

PVC FABRICATION AND APPLICATIONS

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by

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BIOGRAPHIES

W. C. Douglas was graduated from Purdue University in 1958 with a Bachelor of Science degree in Chemical Engineering. He initially joined Standard Oil Company of Ohio where his work centered around the development and technical applications of secondary plasticizers for vinyl resins. Since 1963 he has been employed by The General Tire & Rubber Company as Technical Service Chemist in the field of polyurethane foams. He is a member of the Society of Plastics Engineers.

J. M. Gyenge was graduated from Baldwin Wallace College in 1943 with a Bachelor of Science degree in Chemistry. He has done graduate work at Akron University in polymer chemistry. From 1946 to 1956, he was a development chemist at the Akron Government Development Laboratories of Rubber Reserve. In The General Tire & Rubber Company's Chemical Division he has served as both Technical Service Representative and as Sales Development Engineer. He was appointed to his present position, Manager, Technical Service, in 1959. Mr. Gyenge is a member of the American Chemical Society.

George Hackim was graduated from the University of Akron in 1947 with the degree of Bachelor of Science in Chemistry. First employed by the Sun Rubber Company, he came to The General Tire & Rubber Company in 1948 in the production training program. From a first assignment in Research, he was transferred to the Chemical Division in 1950 as Manager of Technical Service and later became Sales Manager. In the newly formed Chemical Plastics Division he was: Assistant Director of Sales, 1962; General Sales Manager, 1963; and has been Vice President-Industrial Sales since early 1964. Mr. Hackim is a member of the American Chemical Society, the Society of the Plastics Industry, and is former chairman of the Akron Rubber Group.

Albert J. Hanley is Section Head of Plastic Evaluation and Application for The General Tire & Rubber Company. Graduated in 1920 from Massachusetts Institute of Technology with a Bachelor of Science degree in Chemical Engineering, he went on to serve as head of the chemistry department at Mount Saint Mary's College, Maryland, until 1926. He became, in turn, chief chemist at Textileather and Technical Director for Respro, Inc., plastics manufacturers, until these firms were absorbed by the parent company in 1955. At that time he became Group Head of Plastic Evaluation and Application until appointed to his present post in 1962. Mr. Hanley is a member of the American Chemical Society, the Society of Plastics Engineers, and the Society of Plastics Industries.

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FABRICATION AND APPLICATIONS

I. Introduction

The previous papers have described how polyvinyl chloride is obtained as a granular powder. In this state, PVC has very limited use and the conversion of PVC into commercial products depends upon its modification through compounding.

The many compositions obtainable from PVC are highly adaptable to a number of operations which convert the materials into usable products. Most PVC products are obtained by calendering, extrusion, and coating techniques. Other conversion methods such as blow molding, compression molding, injection molding, and fluidized bed are used to a lesser degree.

The molecular weight of the resin, compounding, processing, and finishing all contribute to the performance and appearance of the final product. The great variety of end uses for PVC make it one of America's most thriving and expanding industries. PVC, more than any other polymer, is synonymous with versatility.

II. End Use Applications

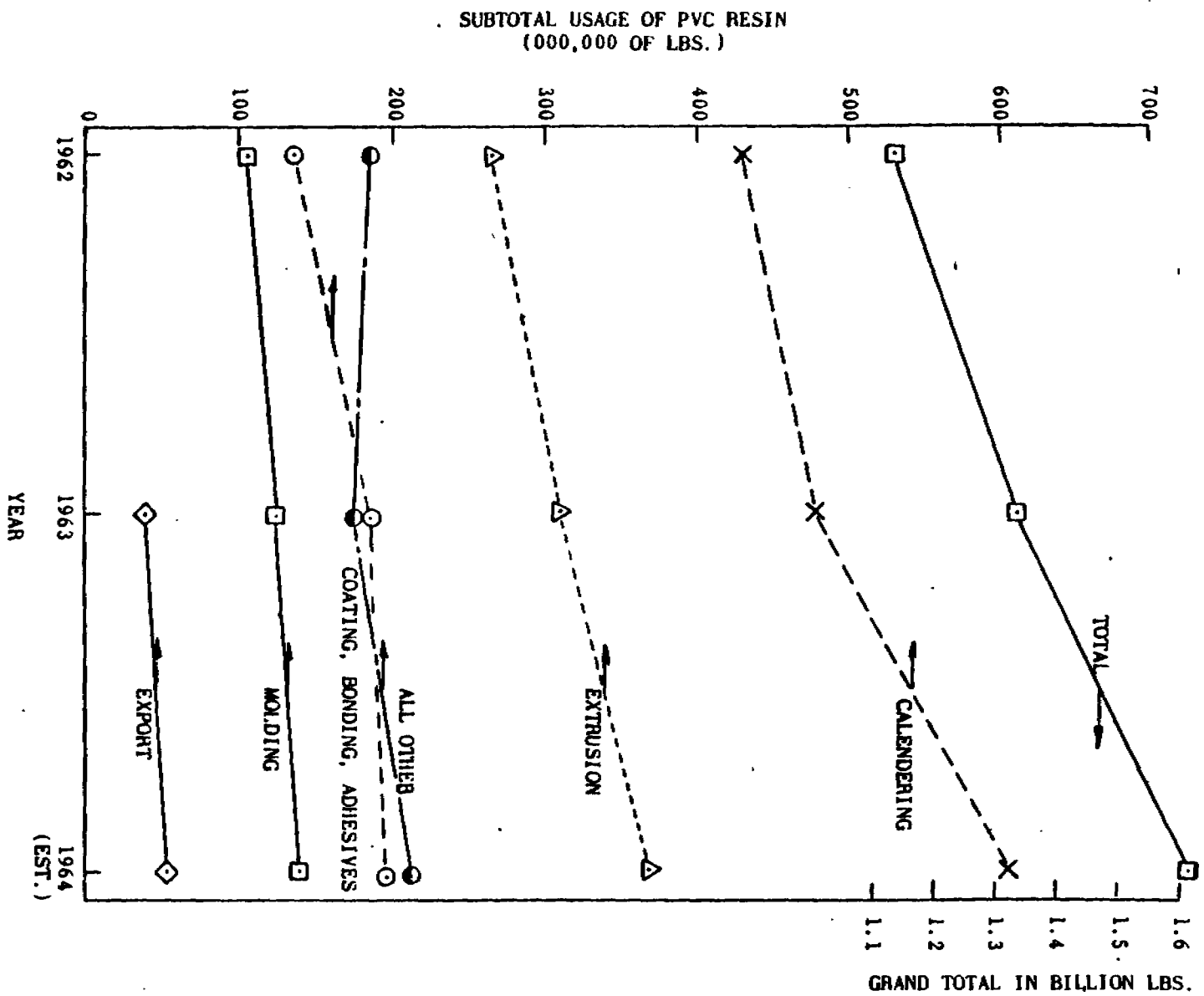
In 1962, PVC became the world's first billion pound plastic. Figure 1 shows the sales volumes of the various classifications of vinyl for 1962 and 1963. It can be seen from the curves that calendering and extrusion captures the bulk of the market. Poundage for 1963 was greater than in 1962 in every classification except miscellaneous, and the total increase for the one year period is 18%. Indications are that 1964 will show a similar increase over 1963 and PVC seems headed toward a two billion pound market in the near future.

As PVC has grown in volume, the price has dropped accordingly, further accelerating the plastics industry's interest in the material. The current low price of 16¢/lb. contributes toward making PVC one of the first materials considered when production of a new plastic article is being planned. Though the 1.40 specific gravity of the unplasticized resin is relatively high, the pound-volume costs of the plasticized compounds are much more favorable.

This poundage is not consumed as a single product or application. PVC has widespread utility in products ranging in stiffness from rigid sheet for construction applications to flexible film for food wrapping. This extreme difference in end product application is possible because the basic vinyl polymer can be solvated by plasticizers over a range of concentrations.

All of these PVC compounds are thermoplastic in character and acquire at some critical elevated temperature a rubber-like consistency. Therefore, it is not surprising that in the early days plasticized vinyl compounds were converted or formed to shape on equipment found in the rubber industry. Experience soon demonstrated that calendering, tubing, extruding, and pressing machines for rubber were inefficient for making quality vinyl products. These same types of converting machines were modified in basic engineering design, temperature range, and automatic control in order to manufacture vinyl end-products to extremely close dimensional tolerances.

FIGURE 1. YEARLY CONSUMPTION OF PVC RESIN



III. PVC Resin Types

As outlined earlier, the basic polyvinyl chloride can be polymerized or copolymerized by suspension, emulsion, or solution techniques. For the purposes of this paper, the emphasis will be placed on the suspension type of resin.

PVC polymer can be made in a wide range of chain lengths or molecular weights. For control and identification purposes, the molecular weight is characterized by the polymer's intrinsic viscosity in a solvent solution. The higher molecular weight polymers possess higher tensile strength and hardness, better resistance to flow at elevated temperatures, and improved solvent resistance, when compared to their lower molecular weight homologs.

Table 1

Effect of Molecular Weight on PVC Properties

Resin	<u>Vygen 85</u>	<u>Vygen 105</u>	<u>Vygen 110</u>	<u>Vygen 120</u>
Molecular Weight*	74,000	83,000	93,000	107,000
Intrinsic Viscosity	.80	.93	1.03	1.18
Tensile Strength, psi**	2160	2490	2730	2890
Ultimate Elongation, %**	230	300	340	350
Tensile Stress at 100% Elongation, psi**	1290	1400	1420	1460
Shore A Hardness,				
0 Sec.	91	91	91	92
10 Sec.	80	80	81	82
Formulation	Resin - 100 parts			
	DOP - 50 parts			
	Ba-Cd Stabilizer - 2 parts			

* D. J. Mead and R. M. Fuoss, J. American Chemical Society, 64, 277, (1942)

** ASTM D-412-61T

In a typical formulation using 50 parts of dioctyl phthalate (DOP) plasticizer per hundred parts of resin and resins of differing intrinsic viscosity ranging from 0.80 to 1.18, it can be seen that the tensile strength, elongation at break, and Shore A hardness increase with increasing molecular weight. Figures 2 and 3 show these points graphically.

FIGURE 2. EFFECT OF MOLECULAR WEIGHT ON TENSILE STRENGTH

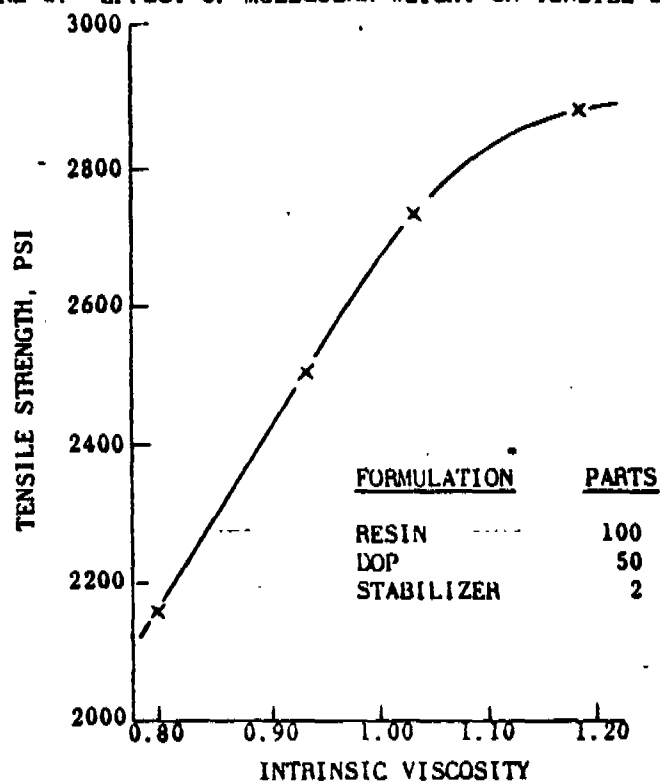
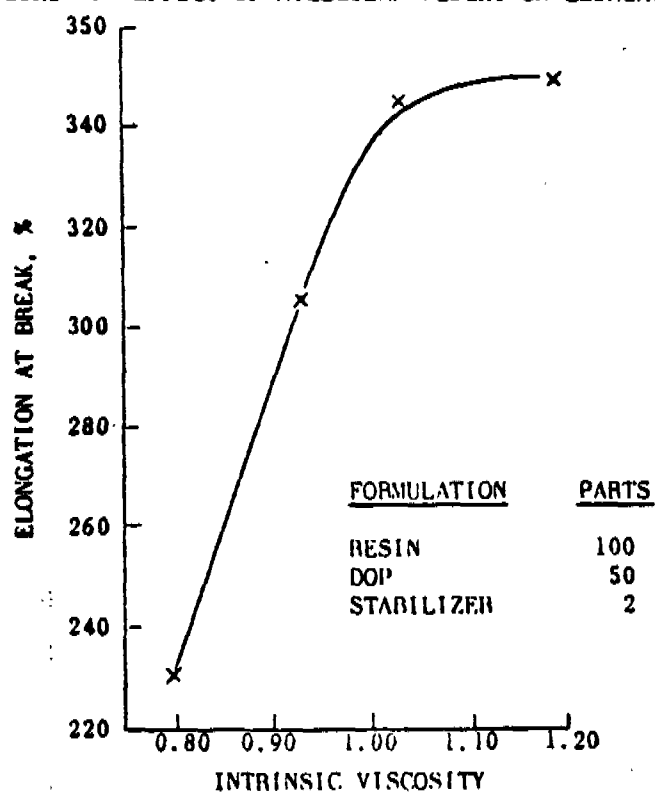
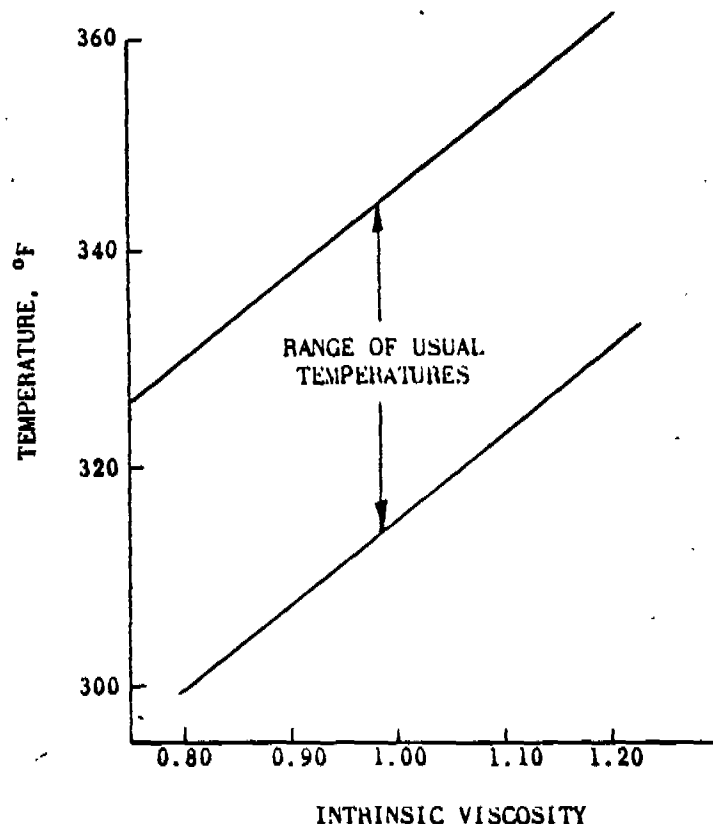


FIGURE 3. EFFECT OF MOLECULAR WEIGHT ON ELONGATION



Calendering temperatures increase from a 300° to 330°F level with a 0.80 viscosity resin to a 330° to 360°F level for the 1.18 viscosity resin, as shown in Figure 4.

FIGURE 4. EFFECT OF MOLECULAR WEIGHT ON CALENDERING TEMPERATURE



Higher processing temperatures tend to create resin instability problems if the processing cycle is of long duration. A compromise must often be made between the molecular weight resin selected and the processing technique.

The higher molecular weight resins are used in extrusions of flexible tubing, wetting, electrical components, garden hose, and calendered film which require short dwell times at the elevated processing temperatures. Intermediate molecular weight resins are used in film and sheet, coated fabrics and rigid applications. Low molecular weight resins are used in fluidized bed coatings, phonograph records and injection molded parts.

IV. Conversion of Resin to Product

A. Compounding

1. Stabilization

Very few polymers inherently possess outstanding heat or light resistance on long term exposure, and polyvinyl chloride is no exception. The science of PVC degradation is well established and, although complicated, is known to involve the loss of a chlorine and a hydrogen atom from adjacent carbon atoms on the backbone chain. Strong alkali promotes this loss of hydrogen chloride. A slightly alkaline metallic salt will act as an acid acceptor and prevent further generation of HCl along the polymer chain. Lead salts such as basic lead carbonate or lead silicate were the earliest stabilizers used in polyvinyl chloride. Lead stabilizers are still used in electrical insulation where the service specifications require up to a 105°C temperature rating.

Organo-tin compounds such as dibutyl tin dilaurate or tin maleate are liquid at processing temperatures and can be dispersed through the PVC compound more readily than solid metallic salts. They also protect the polymer by saturating the double bond created wherever HCl is lost in the first stage of decomposition.

A major advance in stabilization was the discovery that organo-cadmium compounds are synergized in their stabilizing action by companion barium organic compounds. These systems are readily dispersed and have limited solubility in plasticized PVC compounds and make possible haze-free products of good clarity and color.

2. Plasticization

It was stated previously that polyvinyl chloride resins are capable of being compounded into a wide variety of products having different degrees of flexibility and hardness. This great versatility is possible because of the softening action of plasticizers on the hard horny resin. In general, the degree of softness of the compound will be in direct proportion to the plasticizer-resin ratio. By varying this ratio, a wide range of PVC properties can be achieved.

The chemical function of a plasticizer is dependent upon the presence of polar groups in its molecular structure. This polarity allows the plasticizer molecules to be inserted between PVC resin molecules, neutralizing the Van der Waal or secondary valence bonds. This weakening of the Van der Waal forces creates localized flexible areas intermingled with resin strength areas. The combination results in a strong, yet pliable, polymer.

There is evidence that the plasticizer swells the amorphous regions and that the small regions of crystallites are unattacked or unaffected by the plasticizer. This situation is unique to polyvinyl

chloride. It permits the creation of products which are flexible without being weak, are resilient without being snappy, are more leather-like than rubbery, have surface slip without tack, and have good abrasion resistance.

Commercial products of satisfactory durability require that the solvent or plasticizing agent have long term permanence. The plasticizer should be at least as permanent as the properly stabilized resin. To be permanent, the plasticizer must either be a true solvent or be associated with a true solvent for the PVC resin. The plasticizer must resist oxidation both during processing and during long term in-use aging for periods up to five or more years. Its affinity to the resin must be greater than to foreign substances which would normally contact the PVC product in service. For upholstery, these substances would include resistance to wicking into clothing, dust or dirt, and soapy water washing. It must have a very low volatility to eliminate evaporation. It should be odorless and colorless in order to have widespread utility. When the material in question meets these specifications to a practical degree, it becomes known as a primary PVC plasticizer.

Ordinarily, a plasticizer will be a high molecular weight ester formed by the reaction of an aliphatic alcohol of eight to twelve carbon chain length with an acid which may be either phthalic, azelaic, adipic, or sebacic. Polymeric forms of esters are usually in the 2000-5000 molecular weight range. These plasticizers are used where special permanence is required.

Plasticizers are commonly liquids with viscosities which may be as low as a light oil or as thick as honey. They vary widely in their efficiency in flexibilizing the PVC resin and the particular properties contributed to the PVC product. For this reason, it is common practice to blend a mixture of plasticizers to obtain a compromise of their individual assets and defects. It is this type of blending that makes vinyl products so versatile.

Figures 5, 6, and 7 show the effect of DOP plasticizer (di-octyl phthalate) concentration on the tensile strength, elongation, and Shore A Hardness of a Vygen 120 formulation.

Where exceptional permanence or dimensional stability is demanded, chemically bound copolymers and physical polymer blends provide the answer. Nitrile rubber (butadiene/acrylonitrile) can be used, although its poor color limits it to dark colored applications. Other polymers used for modification are chlorinated polyethylene, acrylics, and acrylonitrile-butadiene-styrene (ABS) resins.

FIGURE 5. EFFECT OF DOP LEVEL ON TENSILE STRENGTH

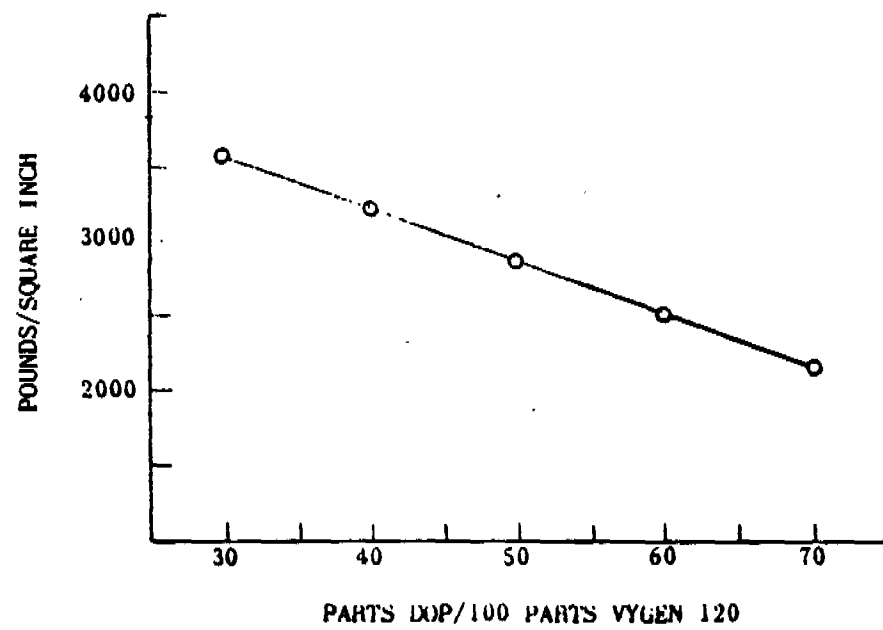


FIGURE 6. EFFECT OF DOP LEVEL ON ELONGATION

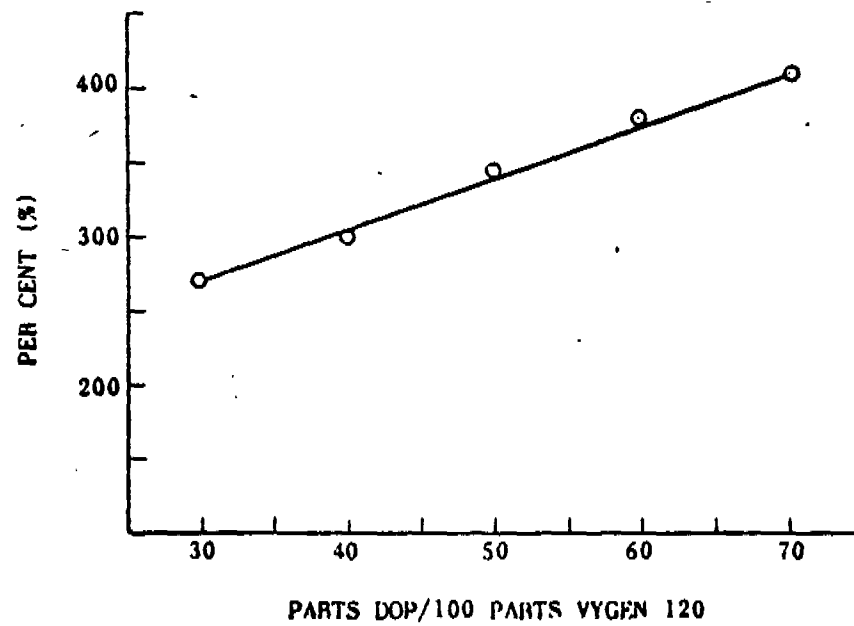
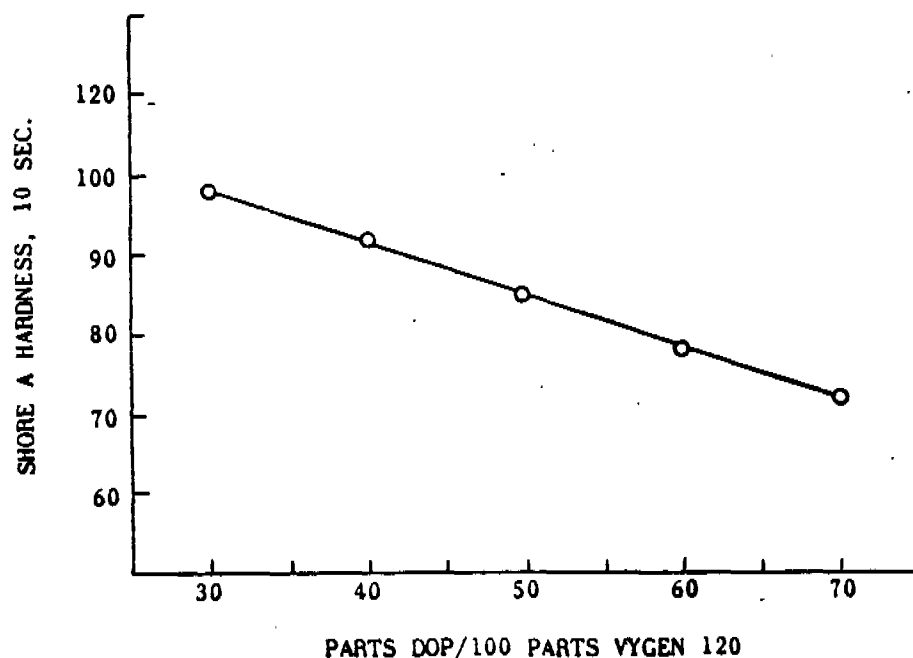


FIGURE 7. EFFECT OF DOP LEVEL ON SHORE A HARDNESS



3. Lubrication

Vinyl is processed and formed by metallic parts which may be a set of rolls, a forming die, a mold, or some other device. During this processing, the vinyl must adhere to the metal so that the plastic draws in, fills, and flows with the forming surfaces. However, this adhesion must not be great enough to cause distortion when the article is removed from these metal surfaces. Adequate parting is obtained by including in the compound trace quantities of lubricants that act as metal release agents. The release agents are soluble to only a limited degree in the vinyl compound at the processing temperatures. Thus, minute particles of the release agent are deposited on the hot metal surfaces and form a semi-continuous coating. Excessive quantities of the release agent should be avoided to prevent exudation on the finished PVC surface. Exudation of lubricant appears after processing and is not only unsightly, but can interfere with the application of decorative finishes or subsequent dielectric heat sealing. Stearic acid is a common release agent, but metallic stearates, waxes, or polyethylene have been used. Proper technology in the use of lubricants is an important factor in successful production of vinyl products.

4. Pigmentation

The growing use of PVC has been due in part to the color possibilities of the plastic.

Automotive and household upholstery are presently made in high style colors to match or contrast with any color scheme. PVC sheeting having superior durability is produced in colors and textures which offer unlimited creative styling possibilities to the designer. The pigments used must be acid resistant, stable to the processing temperatures up to 400°F, nonmigratory, and light stable. The pigments are dispersed to a fine particle size by grinding in a three-roll paint mill with part of the plasticizer. Satisfactory pigments include titanium dioxide, phthalocyanine blues and greens, and high tint carbon blacks.

Fillers are often used for cost reduction. Finely divided calcium carbonate is most often used, but clay, asbestos, and other fillers are common. Certain electrical properties are improved through the use of fillers. Flame resistance is bolstered through the incorporation of antimony trioxide and phosphate plasticizers. Electrical properties are improved with the addition of calcined clay.

B. Processes and Fabrication

1. Dryblending

A PVC compound initially is a heterogeneous mixture of the many components. The major ingredients are a PVC resin powder and a liquid plasticizer which must solvate the resin. The solvation rate of this type of system is time and temperature dependent. The most economical method of solvating the resin is through the use of inexpensive mixing equipment with large capacities. Thus, large stainless steel chambers jacketed for heating are used to churn, tumble, or agitate three to five thousand pounds of the compound. At this stage, only the colorant is omitted. The temperature is maintained at 180° to 200°F for about an hour. This equipment is often a ribbon blender.

2. Banburying

Part of the presolvated resin-plasticizer masterbatch from the pre-blender, together with the pigment paste, is fused into a homogeneous mass in an intensive shear internal mixer such as a Banbury. This machine consists of a two cylindered stator containing two powered rotors. Their operation is such that the plastic compound is sheared against and around the stator's surfaces. The stators and/or the rotors are heated to raise the temperature of the vinyl compound to its fusing temperature between 300-350°F. A plunger retains the compound within the chambers and a sliding door in the bottom of the chambers allows the fused homogeneous compound to be discharged. The capacity of production size Banburys for the vinyl industry varies from a 110 to a 600 lb. batch delivered on five minute cycles.

3. Milling

Normally, a Banbury batch is delivered to one or more 60" to 90" wide two-roll mills designed for high temperature operation. The

threefold function of the mill is: (1) to free the plastic of entrapped air whipped in by a high speed Banbury; (2) to bring the plastic to a controlled temperature (and, therefore, a constant plastic viscosity); and (3) to deliver the plastic in a ribbon of predetermined width and gauge of thickness. This ribbon stock may be fed directly to a calender or an extruder in practically an ideal plastic state, or it may be partially cooled and fed to a dicer or pelletizer to make a reserve compound inventory for future processing.

4. Calendering

A large percentage of the above mill-prepared vinyl plastic compound is fed to a calender which converts the crudely shaped ribbon into continuous lengths of film, sheeting, or coating for a substrate (i.e., woven cloth, knit fabrics, or paper, etc.) of surprisingly accurate widths and thicknesses. For example, a modern plastic calender is capable of delivering a 0.0018" gauge film with a maximum variation in gauge of ± 0.0001 ". Normally, film of this gauge can be more economically produced by extrusion, since a two million dollar calender train must have a high poundage output to justify its capital investment.

A modern calender engineered for handling plastics has four cast chilled iron rolls mounted in a Z type frame so that the influences of forces on any one roll can affect only one adjacent roll. A roll with a working face of 66" width will be from 20" to 24" in diameter while a 96" width roll face will have from 30" to 36" in diameter.

This calender will be automated both to control the gauge of the film and also to emboss, cool, and deliver the film to the packaging unit. These devices and their controls in the calender train represent an investment of a million dollars. The output production of a calender is dependent upon the gauge of the plastic delivered and generally falls in the range of 2000 to 3000 lbs. per hour for a 66" width machine.

The ordinary plastic calender produces film between 0.003" and 0.005" gauges to be used for raincoats, shower or window curtains, aprons, baby pants, food covers, and similar articles. Film between 0.005" and 0.010" gauges is used for inflatable toys, air mattresses, industrial protective covering, and electrical tape. Sheeting between 0.016" and 0.022" is used for novelty purposes such as ladies handbags, belts, wallets, and briefcases. All of these gauges are used for coating fabrics or paper that are widely used in upholstery, rainwear, apparel, boat decking, shoe trimmings, book covers, and many other uses.

Table 2 shows a typical formulation for a General Purpose Film.

Table 2

Typical PVC FormulationGeneral Purpose Film

		<u>Parts</u>
Resin:	Vygen 110	100.00
Plasticizers:	DOP	37.00
	Cresyl diphenyl phosphate	8.00
	Monomeric epoxy plasticizer	5.00
Processing aid:	Stearic acid	0.25
Stabilizer:	Ba-Cd	2.00

5. Extrusion

A second method for shaping a molten plastic into a desired shape is with an extruder. This device consists of a smooth bore cylinder with a close fitting worm screw rotating inside the cylinder. PVC compound as cold pellets, cold dry blended powder, or hot mill ribbon is fed to the extruder. It is homogeneously mixed and brought to its proper working viscosity for ultimate forming by the mechanical energy of the screw and the heat provided by the controlled temperature cylinder or barrel. The changed pitch of the screw at its end alters the screw's function from masticating and mixing to that of a positive displacement pump. The orifice or die mounted at the head of the screw is similar in shape to the desired product. The shaped extrudate is drawn in a measured degree from the die to the cooling medium, usually water. The die must be designed in such a fashion as to compensate for the change in dimensions and shape that this pull or draft exerts on the hot extrudate.

The extruder can form flat film, sheeting, and coated products similar to the products of a calender and, in addition, make hollow articles and complex shapes impossible to obtain from a calender. It is considerably less costly to install, but has only a small fraction of the capacity of a calender.

Film as thin as $\frac{1}{8}$ mil can be extruded by the blown film technique. A tube with a wall thickness of 0.012" is extruded. As the tube of hot plastic issues from the extruder, air is introduced inside the tube in sufficient quantity to expand the plastic to a 72" diameter cylinder. This simultaneously widens the film and reduces the gauge of the wall thickness. The percentage gauge tolerance of this film is far greater than the $\pm 5\%$ allowable for calendered film, but it is adequate for film used in packaging applications.

An alternate procedure to blown film is the use of a slit die with dimensions approximately equal to that of the film desired. This die requires a high degree of engineering sophistication to produce uniform flow of the PVC plastic across wide widths and especially to prevent any sectional areas in the flow of the PVC plastic that are slow moving or "dead." This latter condition can lead to

degradation of the PVC due to the excessive heat history. Slit die extrusion is true plastic forming. The films produced readily conform to close tolerances in gauge not possible with blown film. Lamination of the hot film directly to a preheated substrate such as a fabric or paper is possible with slit die extrusion. Milk carton paper is often coated in this manner.

The extruder is used for making film, monofilament strips, rods, tubing, hose and profile shapes such as refrigerator gasketing. Table 3 shows a typical PVC refrigerator gasket compound.

Table 3

Extruded Refrigerator Gasket

			<u>Parts</u>
Resin:	Vygen 120		100.00
Plasticizers:	Polymeric epoxy plasticizer		10.00
	Polymeric plasticizer		80.00
Filler:	Calcium carbonate		25.00
Stabilizer:	Ba-Cd		1.50
Processing aid:	Lubricant		0.25

The extruder is the universal device used for PVC coating of electrical wire. In this latter application, the copper wire is preheated, passed through a cross head on the extruder and carefully centered in a circular stream of extruding plastic so that an even coating surrounds the wire. The wire is pulled at a constant rate of speed and actually aids the production rate of the extruder in assisting the flow of the plastic. A cross head is a device for changing the flow of the plastic to a right angle with its normal flow.

The capacity of an extruder is rated by the diameter of its cylinder. Extruders are available in a range from 1½" to 12" with the 2½", 4½", and 6" the most popular sizes. Their output capacities are about 175,500, and 1000 pounds per hour, respectively. The technology of the action of various thermoplastic materials during extrusion has received intensive study during the past five years and many plastics have had their behaviour reduced to mathematical terms. For example, screw design has been keyed to specific thermoplastic compositions and the proper ratio of the length of the screw to its diameter (L/D) has been established. Plastic extruders normally have an L/D of at least 20/1 and often are 30/1.

As in the case of calendering, the process of cooling the extrudate and handling during postforming are highly developed operations which affect the surface characteristics, clarity, flatness, shape, and gauge of the product.

a. Rigid Vinyl

Rigid PVC contains only a small amount of plasticizer or none at all. Two types of rigid PVC are available. Type 1 possesses

excellent chemical resistance, physical properties, heat distortion, and weather resistance. Type 2 has slightly lower chemical and physical properties but has better impact resistance, up to 20 times that of Type 1. The impact strength is provided by inclusion of nitrile rubbers or modifying resins, along with stabilizers, fillers, and additives. Fabrication of Type 2 is easier and surface defects are less of a problem. Types 1 and 2 PVC are used in electrical conduit, pipe, construction panels, tank linings, valves and skylights, and many other rigid applications. Table 4 shows the effect of molecular weight and resin modifier on the physical properties of rigid PVC. The use of the ABS resin provides a substantial increase in impact resistance.

Table 4

Effect of Molecular Weight and Modifying
Resin on Rigid PVC Properties

<u>Resin</u>	<u>Intrinsic Viscosity</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>
Vygen 65	0.70	100	-	-	-	-
Vygen 85	0.80	-	100	-	70	-
Vygen 120	1.18	-	-	100	-	70
ABS*	-	-	-	-	30	30
<u>Properties</u>						
Tensile Strength, psi		7,750	7,775	7,850	6,150	6,250
Flexural Strength, psi		11,750	12,000	12,500	9,225	9,600
Flexural Modulus, psi		4.2×10^5	4.2×10^5	4.4×10^5	3.3×10^5	3.6×10^5
Notched Izod @ 77°F, ft. lb./in.		0.44	0.50	0.80	14.0	18.0
<u>Heat Distortion @ 264 psi, °C</u>						
10 mil deflection		69	69	75	66	72
60 mil deflection		75	76	80	74	78
Rockwell "R" Hardness		115	115	116	107	108

* Acrylonitrile-Butadiene-Styrene resin

b. Vinyl Foam

Vinyl foam may be prepared from suspension resin by extrusion. Nitrogen compounds which decompose under heat are used to provide the gas needed for expansion. The decomposition temperature is adjustable by a post expansion technique. In this process, the material is extruded at a temperature below the blowing agent decomposition temperature; subsequent expansion

of the foam is accomplished by heating. Minimum practical density is seven pounds per cubic foot by post expansion.

High density (40 lb./cu. ft. and higher) closed cell foam may be produced by direct extrusion and blowing of the compound within the barrel of the extruder. Expansion occurs upon the emergence of the compound from the extruder head.

Closed cell vinyl foams are also made from blends of vinyl and nitrile rubber. The proper relationship must be maintained between the cure of the nitrile and the decomposition of the blowing agent, since the curing nitrile supports the cellular matrix. Too rapid a cure leads to ruptured cells; too slow a cure results in lost gas, giving high densities. Proper balancing of the system gives densities as low as four to six pounds per cubic foot.

6. Blow Molding

Blow molding is a well-accepted process for the production of plastic bottles especially, but the use of vinyl in this process in the U.S.A. has not reached the volume which it enjoys in Europe. The slower growth of blown PVC bottles in this country has been due to a lack of stabilizers which will permit clarity of the finished bottle and still pass the toxicity requirements of the Food and Drug Administration.

Blown PVC bottles do show superior properties to polyethylene types. In addition to high clarity and good oil resistance, PVC bottles have 1/10 the oxygen permeability of similar PE bottles. Due to the high rigidity of PVC, thinner walls can be used.

An extruder is the source of the prepared hot plastic compound for blow molding. In this process a cylinder of hot plastic falls in a vertical position below the extruder head and between the opening of a split mold. The split mold closes to pinch the ends of the plastic, making a sealed tube. A hypodermic needle penetrates the interior of the sealed tube, and pressurized air is injected to expand the sealed tube until it fills the mold cavity. The cold or relatively cold mold converts the plastic to its hardened condition in a few seconds. The mold opens and discharges the molded object, and the cycle repeats itself automatically. The formed object may be a waste basket, an automobile arm rest, or a part of a toy doll, although PVC bottles have one of the most interesting possibilities for future markets. This is an intricate art requiring extremely accurate control of the temperature (i.e., viscosity) of the PVC compound.

Clarity is achieved through proper compounding and is based mainly on the stabilizer used, although the chilling rate of the hot article, particularly bottles, is also important. A rapid chill usually improves the clarity. Some degree of clarity is lost due to the increased molecular weight needed for impact strength.

Higher molecular weight also necessitates the use of higher processing temperatures.

Stabilizers sanctioned by FDA are primarily zinc and calcium types. However, these materials give less protection at processing temperatures than the barium-cadmium and tin types. The success of PVC blow molding in Europe is due to the use of di-octyl tin compounds, which are as yet unacceptable in this country.

As more acceptable stabilizers are developed, a large market will be created for PVC bottles where other thermoplastics are unacceptable. The future should see PVC bottles used to package gasoline, motor and mineral oils, polishes and insecticides, cosmetics, perfumes, disinfectants, detergents, foods, and soft drinks.

7. Compression Molding

The molders of phonograph player records consume large tonnage of vinyl compounds for compression molding of their disks. They use a low molecular weight homopolymer or copolymer resin for this purpose and the application is a specialized industry. Clear rigid sheeting as windows for instrument panels, flexible clear sheeting as rear windows in automobiles and novelty applications, are also press molded.

8. Injection Molding

PVC compounds are used to a limited extent in injection molded parts. The rotating plasticating screw plunger type of machine is definitely preferred in processing vinyl.

9. Fluidized Bed Coatings

The fluidized bed coating technique is excellent for coating intricate metallic parts. This can be done with a powder blend containing all plasticizers, pigments, and stabilizers. The more popular and successful method is to fuse the powder blend and to then pulverize it into a fine powder.

The coating technique is to heat the part to be coated to a temperature in excess of 450°F. The heated part is then suspended in an environment of the powdered resin blend which is fluidized with a stream of air. The thickness of the fused layers can be controlled very accurately. Repeated dippings can build up thick and uniform coatings.

10. Contour Forming

Irregular formed parts, such as automotive crash pads, are usually made from flat sheets which are postformed to the desired shape. The most common procedure is to use the vacuum forming system.

In this technique the flat sheeting is softened by radiant heat to the forming temperature. The preheated sheet is then placed over

a female mold, a vacuum is drawn in the mold and the atmospheric air pressure causes the vinyl sheeting to flow and fill the contours of the mold. Since the mold is cold, the vinyl sheet loses its heat rapidly and can be lifted from the mold a minute or two later.

An alternative type of molding to vacuum forming uses air pressure to distort the hot vinyl sheeting into a female mold providing it is equipped with holes for the escape of air entrapped in the molds. The use of matched male and female molds results in products with the closest dimensional tolerance.

11. Assembly of PVC Products

PVC products are readily cut to size in multiple layers by the commonly employed motor driven circular knives or by cutting with pattern shaped dies.

Dielectric heat sealing is often used to seal PVC films and flexible sheets. In the process, the PVC to be joined is placed between two electrode sealing bars which transmit a high frequency current to the PVC and exert the required pressure on it. Heat provided by friction from shifting of the polar chains within the material causes the films to flow together and seal. The resultant seams have bond strengths equal to the strength of the goods.

The use of recommended solvent cements to make assemblies is as satisfactory as dielectric sealing and are used for large objects such as in tent-making or swimming pools. Fabric backed or supported PVC products are sewn with thread as in upholstery assembly.

C. Decorative Effects

A high percentage of vinyl resin products are consumer items and dependent upon their attractive surface appearance and style to sell. These effects are obtained by either embossing or printing the colored surface, or both.

1. Embossing

Embossing of the plastic is achieved using steel rolls engraved with impressions that will give a pleasing appearance. These rolls are mounted over rubber backup rolls in the calender or extruder train as close to the forming orifice as possible. At this location, the plastic sheet is in its ideal rheological condition to form into and permanently retain the configuration of the delicate engraving pattern of the embossing roll.

2. Printing

The majority of automotive upholstery is currently finished in metallic effects across the entire surface. These chrome tones cannot be obtained directly from the calender since the aluminum flake does not have an opportunity to "leaf" as it does in a highly

fluid vehicle. The finish must be from a colored solution using a rotogravure print technique. The fabric is subsequently dried free of solvent.

Design print falls into two classes. There are the delicate and subtle shadings associated with high grade leather effects and the gaudy and often multi-color effects of houseware and apparel materials. These are also applied on rotogravure print machines equipped with print rolls having the appropriate design engraved into their surface. At times, print machines must have up to eight stations applying different colors which print in register to make a flower reproduction.

D. Mixing and Processing of Plastisol Resins

So far we have discussed how PVC suspension produced resins are compounded and processed. Plastisol resins are handled and processed in an entirely different manner. Plastisol compounds are made so that when the resin is blended with a liquid plasticizer, the mixture is in the form of a fluid.

Plastisol resins are often termed "stir-in resins," for a common method of blending a plastisol resin formulation is the use of a simple agitator. Hi-shear mixers are quite common, although practically any method by which the resin can be dispersed uniformly in the plasticizer and/or solvents is acceptable.

In the blending process, the liquids in a formulation are charged to a vessel and agitated until mixed. Then the plastisol resin and other powders are added gradually under agitation until all materials are charged and a uniform liquid, called a "plastisol," is produced. When organic solvents are included in the formulation, the liquid is termed an "organosol." The solvents are used as viscosity reducing agents. The rheology of these liquid systems is quite critical, since they are processed by methods where the flowability must be closely controlled. Platisols are used in the following ways:

1. Dip Coating

A widely used process is dip coating. In this process, an article, such as a wire dish drainer, is dipped into the plastisol and removed. The coating is then fused onto the dipped article in forced draft ovens. When an organosol is used, the heating of the article must be carried out in two stages. The first stage consists of evaporation of the solvent under low heat; the second stage consists of fusion of the vinyl. In this way, surface imperfections due to boiling solvent during fusion are eliminated. Usually, a solvent recovery system is installed in plants using organosols for reasons of economy. In a variation of this process, cotton gloves on metal hands are dip coated in order to impart chemical protection and solvent resistance to work gloves. Articles too large for dip coating may be sprayed with plastisol and subsequently fused.

2. Slush Molding

Slush molding is, in a sense, the reverse process of dip coating. In this process the plastisol is poured into a heated mold. The mold is then inverted and only a coating of the gelled vinyl remains in the mold. Fusion and stripping of the article from the mold complete the process. Boots are made by such a technique. The main restriction of slush molding is that the article must have at least one sizeable opening to the interior to permit filling and emptying the mold of plastisol.

3. Rotational Molding

Rotational molding is much like slush molding, except that there need be no opening in the article for the introduction of plastisol. It is used for complex shapes like dolls' heads, arms, etc. It is also used for play balls, footballs, and basketballs. In the technique, a quantity of plastisol is poured into a mold, the mold is closed and rotated in three dimensions while heat is used to fuse the formulation inside. Temperatures must be controlled so as to permit even fusion and uniform flow characteristics.

4. PVC Foams

PVC foams are easily prepared from plastisols. Either a chemical which decomposes under heat or a mechanical entrapment of gas may be used. The plastisol is often laid down as a thin coating over another vinyl layer which may or may not be fused. When blown, the combination is effectively used as an insulating material resembling leather for use in outerwear. The areas of cushioning and insulating are more often captured by urethanes or polystyrenes.

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