hard finish coatings, extra care is required to assure that the thinners are evaporated before fusion. Too rapid gelation and fusion may result in bubbling in the finish coatings. The lower the solids content, the more costly an organosol coating will be, since the thinner is lost and extra energy is required to volatilize it.

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Raw materials

PVC resins used in plastisol compounding are generally known as dispersion resins. The primary dispersion resins are produced by highly sophisticated technology which yields carefully controlled particle size distributions with average diameters in the neighborhood of 1 micron. High-molecular-weight homopolymers are preferred for most coating and molding applications. Copolymers of vinyl acetate with vinyl chloride are employed in specialty areas requiring lower fusion temperatures. A number of low- and medium-molecular-weight homopolymers also are produced to satisfy special property requirements.

Plastisol blending resins often are used to replace 10 to 50% of the dispersion resin. Blending resins contribute versatility to the formulating scheme as they offer viscosity reduction, cost savings, gloss control, air release improvement, and gel retardation. Modern blending resins are available in well-controlled particle size ranges averaging 20 to 25 microns. A range of molecular weights permits selection of a blending resin to match the dispersion resin. When used at moderate levels they may fuse as well as the primary dispersion resin and in some cases may actually improve physical properties.

Plasticizers for PVC dispersions must be chosen for their effects upon viscosity as well as fusion properties. Most commonly used are the monomeric esters, with dioctyl phthalate the basis for the majority of applications. The longer chain, linear phthalates offer improved viscosity control, low temperature flexibility and permanence at a modest cost increase. High-solvating types such as butyl benzyl phthalate are employed to enhance fusion properties and for special properties, e.g., stain resistance in coated flooring wear layers. Adipate and azelate esters, substituted for a minor proportion of the total plasticizer system, greatly reduce the plastisol viscosity while improving low-temperature performance and hand or rubbery quality. Least common are the polymeric types, whose high cost and high viscosity must be justified by a need for exceptional extraction resistance.

Plastisols, like other PVC compounds, require stabilization against degradation by heat and light. Barium-cadium-zinc liquids are most commonly used because of their favorable balance of stabilizing efficiency, air release, and viscosity control effects. Calcium-zinc liquids may be preferred for low toxicity and stain resistance. Epoxidized oils which are often included in the plasticizer system act synergistically with the metal stabilizers. Special requirements may call for tin or lead stabilizers.

Auxiliary components of plastisols include fillers, used chiefly for cost reduction, color pigments, blowing agents, sur-

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factants, mold release agents, and adhesion promoters. Any of these may be combined with a variety of resins, plasticizers, and stabilizers to achieve specific end-use properties.

Application processes

Fabric coating. Leather-like, vinyl-coated fabrics are widely used in automotive interiors, furniture, upholstery, shoe products, luggage, and handbags. Knife coating of fabrics was one of the earliest applications of plastisols. Relatively high-viscosity compounds can be used and the rheology can be adjusted to permit the coating of loose weave fabrics without excessive penetration or strike-through.

Reverse roll coaters are used for high-speed, high-volume coatings. Plastisol rheology is critical on a reverse roll coater. The high speed and extremely high shear demand low viscosity and near-Newtonian flow properties. In return for a relatively high capital investment, the reverse roll coater enables the processor to produce high yardage of high-quality coated fabrics with good gage control.

Another approach to coated fabrics is based on the use of embossed release paper. The paper, embossed with the desired grain pattern, is the carrier medium through the oven. A skin coat of solid plastisol is cast first, then gelled in a short heating zone. One or more inner layers are cast next and also gelled. The inner portion may be a foamable plastisol, containing a chemical blowing agent such as azodicarbonamide. Finally, the fabric backing is applied and gently pressed into the last semi-gelled layer with a kiss roll, and the entire construction passes through the fusion oven where the multiple layers are fused, bonded securely together, and the foamable layer expands to give a cellular core. This method produces coated fabrics combining a luxurious soft hand, a tough abrasion-resistant skin, and a permanent, molded-in grain that cannot be obtained by post-embossing. The release paper is rewound and reused as many times as possible for economy.

A wide variety of film and/or foam constructions is produced without supporting fabrics. These can include place mats, tape, various upholstery items, and certain apparel items. Production of such items usually is accomplished by casting on release paper or stainless steel belt. The film or film and foam construction may be cast as described above, fused, separated from the carrier medium, and cooled before being wound on a roll to prevent distortion.

Coated flooring. Today's extra-wide roll goods flooring is produced by reverse roll coating (normally on asbestos felt) and rotogravure printing. Designs are multicolored and almost unlimited in complexity and artistic beauty. Many have an expanded vinyl plastisol cushioning layer beneath the printed pattern and the clear top coat or wear layer. Embossing of the foam layer aids in producing a three-dimensional effect in the pattern. Embossing may be accomplished either by mechanical methods or by a patented chemical embossing technique. If a mechanical emboss is used, it is the last step of the process.

Coil coating. Protective and/or decorative coatings are applied to sheet metal or aluminum in the mill, before the coils are shipped to the forming plant. Thin coatings of plastisol or organosol are applied by reverse roll coater and baked to produce a durable finish. The metal strip may then be formed into siding or other shapes without additional decorating. Adhesion is obtained by the use of a suitable primer.

Glove dipping. Both unsupported and fabric-supported vinyl gloves are produced by dipping. In the former case, a thin coating is fused on the mold after allowing the excess to drain thoroughly. The fabric type is produced by stretching a cotton liner over the mold form, then dipping it briefly into the plastisol, draining, and fusing. Rheology of the plastisol is all-important as the coating weight, flexibility, and degree of penetration must be carefully balanced.

Dip coating. Many metal items are given a protective coating by dipping in a plastisol. A common example is the addition of cushioning grips to tools. The usual method is by hot dipping, wherein the preheated metal causes a certain thickness of the compound to be picked up through gelation. A variation of this process is dip molding, in which the mold is removed and reused while the molded vinyl becomes the complete object. Small items such as bicycle grips may be economically produced by dip molding.

Another variation is cold dipping. The plastisol must display highly pseudoplastic flow behavior to coat an object such as a dishdrain rack. A relatively heavy coating is carried on the object solely through its high viscosity and must resist sagging or running through the subsequent gelation and fusion steps.

Slush molding. Articles such as boots and doll heads are molded by using heat to gel a plastisol coating onto the mold. The molds may be either preheated or cold-filled. In the latter case, heat is applied to the exterior of the mold under carefully controlled conditions after filling. The ungelled plastisol is then drained and recycled and the mold is carried into a fusion oven. After cooling, the built up coating can be stripped. Its exterior surface will exactly reproduce the mold interior.

Rotational casting. This technique is similar to the process used to produce hollow chocolate Easter bunnies. Typical products include balls, toys, and automotive arm rests. A measured charge of plastisol is delivered into half of a split mold. The mold is closed and mounted on the arm of a rotational molding machine. As the molds are simultaneously rotated around two perpendicular axes, the plastisol flows over and evenly coats all surfaces of the mold interior. This takes place within the fusion oven, so that on subsequent cooling and opening of the mold a closed, hollow object is produced.

Cavity or in-place molding. This method is used to produce diverse items including automotive air filter gaskets, synthetic fishing lures, and novelty items. A plastisol in this application generally is poured or metered into a tray-type mold and subsequently fused.

Another application deserves special attention. Closure sealers that are formed in place represent a fairly important market. In the case of caps, usually the entire inside area of the cap is coated, while in jar lids it normally is limited to a ring around the area that makes contact with the jar.

Caulks and sealants. Plastisols with extremely high viscosity are used as sealants for automotive body joints, drip rails, and refrigerator cabinets. Rheology is important to prevent sagging prior to fusion.

Strand coating. A relatively new and growing area is the coating of fibers using wiping dies. Chiefly applied to glass fiber strands, the technique permits high-speed application of thin coatings. After fusion, the strands are woven and heat-fused together to produce insect screening. Plastisol rheology and particle size control are essential to successful operation.

Spray coating. Plastisols also can be sprayed, and such has been the case in many metal-coating applications. Control of compound viscosity and spray conditions can lead to a variety of possible textures. This area is finding new prominence with the increasing use in automotive undercoating applications.

Cellular vinyl

Cellular vinyl may be used in any of the above processes. Cellular vinyl is known as vinyl foam, vinyl sponge, or expanded vinyl, and while some may differentiate between these according to the method of production and/or the type of cell structure, there is no universally accepted nomenclature. The foam may be open celled or closed cell.

Mechanical foam is the term applied to foam produced by mechanical introduction of air or other gases into the plastisol. Most commonly, air is introduced into a plastisol which includes a frothing agent. The gas is dissolved in the plastisol under pressure at a low temperature. When the plastisol is released to atmospheric pressure, the froth is formed. The froth is then subjected to heat for final fusion. This process produces predominantly open cell foam.

Chemically blown foam is produced when a chemical blowing agent which has been mixed with the plastisol decomposes to produce a gas which expands the vinyl compound. This decomposition may occur in the plastisol compound at atmospheric pressure (which is usually the case) or in closed molds under pressure. There are two general types of processes that operate at atmospheric pressure:

1) Using a blowing agent that releases gas at relatively low temperatures, the plastisol is heated to a point below its gelation temperature where the gas is released to form a froth. The froth is then heated to the fusion temperature and cooled. This process produces largely open cell foam but it finds little use because of its critical nature.

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By F.T. Osther

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vinyl is produced by a process using a blowing agent which releases gas near the fusion temperature of the plastisol to expand the hot melt. Azodicarbonamide is most commonly used. This method produces a mixture of open and closed cells but under most conditions the closed cells predominate. In general, the higher the melt viscosity at the point of gas release, the more closed cells. Too high a melt viscosity will result in an irregular surface while too low a melt viscosity will result in large cells (possibly collapsed) and a loss of gas. Melt viscosity at the gas release temperature can be controlled by the molecular weight of the vinyl resin, the type and amount of plasticizer, and the fusion temperature. In addition, the gas release temperature can be varied to suit a particular formulation either by changing the blowing agent or by changing the stabilizer-activator system to vary the gas release temperature of a given blowing agent.

Above atmospheric pressure processes are used to produce foam with nearly 100% closed cells (sometimes called unicellular foam) such as is used in flotation equipment. As in the case of other chemically blown foams, a blowing agent is mixed into the plastisol compound. This compound is then used to fill pressure molds and fusion takes place in a press under sufficient pressure to contain the gas released by the blowing agent. The fused compound is cooled while under pressure until it is strong enough to contain the gas when the pressure is released. When the fused parts are removed from the mold, the expansion is not complete; the parts must be heated in a low-temperature oven (210 to 220° F.) for several hours to complete the expansion and relieve stresses. Sometimes steam is used to aid this process. This is an expensive process and both formulation and post treatment are important to the dimensional stability of the parts produced.

Post-production handling

Molded parts removal

By F.T. Osther

Mechanical parts removal systems can substantially reduce labor costs and improve part quality. Constant machine cycle times normally produce a more consistent product, especially on close tolerance work. The systems are capable of working repetitively with a precision of fractions of a second. Positive handling can protect the product from possible surface marring caused when dropping from the molds. Contamination can be prevented as required in many medical parts. Equipment can be selected to handle heavy, large parts or small, delicate parts requiring accurate and gentle placement. More parts may meet quality control requirements.

Add the obvious safety benefits of keeping operators out of the platen area to the savings in direct costs, increased machine productivity, and improved quality, and it is easy to see why a molder should consider automation.

Automatic parts handling systems can be divided into four main groups: bulk handling, unscrambling, controlled drop, and positive takeout.

The best system for a particular application will depend on part size, geometry and strength, machine cycle time, mold design, number of cavities, mold runner system, length of production run, and raw material. A processor can choose from a wide range of sophisticated equipment from the relatively simple carton and conveyor systems to the programmable robot duplicating operator movements.

Bulk handling

The simplest and least expensive approach, bulk handling, is ideally suited to a range of small parts, particularly in short production runs. It is also the most versatile since part geometry, raw material, and mold design have no effect on handling procedures.

With bulk handling, the product is ejected from the mold and deposited into a carton or tote bin. If no further processing is required, a shipping carton may be used to collect the parts. When small parts are deposited into large cartons, operator attendance at the machine is only required every few hours to replace the carton. With larger parts, an automatic counting or weighing system may be required which indexes filled cartons away from the loading area. Operator attendance can be minimized by providing sufficient inventory of empty cartons and adequate storage space for the filled containers.

Runnerless molds simplify the use of bulk handling, since only the parts need be handled. With cold runner molds, a parts runner separator between the mold and carton loading station separates parts from the runners for regrinding. With automatic scrap regrinding and recirculation to the machine hopper, this approach is almost as reliable as completely runnerless molding.

Parts unscrambling

Many unscrambling systems use a vibratory bowl feeder. Stacking devices that orient and count the parts—containers, lids, drinking glasses, etc.—are widely used. Unscramblers must accumulate sufficient inventory of the finished product to enable an operator to handle the output of several machine lines. With cold runner molds, a parts runner separator can be used between the mold and the unscrambling device.

While this approach is inexpensive and reliable, it has two major limitations. Due to the vibrating action of these systems, fragile parts and components that are sensitive to scratching cannot be handled. Because part geometry and center of gravity are critical, the unscrambling equipment usually is custom designed for handling a particular product. As a result, often considerable on-line debugging is required to achieve acceptable operating efficiencies, and even relatively minor part design changes can obsolete the unscrambler.

Controlled dropping

Another effective handling method is one in which injection molded parts are ejected in the normal way, but the drop is controlled so as to maintain part orientation. For large shallow parts and single-cavity molds, opening the mold only a short distance permits the stationary mold half to guide the mold part as it falls. With multicavity molds, a special guiding mechanism—side tracks or rails within the molds—usually is required. When the mold is closed, the rails are shuttled by a cam mechanism to a position outside the molding surfaces. As the mold opens, the rails are indexed inward surrounding the side surfaces of the ejected parts. Stationary tracks installed below the mold guide the parts downward and move them towards a subsequent processing or packing station.

While controlled drop systems ensure 100% reliability in part orientation, they are limited to relatively shallow parts (2 in. maximum depth). Round and square shapes are handled most effectively by this means, with at least two points of symmetry required for proper tracking.

Because the rails must entrap the part, the runner system and method of gating are critical. Runnerless molds simplify the use of guide rails. With cold runner molds, runners must be separated from the part before the rails move into position. Either three-plate or self-degating molds (with secondary ejection of the runners) may be used for cold runner applications.

Positive takeout

The most effective means of orienting parts is to grasp them directly as they are ejected from the mold. A wide range of part sizes and shapes can be handled since pickup devices can be designed to specific part configurations. Runners can be removed simultaneously or ejected sepa-

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