

A high-contrast, black and white micrograph showing a complex, layered, and fibrous structure, likely a cross-section of a plastic material. The structure consists of numerous parallel and intersecting lines, creating a dense, textured appearance. The lighting highlights the edges and ridges of the layers, giving it a three-dimensional feel.

**THE STORY
OF THE
PLASTICS
INDUSTRY**

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FORWARD

FOREWORD

1. The first step is to identify the problem. This involves understanding the current situation and the goals that need to be achieved.

THE STORY OF THE PLASTICS INDUSTRY

The U.S. plastics industry is a multi-billion dollar business—and still growing at a rate faster than most other industries in this country. The 27 billion pounds of plastics it produced in the mid-1970's found use in every major market in the United States: construction, packaging, automobiles and boats, electrical/electronics, pipe and fittings, and consumer goods, to mention just a few.

Plastics are, in fact, a basic material of use—on a par with metals, glass, wood, and paper—and critical to the needs of virtually the entire spectrum of U.S. business. As life styles change, they are becoming ever more critical to tomorrow's advanced new concepts in architecture, aerospace, communications, transportation—even medicine and the arts.

Yet the materials trace their origin in this country back to only 1868 when a young printer named John Wesley Hyatt came up

with Celluloid—the first American plastic.

Because of their rapid growth in this relatively short span of time, compounded by a versatility that has spawned dozens of different families and types of plastics, each with its own special properties, public awareness of plastics has not kept pace with public interest. This booklet, therefore, has been prepared by The Society of the Plastics Industry, Inc., representing some 1400 member companies who are responsible for about 75% of plastics sales in the U.S., to answer the need. It is intended to answer your basic questions about plastics and the plastics industry, what plastics are and where and how they are used, how they can benefit both consumer and industry, and what opportunities they represent for businessmen seeking ways in which to use plastics or students, technicians, or workers looking for career opportunities in this exciting and fast-moving industry.

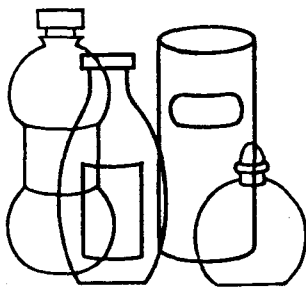
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HOW IT ALL BEGAN... AND WHERE IT'S ALL GOING

Plastics are the ultimate tribute to man's creativity and inventiveness. They are true man-made materials. But like any material, they have their origins in nature, in such basic chemical elements as carbon, oxygen, hydrogen, nitrogen, chlorine, or sulfur that are, in turn, extracted from nature's storehouse of air, water, gas, oil, coal, even plant life itself. It was man's inspiration to take these elements and combine them via various chemical reactions in an almost unending series of combinations to produce the rich variety of materials we know today as plastics.

It is possible today to create different plastics from different combinations of elements with almost any quality desired in an end-product—some similar to existing conventional materials but with greater economic values, some representing significant property improvements over existing materials, and some that can only be described as unique prime materials with characteristics unlike any previously known to man.

There are plastics that will melt at 200 F. and others that can go well over 1000 F. The heat shield that protects astronauts travelling in space is based on a concept known as "ablativ plastics." There is a "plastic armor" commercial today that can stop a bullet, even shell fragments. There are flexible plastics films that you wrap sandwiches in for a picnic lunch and there are rigid plastics rugged enough to serve as supporting members in a building.



Plastics' varied uses range from packaging....

Plastics are among the best electrical insulating materials in the world, but you can also formulate them to actually act as conductors of electricity. Plastics are the rugged shaft of a golf club, but they're also the flexible upholstery that covers your chair. They're the impact-resistant transparent safety glazing in a shower door, but they're also the transparent box you buy at a notions counter to store needles and thread.

The number of permutations possible in combining chemical elements to create plastics with different properties is almost endless. It is this diversity that has made plastics so applicable to such a broad range of end-uses and products today. Yet, paradoxically, it is also this diversity that has made it difficult for the layman to grasp the concept of a single family of materials that can encompass such a far-reaching span of properties and characteristics.

WHERE IT BEGAN

Given this kind of versatility and the role that plastics play in modern living, it's surprising to realize that a little over a century ago, there was no such thing as a commercial plastic in the United States. It is true that during the 1850s and 1860s, development work was going on with hard rubbers and cellulose materials that would pave the way for later work in plastics. But the U. S. plastics industry officially dates its beginnings back to 1868 when John Wesley Hyatt mixed pyroxylin, made from cotton (one of nature's polymers) and nitric acid, with camphor to create an entirely different and new product he called Celluloid—the first commercial plastic in the U.S. The development was in response to a competition sponsored by a manufacturer of billiard balls. It came about when a shortage developed in ivory from which billiard balls were made and the manufacturer sought another production method. Celluloid was one of the materials considered—and the U.S. plastics industry was born.

As has been typical of new plastics materials ever since then, Celluloid quickly moved into other markets. It is perhaps best remembered as the material from which wipe-clean collars, cuffs, and shirt fronts were made and as the window curtains on early automobiles. More important, the first photographic film used by Eastman was made of Celluloid to produce the first motion picture film in 1882. The material is still in use today, under its chemical name of cellulose nitrate, for making products like eyeglass frames.

Forty-one years were to pass before the plastics industry took its second major step forward. In 1909, Dr. Leo Hendrik Baekeland introduced phenolformaldehyde plastics (or phenolics as they are more popularly known)—the first plastic to achieve world-wide acceptance. More importantly, he also evolved techniques for controlling and modifying the phenolformaldehyde reaction so that useful products like marbled clock bases or electric iron handles could be formed under heat and pressure from the material. This characteristic of liquefying the material so it can be formed into various shapes under heat and pressure is still common to most plastics.

The third big thrust in plastics development took place in the 1920s with the introduction of cellulose acetate (which was similar in structure to cellulose nitrate but safer in processing and use), urea-formaldehyde (which could be processed like the phenolics but could be molded into light colored articles that were more attractive than the phenolic's blacks and browns), and poly (vinyl chloride) or vinyl or PVC, as it is also called—eventually to become the second largest selling plastic for such applications as flooring, upholstery, wire and cable insulation, pipe and fittings, and apparel use. Nylon, which you know best as fiber but which the industry also knows as an important industrial material, was developed in the late '20s through the classic research of W. T. Carothers.

As is evident in the list on page 5 which gives the year each plastic was introduced and identifies a typical end-product, the tempo of plastics development picked up considerably in the 1930s and the 1940s. Each decade saw the introduction of newer, more exciting, more versatile plastics. In the 1930s there were acrylic resins for signs and glazing and the



...to outer space. Proposed space shuttle (above) will have a large external fuel tank with an outer insulating skin based on a plastic material called polyurethane.

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commercialization of polystyrene (which had been familiar to chemists since the 1830s, but as nothing more than a curiosity). Polystyrene, of course, was destined to grow to become the third largest-selling plastic and to literally revolutionize segments of the housewares, toys, and packaging industries. Melamine resins were also introduced for use in dishware, paints, and wet-strength paper. Although not recognized as such by the consumer, they later became a critical element (in the form of a binder) in the development of decorative laminate kitchen counter tops, table tops, vertical surfacing, and the like.

In the World War II years of the 1940s, the demand for plastics accelerated as did research into new plastics that could aid in the defense effort. Polyethylene—today, the most important plastic in the world—was a war-time development that grew out of the need for a superior insulating material that could be used for applications like radar cable. The thermoset polyester resins that only a decade or so later were to radically change the boat-building business in the United States were also a war-time development introduced for military use. And acrylonitrile-butadienestyrene plastics (or ABS)—which you know best today in appliance housings, refrigerator liners, safety helmets, pipe, telephone handsets, and luggage—owes its origins to research work emanating from the war-time crash program on the large-scale production of synthetic rubber.

By the start of the 1950s, plastics were on their way to being accepted by designers and engineers as basic materials along with the more conventional ones. This decade also saw the introduction of polypropylene—following the Nobel Award-winning work of Karl Ziegler in Germany and Giulio Natta in Italy for “ordering” the molecular arrangement of plastics. Also highlighting this decade was the development of acetal and polycarbonate—two plastics that, along with nylon, came to form the nucleus of a subgroup in the plastics family known as the “engineering thermoplastics”. Their outstanding impact strength and thermal and dimensional stability enabled them to

compete directly with metals. This subgroup has grown since then to include a number of new plastics as well as improved variations on older plastics that could similarly qualify for inclusion.

The 1960s and 1970s also had their share of new plastic introductions, most notably thermoplastic polyesters (typical uses: exterior automotive parts, under-the-hood applications, and bottles) and high nitrile barrier resins with the kind of outstanding resistance to gas permeation that made them applicable for use in packaging. During this time span, another sub-group of the plastics family also started to form: the so-called “high-temperature plastics.” Including such materials as polyimides, polyamide-imides, aromatic polyesters, polyphenylene sulfide, polyether sulfone, and the like. These materials historically had their impetus in meeting the demanding thermal needs of aerospace and aircraft applications. Today, however, they have moved into the commercial areas that require their ability to operate at continuous temperatures of 400 F or more (in many cases, these materials can sustain 1000 F continuous service with 50% retention of original mechanical properties).

HOW THE INDUSTRY HAS GROWN

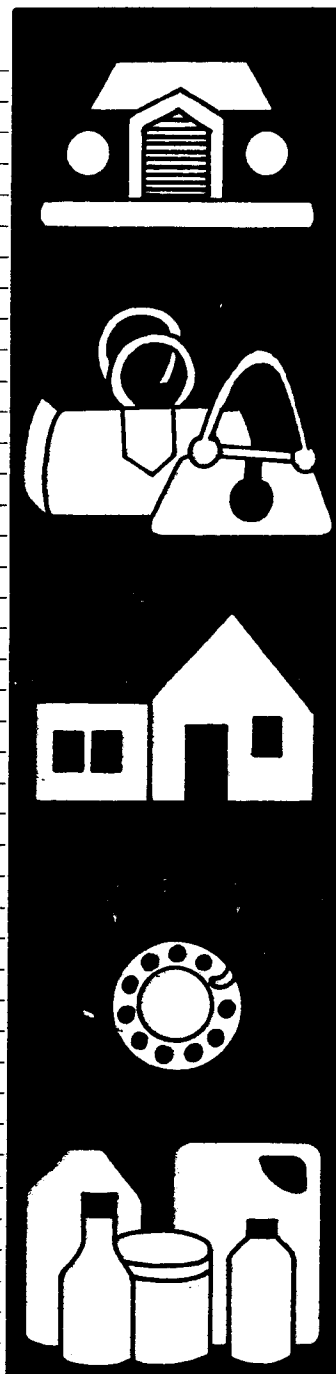
Each of these new plastics—from 1868 up until today—represented a new market possibility and each eventually resulted in a significant increase in sales. It took the U. S. plastics industry almost 80 years to reach a one-billion pound production level in the mid-1940s, but only about 20 years after that to grow to 15-billion pounds in 1967, and less than 10 years after that to approach doubling that figure to 29.3 billion pounds in 1974. Polyethylene alone had a production capacity of almost 6 billion pounds in 1974—which was more than the entire industry sold in 1959. And polyethylene wasn't even introduced to the marketplace until 1942.

Estimates are that by the year 2000, plastics materials will have grown 10-fold to a 225-billion-pound production level in the United States alone—making it one of the world's most important materials of use.

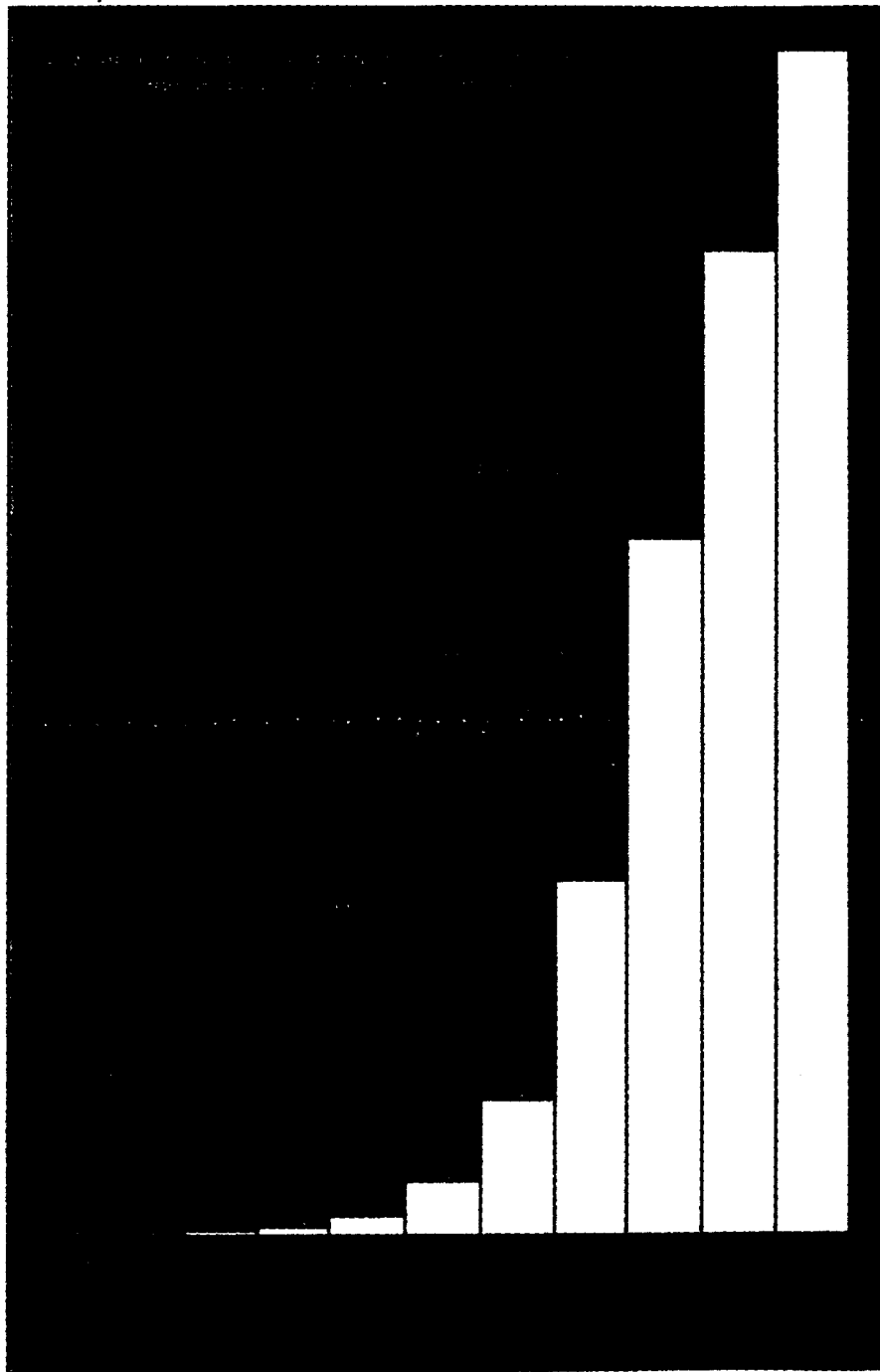
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INTRODUCTION OF PLASTICS MATERIALS

DATE	MATERIAL	TYPICAL USE
1868	CELLULOSE NITRATE	EYE GLASS FRAMES
1909	PHENOL-FORMALDEHYDE	TELEPHONE HANDSET
1909	COLD MOLDED	KNOBS AND HANDLES
1919	CASEIN	KNITTING NEEDLES
1926	ALKYD	ELECTRICAL BASES
1926	ANALINE-FORMALDEHYDE	TERMINAL BOARDS
1927	CELLULOSE ACETATE	TOOTH BRUSHES, PACKAGING
1927	POLYVINYL CHLORIDE	RAIN COATS
1929	UREA-FORMALDEHYDE	LIGHTING FIXTURES
1935	ETHYL CELLULOSE	FLASHLIGHT CASES
1936	ACRYLIC	BRUSH BACKS, DISPLAYS
1936	POLYVINYL ACETATE	FLASH BULB LINING
1938	CELLULOSE ACETATE BUTYRATE	IRRIGATION PIPE
1938	POLYSTYRENE OR STYRENE	KITCHEN HOUSEWARES
1938	NYLON (POLYAMIDE)	GEARS
1938	POLYVINYL ACETAL	SAFETY GLASS INTERLAYER
1939	POLYVINYLIDENE CHLORIDE	AUTO SEAT COVERS
1939	MELAMINE-FORMALDEHYDE	TABLEWARE
1942	POLYESTER	BOAT HULLS
1942	POLYETHYLENE	SQUEEZABLE BOTTLES
1943	FLUOROCARBON	INDUSTRIAL GASKETS
1943	SILICONE	MOTOR INSULATION
1945	CELLULOSE PROPIONATE	AUTOMATIC PENS AND PENCILS
1947	EPOXY	TOOLS AND JIGS
1948	ACRYLONITRILE-BUTADIENE-STYRENE	LUGGAGE
1949	ALLYLIC	ELECTRICAL CONNECTORS
1954	POLYURETHANE OR URETHANE	FOAM CUSHIONS
1956	ACETAL	AUTOMOTIVE PARTS
1957	POLYPROPYLENE	SAFETY HELMETS
1957	POLYCARBONATE	APPLIANCE PARTS
1959	CHLORINATED POLYETHER	VALVES AND FITTINGS
1962	PHENOXY	BOTTLES
1962	POLYALLOMER	TYPEWRITER CASES
1964	IONOMER	SKIN PACKAGES
1964	POLYPHENYLENE OXIDE	BATTERY CASES
1964	POLYIMIDE	BEARINGS
1964	ETHYLENE-VINYL ACETATE	HEAVY GAUGE FLEXIBLE SHEETING
1965	PARYLENE	INSULATING COATINGS
1965	POLYSULFONE	ELECTRICAL/ELECTRONIC PARTS
1970	THERMOPLASTIC POLYESTER	ELECTRICAL/ELECTRONIC PARTS
1973	POLYBUTYLENE	PIPING
1975	NITRILE BARRIER RESINS	CONTAINERS



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PLASTICS—PARTNER IN TODAY'S LIVING

Plastics are already one of the more important materials of use—taking their place in commerce along with metals, glass, wood, and paper. One would be hard put to find a market in the United States today into which plastics, either by themselves or in combination with other materials, do not play a vital role. One would be hard put to visualize a world offering similar comfort and convenience that did not include plastics.

Because of the diversity of plastics, many of their uses still go unrecognized. Every consumer certainly is aware of plastics in the form of housewares, toys, appliance parts, knobs, handles, electrical fixtures, toothbrushes, cups and lids, packages, and household detergent bottles.

But few are aware that the lifelines of all communications—television, radio, telephone, radar, sonar, telstar—are based on plastics for insulation and other vital components

... that plastics provided the material needed to develop the automobile ignition system and that the average car in the mid-1970s contained over 160 pounds of plastics, including those plastics that have helped Detroit meet exacting new safety standards

... that plastics foams changed modern-day concepts of cushioning and insulation

... that plastics played key roles in the miniaturization and printed circuitry concepts that revamped the entire electrical/electronics industry in the 1950s

... that plastics are essential to modern-day prosthetics and to the life-saving concept of replacing defective heart valves, sockets and joints, and other parts of the human body with plastic parts

... that most of the domes that cover modern-day sports stadiums are a plastic development or that quick-to-erect plastics shelters have helped thousands of victims of earthquakes, floods, or other disasters

... or that in aerospace and aircraft, plastics contributed to the pioneering flights of Alcock and Brown, Lindbergh, Byrd, Shepard, and Glenn (it is even said that the Wright Brothers in the '80s used

plastics—cellulose nitrate solutions on glider wings and on the wings of the plane in which they made their historic flight in 1903).

There are plastics uses that go unrecognized because they show up in combination with other materials. All "paper" cartons for milk have protective coatings of polyethylene, many metal cans have protective plastics linings, many glass bottles have protective plastics coverings. So-called "decorative laminates" for counter and table tops are based on liquid plastics as a binder and surfacing material combined with layers of paper and compressed under heat and pressure.

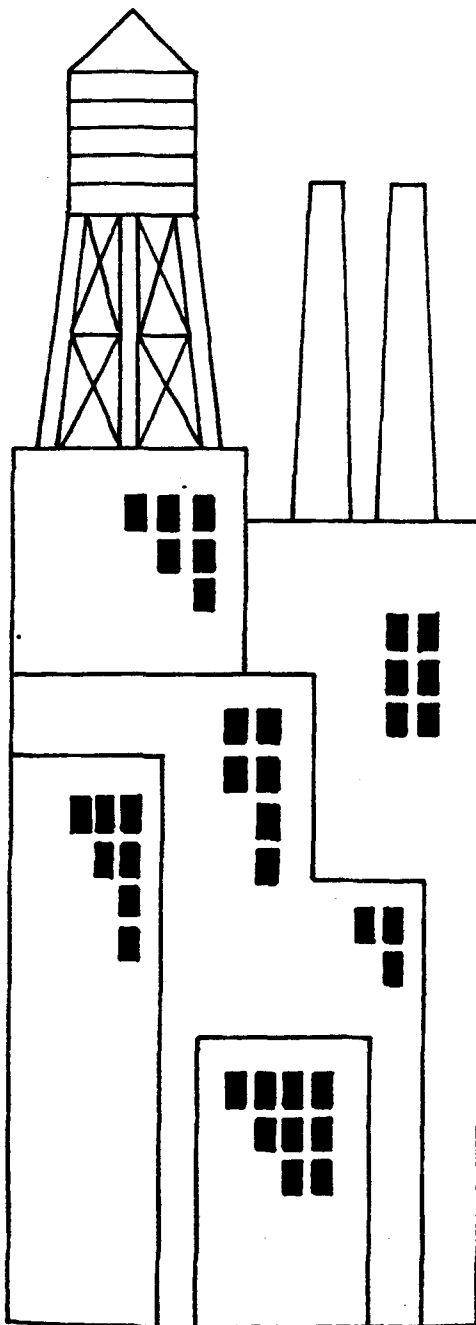
There are other plastics uses that go unrecognized because of the similar appearance of the plastics to other materials—such as plastics outerwear apparel with the gloss of leather or plastics furniture with integral wood grain patterns or plastic automotive grilles that can be electroplated with a metallic surface.

There are still other plastics uses that go unrecognized because they are essentially hidden in the finished product, like the myriad uses of plastics for electrical insulation or the use of urethane foam as thermal insulation in refrigerators—a concept that has given you more food-storing capacity without increasing the outside dimensions of your refrigerator. There are not many people who know that all U.S. automotive windshields contain a plastic interliner which greatly improves safety.

But one thing is certain. Plastics do contribute much to the way in which we live, work, and play. And the end is not yet in sight. Hundreds of millions of dollars continue to be spent by the industry each year in the development of new plastics or the improvement of existing plastics. The industry's technology is now at a point where plastics materials can be tailored to meet the specific demands of special applications.

No matter how our society may change in the future, no matter what transitions we may see in our life styles, chances are that the fertile mind of man will be able to formulate a plastic that will make those changes and transitions just that much easier to accomplish.

THE STRUCTURE OF THE PLASTICS INDUSTRY



Today, a minimum of 6,000 companies in the United States make plastics their business—that is, they produce basic materials or they process or fabricate plastics into products or parts or they finish these goods in some way by decorating or other means. The number of companies that are customers for these materials and services or that use plastics in one way or another number well into the tens of thousands. Sometimes there is an overlapping of functions between industry and market (e.g., customer companies like automotive and packaging are themselves among the world's largest processors of plastics into products and parts), just as there is an overlapping of functions within the industry itself (e.g., materials manufacturers may also do processing and finishing). Basically, however, the structure of the plastics industry breaks down along the following lines:

PLASTICS MATERIALS MANUFACTURERS

These manufacturers or suppliers use chemical reactions to transform basic feedstocks (usually called monomers and derived from gas, oil, etc.) into plastics materials (or polymers or resin, as they are also called). These materials are then sold in the form of granules, powder, pellets, flake, or liquids for eventual processing into finished products.

MANUFACTURERS OF CHEMICALS, ADDITIVES, MODIFIERS

Between the polymer which the materials manufacturer offers and the finished compound that goes to the processor, there is often an intermediate step that involves the addition of modifiers, chemicals, and additives which serve to impart special properties to the plastic or upgrade existing ones. For example, plastics can be integrally colored (with pigments or dyes) or made more flexible (with plasticizers) or more resistant to light and heat (with stabilizers) or even stronger and more impact resistant (with fiber reinforcements). The companies that supply these modifiers are often the materials manufacturers themselves; in other instances, they are separate companies specializing in the production of one or more specific types of modifiers for plastics.

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COMPOUNDING/ FORMULATING

Again, the compounding or formulating of the base resin (through the addition of the modifiers described above) into the finished plastic material that goes to the processor is usually performed by the materials manufacturer. However, there is a group within the plastics industry that will buy the base polymer from the materials manufacturer and then specially compound it (e.g., add color, modifiers, additives, etc.) for re-sale to the processor. They are known as compounders. It is also possible for the processor to buy base polymers, modifiers, and additives directly and do his own compounding.

THE PROCESSOR

The plastics processor is at the heart of the industry. It is his function to turn the plastics material into secondary products (e.g., film, sheet, rod, tube, etc.), component parts, or finished end-products. In general terms, processors are classified according to whether they are doing the processing on a custom basis for end-users ("custom processors"), or whether they are manufacturing plastics products, like say housewares or toys, for direct sale to consumers ("proprietary processors"), or whether they represent captive (in-house) production facilities for manufacturers who use plastics parts in large volume ("captive processors"). Again, functions often overlap. Many custom processors also carry proprietary plastics lines.

In more specific terms, plastics processors are classified according to the type of processing they do, as follows:

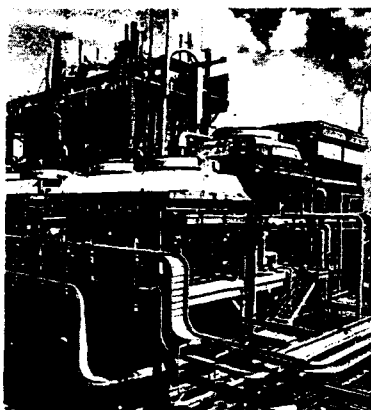
MOLDERS produce finished products by forcing melted plastic (in its molten state) into a mold of the desired shape where it cools and is ejected as a finished piece. They are further sub-classified by the type of molding they do: conventional injection molding, structural foam molding, reaction injection molding, compression/transfer molding, blow molding, etc.

EXTRUDERS generally produce a continuous shape by forcing melted plastic through a shaping die, then cooling it so that it solidifies into such products as film, sheet, rod, tube, pipe, wire covering, paper coating, heavy monofilaments, or thread-like filaments that can be woven into fabrics for upholstery, screening, etc.

CALENDERING is another technique for producing film and sheeting by squeezing plastics down between heated metal rolls.

CASTERS work with liquid systems that they pour into molds where they set up into either solid or foamed parts that duplicate the contours of the mold cavity. Casting can also be used to produce film and sheet. An offshoot of the casting business is the potting and encapsulation of electrical/electronic components.

HIGH-PRESSURE LAMINATORS form sheets, rods, and tubes from paper, cloth, glass and wood that have been impregnated with resin solutions, then subjected to heat and pressure.



Typical chemical plant for transforming a gaseous monomer into the finished plastic material...



...which is then granulated or pelletized into a free-flowing form to be shipped to processors.

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COATERS make use of various coating techniques (spread coating, dip coating, etc.) to coat such substrates as fabric, metal, and paper with plastics. Since both extrusion and calendering methods can also be used for coating, there is some overlap between the three classifications.

REINFORCED PLASTICS MANUFACTURING applies to the production of products based on plastics resins that have been combined with such fiber reinforcements as glass, graphite, synthetics, etc. There are many processing techniques unique to these manufacturers (e.g., hand lay-up, filament winding, autoclave molding, etc.), but it is also possible to use many of the more conventional molding or fabrication methods described in this section to produce reinforced plastics parts.

FOAMED PLASTICS PROCESSING also cuts across many of the processing classifications listed above. While there are again some techniques unique to plastics foams (e.g., pour-in-place, frothing, slab stock manufacturing), many processors who mold, cast, extrude, calender, or coat can, and have, worked with plastics foams.

THE FABRICATOR

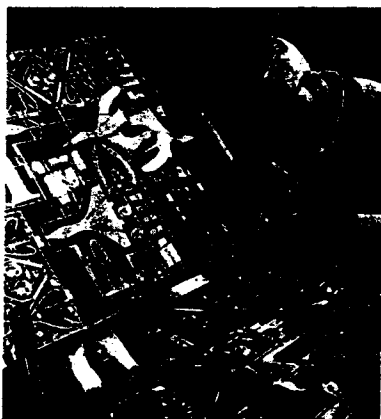
In industry terminology, the fabricator's role is to turn secondary products such as film, sheet, rod, tubes, and special shapes into end-products.

Fabricators can work with conventional machine tools and simple bending techniques to convert rigid plastics shapes into industrial parts, jewelry, signs, furniture, etc., or they can work with various die cutting and sealing methods to turn flexible film and sheeting into shower curtains, rainwear, inflatables, upholstery, packaging overwrap.

A very special category in the fabricating area involves the thermoforming process—that is, shaping heated plastic film or sheet over or into a mold by either pulling a vacuum or applying pressure in various ways. This process is used for making skin or blister packages, signs, boat hulls, sinks and basins, even entire modular bathroom units. A more recent offshoot of the process is known as stamping or forging. These techniques require considerably less heat and are applicable to modified metal stamping equipment.

FINISHING THE PRODUCT

Finishing, decorating, and assembly of the plastics end-product can either be done in-house by the plastics processor or fabricator or can be sent to companies that may specialize in various finishing techniques. Such a specialty might be the metallizing of plastics products like shower heads or car door handles to give them a chrome-like appearance or the large-volume printing of plastics film and sheet.

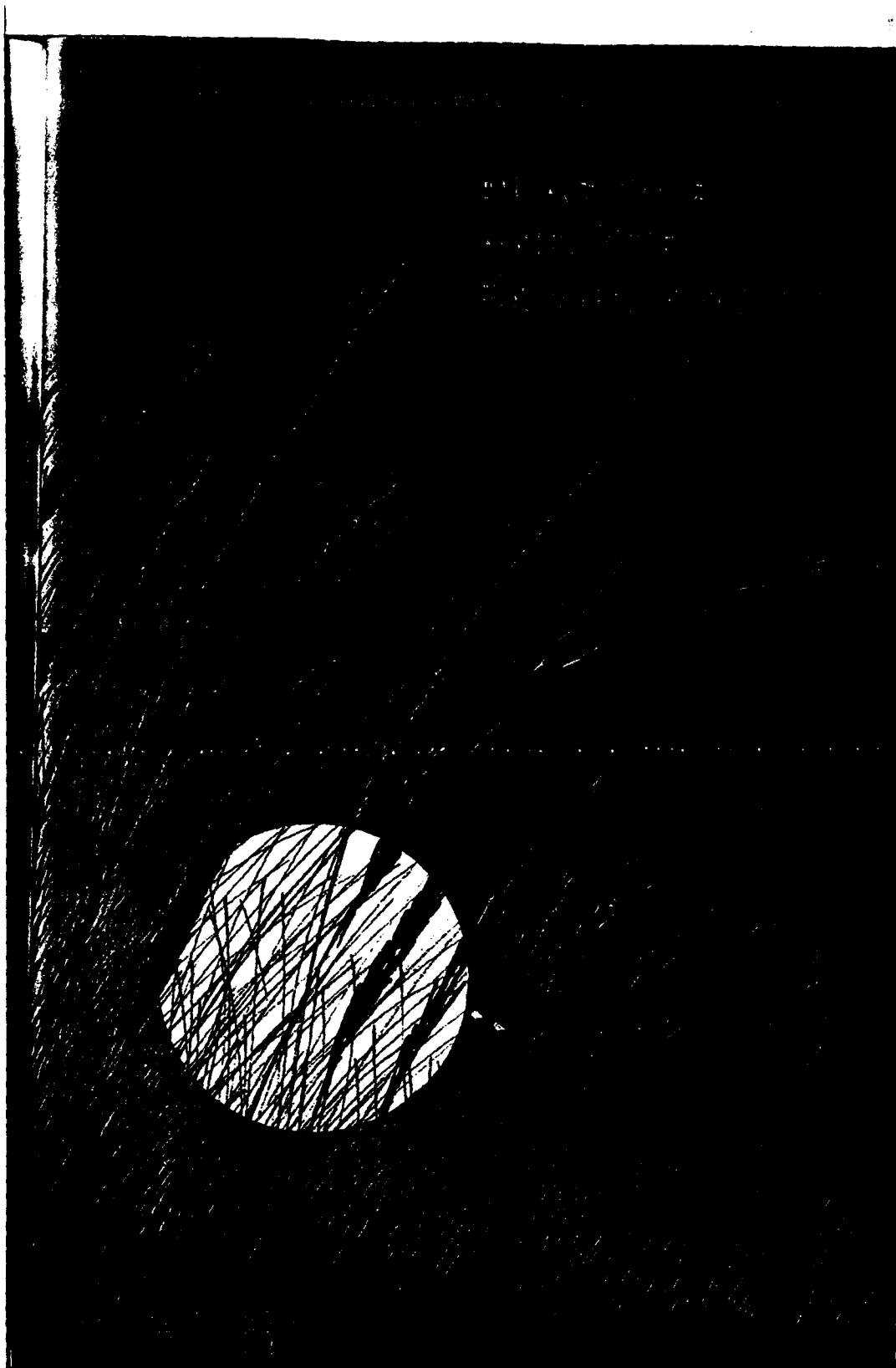


At the processor's shop, skilled mold-maker works on a mold for producing plastics parts for toy model kit (shown at left of mold).



Last stop for a plastic part is the finishing operation. Here, a wood grain-printed foil is being applied to a polystyrene TV housing.

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As man-made materials, plastics were created to meet specific needs of society, to do specific jobs. When medical men sought a unique material that could be used for replacing parts of the human body, and which would be non-toxic and would not degrade or decompose, they found it in plastics. In the automobile industry, the light weight of plastics has been a major key to fuel conservation, just as their impact resistance and flexibility have contributed to safety. In the packaging industry, the durability and versatility of plastics helped usher in a new era of convenience and safety that has markedly changed the way we buy and use packaged goods.

The list of such developments is extensive, including, more recently, the utilization of plastics' unique resistance to corrosion in the design of modern pollution control equipment, and the use of its thermal insulating properties to help reduce home heating requirements and conserve energy.

Yet, in the 1960s and early 1970s when environmental concerns mounted, some of the characteristics of plastics that had been considered desirable were turned 180 degrees and listed as detrimental. First, there was some concern about the manufacturing process itself, as there was at that time for all manufacturing industries. But steps were quickly taken to meet existing standards and regulations.

However, the major environmental concerns about plastics related more to the

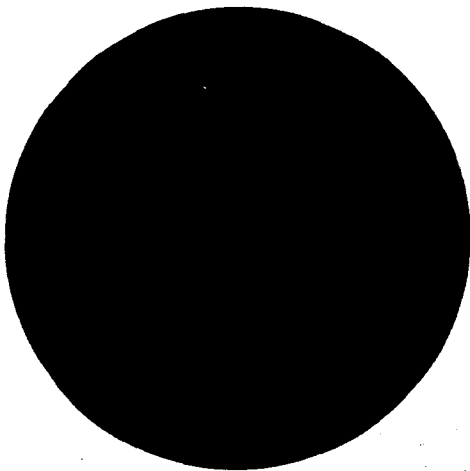
point in its life when a product went into use and was then discarded—the generation of solid waste in the form of household rubbish, trash and garbage. The issues concerning plastics centered on their role in litter, in incineration, in landfill and in recycling.

Some of the issues have since been found to have little substance, while others are still being debated. In the "littering" issue, for example, there is fairly general agreement that this is a "people" problem and not a "materials" problem. The issue arises more from the disposable nature of some products than it does from the materials used for the products (e.g., plastics and glass bottles, metal cans, newspapers, paper cartons, etc.).

In the "problem" of incineration, modern technology has made it clear that in an efficiently operated incinerator there is little problem with the gases, smoke or soot from any material, including plastics. In a substandard incinerator, there can be problems with many materials, again including plastics but also including food waste, paper etc.

In sanitary landfill, where waste is compacted and covered with soil for eventual recovery and reuse of the land, the resistance of various plastics to degradation has been labeled by various groups as a disadvantage. This characteristic is one of the very reasons, of course, why plastics are used in so many applications. And there are many sanitation officials who feel that nondegradable plastics make a very stable material for landfills because they do not break down and pollute the water table with decaying matter or chemical residues, nor do they continue to settle over the years. A landfill with a heavy proportion of plastics in it could thus be quickly turned into reclaimed land. This debate on "biodegradability" continues.

In recycling, the problem does not lie with the ability of plastics to be recycled. That is relatively easy to do, simply by grinding the plastic product down to a pellet form that can then be fed directly back into a processing machine to make another product. The major problem arises, instead, in separating the many diverse plastics and non-plastics materials out of a mixed waste stream so that each can be recycled. The economics have not supported this



activity, and the technology exists to do it.

The plastics industry believes, however, that the more logical approach is to recover the energy and basic feedstocks that are locked inside the plastic rather than recover the plastic material itself.

Using the technique of pyrolysis, for example, mixtures of plastics or mixtures of plastics and other organic wastes are broken down into gases that can be recovered and then recycled into feedstocks that can be used again to make new plastics. Also, advanced incineration techniques can be used to exploit the very high energy value of plastics (comparable to coal) to generate steam for conversion to electricity. Both of these techniques are closed systems which provide a continuous renewal of resources and energy. In pyrolysis, we go from feedstock to plastic to product through pyrolysis and back to feedstock and to plastic. In the case of incineration, we can go from petroleum (energy) to plastic to product and through incineration to release the energy in plastics to provide heat and light for our cities.

PLASTICS AND HEALTH

In the early and mid-1970s, another concern came to the front of public consciousness—the effect of some of the new materials born in the technological revolution after World War II, like chemicals, pharmaceuticals and yes, plastics, on the health and safety of those who work with these materials and those who use them. The subject was obviously of equal concern

to the plastics industry. The industry had been called the attention of the Federal agencies to problems indicated by the public and by scientists. The industry was not only concerned with the health and safety of those who work with plastics and plastics in the operations that would protect everyone's concern.

The enactment of the Toxic Substances Control Act caused the Society of the Plastics Industry to go into action. As the trade association and spokesman of the plastics industry, SPI took the lead in collecting data required by the law. It also undertook the task of determining where there were gaps in knowledge and then filling those gaps by research or experiments.

SPI has also financed a wide range of research on the combustibility of plastics and plastics. Federal agencies and private organizations that replace conjecture with fact. Beyond that, using information from these research projects, SPI financed the development of a course for fire fighters' training on plastics as a means to recognize danger signs and how to overcome them. Those cases where plastics are different from other organic materials.

The health and safety of government and industry continues today with many plastics suppliers, a few who are scientists maintain extensive and heavily financed health and testing labs among the finest in the world that subject old and new materials to a rigorous battery. SPI and other trade organizations have sponsored investigations by the Federal and State agencies as the Food and Drug Administration, the Environmental Protection Agency, the Occupational Safety and Health Administration, and the National Institute of Environmental Health Sciences. The results of these investigations are being published in the public domain.

PLASTICS AND ENERGY

As the world grows more dependent on energy, the plastics industry is looking for ways to use plastics in energy production. The plastics industry is looking for ways to use plastics in energy production. The plastics industry is looking for ways to use plastics in energy production.

public awareness that plastics largely derive from petrochemicals which are products of gas and oil refining. However, the use of energy by plastics was blown far out of proportion.

At the record heights of production in the mid-1970s, petrochemicals (including those used for the manufacture of synthetic fibers, antifreeze and other products as well as plastics) never took more than four percent of the total oil barrel.

An analogy to this overemphasis by the public upon the role of plastics can be drawn from the issue of solid waste. At the height of the public outcry in the mid-1960s against plastics in the solid waste stream (described above), plastics actually accounted for less than one percent of the 360 million tons of municipal refuse then being generated from household, commercial and industrial sources.

The question of how much energy is used in making plastics also has been misunderstood. In total energy consumption (manufacturing materials, converting them into products, using the products, and then disposing of them), plastics use less energy than some prominent, competitive materials... even when we include the energy value of the petrochemical feedstock used to make the plastic. In part, this derives from the fact that the actual manufacturing operations for plastics and plastics products use relatively little energy compared to other materials. Another contributing factor: the lighter weight of plas-

tics reduces energy consumption in the shipping and distribution of products. Most products based on plastics also use less material by weight than if they were based on nonplastics.

THE ROLE OF PLASTICS

Plastics constitute a family of materials, each with its own distinctive characteristics, and neither industry nor the public should take an "all or nothing" view on their role in society. In terms of environment, health and energy, they are neither the perfect material nor the worst material. On one hand, plastics are increasingly contributing to our enjoyment of life and leisure in a way no other material has done before and there are many plastics that are totally sound in terms of environment and health. Yet it is also true that some plastics (as in any family of materials) have limitations that must be taken into account, and can be taken into account, to make sure that their use proceeds along safe and beneficial lines.

There is much the public still has to learn about plastics. The image of plastics as "synthetic" or "unnatural" or "cheap" is drawn from an industry that existed some time around World War II—and is long since gone! The concept of "plastics" as a single, all-encompassing description of a material never really existed in fact, although it existed in the minds of many. Plastics are a family—a broad and diverse family—of different materials. An environmental problem raised by one plastic cannot be arbitrarily extended to all plastics, nor conversely can the characteristics of one plastic that may be sound for the environment and health be extended to all.

As the industry continues to develop and refine the ways in which it makes and uses plastics, it is committed to safeguarding the environment and public health, while it promotes exciting, new, and worthwhile applications. Thanks to the diligence of our own scientists and technologists, the interest of government agencies which monitor us, and the concern of the public which depends on us, society will continue to benefit from the improved quality of life that plastics and other materials can bring. At the same time, we can preserve our environment, safeguard our health, and conserve our energy.

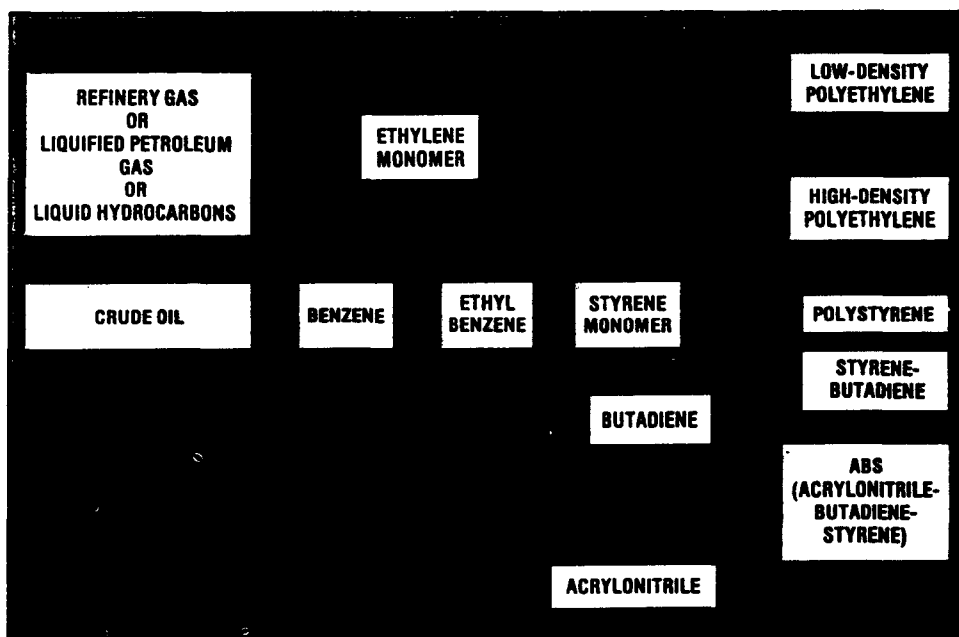
ALL ABOUT PLASTICS

To understand plastics, one must first appreciate and accept the polymer chemist's ability to literally re-arrange the molecular structure of the plastic or polymer to provide an almost infinite variety of compositions that differ in form, appearance, properties, and characteristics.

One must also approach the subject with a completely open mind that will accept all the contradictions that make it so difficult to pin common labels on the different families of plastics—or even on the various types within a single family. In the family of polyethylenes, for example, consumers are most aware of the so-called low-density polyethylenes, which are flexible materials most familiar in housewares, toys, trash bags, film overwraps, and the like. But there is another type of polyethylene called high-density polyethylene that is rigid and tough enough to be used in the manufacture of materials-handling pallets that can support thousands of pounds of stacked-up boxes. To compound the confusion even more, high-density polyethylene can also be produced in a flexible film form with properties quite different from low-density polyethylene film. Many of today's

supermarkets use shopping bags based on high-density polyethylene film.

Finally, to fully understand plastics, one must be aware of the many different routes that the starting materials for plastics can take on the way to consumer or industry. In this brochure, we are concerned primarily with those resins (or polymers) that are supplied to the processor in the form of granules, powder, pellets, flake, or liquids and are transformed by him into solid or cellular plastics products, shapes, film or sheeting, or coatings and surfaces for various substrates. However, the same starting materials used to make these resins can take another route and end up in the textile industry (nylon fibers share common roots with a molded nylon gear; acrylic fibers share common roots with acrylic sheet for glazing; etc.), the paint industry (the alkyd paints you use in your home and the alkyd resins that are processed into solid products for the electrical industry also have much in common), and the adhesives industry (the epoxy adhesives that you buy in your local hardware store are first cousin to the epoxy resin binders used for industrial reinforced plastic products).



Flow chart shows ethylene's role in the manufacture of polyethylene, polystyrene, and styrene copolymers.

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Three-dimensional model indicates the way in which small molecules link together to form longer molecules—the basic structure of most plastics. The polymer chemist is capable of changing the arrangement of the molecules to create different plastics with different properties.

A starting point for plastics

Many plastics derive from fractions of petroleum or gas that are recovered during the refining process. For example, ethylene monomer (one of the more important

on p. 15 indicates, ethylene monomer (in a gaseous form) can be combined with benzene and further chemically modified to produce another—and quite unique—monomer called a styrene monomer. When styrene monomer is polymerized, it becomes a styrene polymer or polystyrene,

not the only basic source that is used in making feedstocks for plastics, they are among the most popular and economical in use today. Coal is another excellent source in the manufacturing of feedstocks for plastics and there are other materials—including such unique possibilities as agricultural oils like castor oil or tung oil derived from plant life—that are also adaptable.

From these basic sources come the feedstocks we call monomers (that is, a small molecule or, from the prefix 'mono,' a single 'mer'). The monomer is then subjected to a chemical reaction known as polymerization that causes the small molecules to link together into ever-increasing longer molecules. Chemically, the polymerization reaction has turned the monomer into a polymer (or, from the prefix 'poly,' many 'mers'). The transformation from monomer to polymer may also help you understand why the names of so many plastics materials begin with the prefix 'poly.' Thus, a polymer may be defined as a high molecular weight compound which contains comparatively simple recurring units.

Outside of the plastics field, monomers can take different routes to produce a variety of other important products—from anti-freeze to fertilizers. Even within the plastics field, a single monomer can contribute to the manufacture of a variety of different polymers, each with its own distinctive characteristics. As the chart

Basically, there is a great deal of flexibility in the plastic manufacturing process for creating a wide range of materials. The way in which the small molecules link together into larger molecules and the structural arrangement they take (e.g., packed closely together, or separated by side protrusions or branches) is one determinant of the properties of the plastic. The length of molecules in the polymer chain is a second. The type of molecule is a third (e.g., substituting methyl groups or benzene rings or chloride atoms for hydrogen atoms; etc.). Polymerizing two or more different monomers together (a process known as copolymerization) is a fourth. And incorporating various chemicals or additives during or after polymerization is a fifth. Other modifying techniques are in use and polymer chemists continue to come up with new ones.

Turning the polymer into a product

The polymer or plastic resin must next be prepared for use by the processor who will turn it into a finished product. In some instances, it is possible to use the plastic resin as it comes out of the polymerization reaction. More often, however, it goes through other steps that put it into a form that can be more easily handled by the processor and more easily run through processing equipment. The most popular solid forms for the plastic resin are as

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pellets, granules, flake, or powder. In the hands of the processor, these solids are generally subjected to heat and pressure, melted, forced into the desired shape, then allowed to cure and set into a finished product. Plastics resins are also available as semi-solids (e.g., pastes) or as liquids, for casting.

Liquids can also be used to impregnate fibrous materials that can then be allowed to harden into so-called 'reinforced plastics'.

Another option available to processors is to use resin incorporating a blowing agent. Subjected to the heat of processing or the heat from the chemical reaction, these agents decompose and release gases that can turn a solid product into a foamed product (i.e., the gases create bubbles or cells within the plastic that impart a cellular construction).

No matter what direction is taken, however, it is important in understanding plastics to understand the general flow from basic feedstock to end-product—while also accepting the fact that there are probably exceptions to the rule all along the way (e.g., some monomers do not have to be polymerized before being processed into an end-product; rather, they can be cast to shape and polymerized in-situ, that is, while the end-product is being shaped). In most cases, however, the flow will proceed along these lines: feedstocks, known as monomers, are polymerized by chemical reaction into polymers (or plastics resins); the resins are then made into forms useful for processing, sometimes called molding or extrusion compounds (this step can also involve the incorporation, or com-

pounding in, of additives, plasticizers, modifiers, colorants, reinforcements, etc.); the compound now goes to the processor who has several techniques available to him for turning the resin into a finished product or part, into a secondary product (like sheet, rod, tube, shapes, etc.) that goes through subsequent fabricating operations, or into a coating or surfacing that can be applied to various substrates. At the processing level, plastics can also be turned into monofilaments for use in rope or household screening; or as binders, they are used with materials such as fibers (in "reinforced plastics") or sheets of paper (in "laminates") or sheets of wood (in "plywood") to turn out products like boat hulls, table tops, or airplane wing tips.

The family of plastics

There is a generally accepted definition for plastics that goes like this: Any one of a large and varied group of materials consisting wholly or in part of combinations of carbon with oxygen, hydrogen, nitrogen, and other organic and inorganic elements which, while solid in the finished state, at some stage in its manufacture is made liquid, and thus capable of being formed into various shapes, most usually (although not necessarily) through the application, either singly or together, of heat and pressure.

Plastics are a family of materials, not a single material, each member of which has its own distinct and special advantages. Whatever their properties or form, however, most plastics fall into one of two groups—the *thermoplastics* or the *thermosets*.



Thermoplastics materials melt under heat and liquify; on cooling, they solidify—like an ice cube. Process can be repeated indefinitely.

Thermoset materials solidify under heat and cannot be made liquid again—like a hard-boiled egg.

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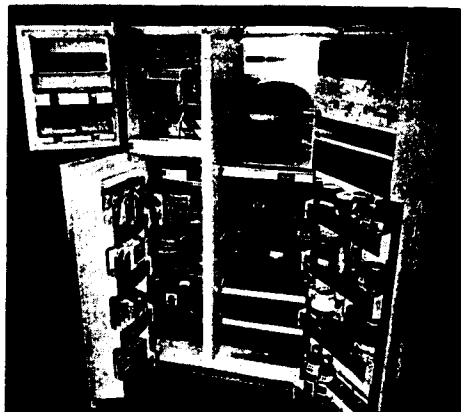
Thermoplastic resins consist of long molecules, either linear or branched, having side chains or groups that are not attached to other polymer molecules. Thus, they can be repeatedly softened and hardened by heating and cooling. Usually, thermoplastic resins are purchased as pellets or granules that are softened by heat under pressure so they can be formed, then cooled so that they harden into the final desired shape. No chemical changes generally take place during forming. The analogy would be to a block of ice that can be softened (i.e., turned back into a liquid), poured into any shape of cavity, then cooled to become a solid again.

In thermosetting resins, reactive portions of the molecules form cross-links between the long molecules during polymerization. The linear polymer chains are thus bonded together to form a three-dimensional network. Therefore, once polymerized or hardened, the material cannot be softened by heating without degrading some linkages. Thermosets are usually purchased as liquid monomer-polymer mixtures or as a partially polymerized molding compound. In this uncured condition, they can be formed to the finished shape with or without pressure and polymerized with chemicals or heat. The analogy in this case would be to a hard-boiled egg that's turned from a liquid (i.e., the yolk) to a solid (the hard-boiled egg) and cannot be converted back to a liquid.

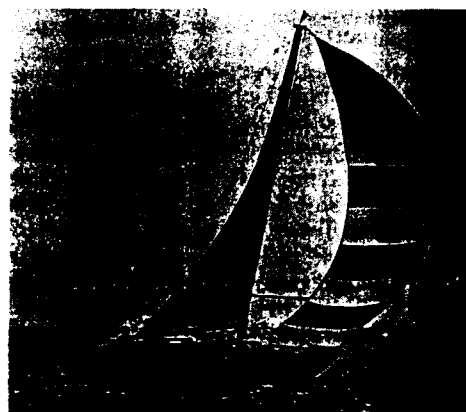
Within this framework, we've described below the major plastics materials—both thermoplastic and thermoset. Bear in mind that these descriptions are intended only to put the various plastics into perspective. None of the actual numbers used or even the word descriptions can be accepted as absolutes. It is just too easy to modify plastics in one way or another (e.g., by reinforcing with fibers or mineral fillers) to turn out a grade that would be quite different from the majority of others that exist under a specific heading.

ABS (Acrylonitrile-butadiene-styrene)

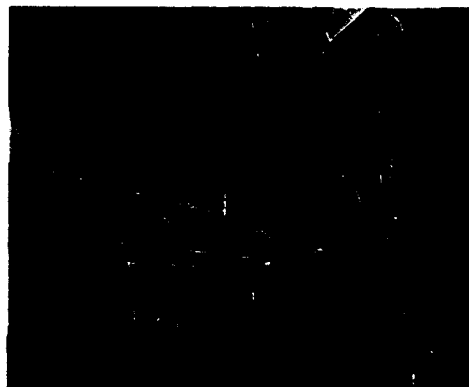
Thermoplastic. Chemically, this family of plastics are called terpolymers, in that they involve the combination of three different monomers—acrylonitrile, butadiene, and styrene—to create a single material that



MAJOR APPLIANCES: Refrigerator door panels, food liners, and crispers are based on polystyrene and ABS—tough, smooth, easy to maintain.



MARINE: Corrosion-resistant, durable reinforced plastics hulls are basic to today's sailboats, power boats, even minesweepers and ocean-going yachts.



PRINTING: Printing plates made of photosensitive polymers herald new era in the more efficient, more economical printing of newspapers.

draws from the best properties of all three. ABS, which are the initials by which it is most popularly known by industry and consumers, was introduced to the market in 1948, primarily as a result of activities that had taken place during the war years in the development of synthetic rubbers.

In terms of properties, ABS possesses outstanding impact strength and high mechanical strength, which makes it so suitable for tough consumer products. They have good dimensional stability and good electrical insulating properties.

ABS plastics are available as powder or granules for injection molding, extrusion, and calendering. They can also be blow molded; as sheet, they can be vacuum formed, pressure formed, or even "cold" stamped. Expandable grades are now commercial for producing foamed ABS parts.

You may know ABS best as the material in your telephone body or as the inner door liner in your refrigerator. Safety helmets, housings for small appliances and business machines, instrument clusters and other automotive parts (including grilles), TV and radio housings, and pipe and pipe fittings are also typical uses. In the 1960s, ABS found wide outlet as a substrate for metallizing (i.e., applying a chrome-like metallic finish to the plastic) and appeared in such products as shower heads, door handles, faucet handles, and the automotive front grilles mentioned above. Other applications: valve bodies, toys, tool handles, sailboat hulls, electric cart bodies, materials-handling trays and boxes, etc.

By eliminating the butadiene phase in an ABS resin, it is possible to create another type of plastic known as SAN or styrene acrylonitrile. SAN is known as a copolymer since it involves the mixture of only two monomers—styrene and acrylonitrile—as contrasted to three monomers in the ABS terpolymer. SAN materials, introduced in the 1950s, are rigid, transparent, and characterized by outstanding chemical resistance. Typical applications: automobile instrument panels, instrument lenses, tumblers, and housewares.

ACETAL RESINS

Thermoplastic. Acetal resins are available both as homopolymers and copolymers. They were introduced to industry in 1956

as a potential replacement for die-cast metals (especially die-cast zinc and aluminum). They were, in fact, one of the pioneers in the concept of "engineering thermoplastics"—materials that would offer greater toughness and rigidity. More important, these plastics were formulated to retain their high level of performance under load and over a wide range of temperatures and environment.

Industrial end-users are very familiar with the acetals in the form of gears, bearings, bushings, cams, housings, conveyors, and any number of moving parts in appliances, business machines, etc. Consumers may be more familiar with its uses than they realize. In today's automobile, visible acetal parts include hardware such as door handles, electrical switches, and seat belt components; in plumbing, there are valves, pumps, sinks, and faucets molded of the acetals; the bodies of lighters, replaceable cartridges in shavers, and various parts of high-quality toys are often based on acetal; and there are even acetal zippers and gas tank caps.

Acetals are extremely rigid without being brittle. They have a high melting point, high strength, good frictional properties, and resistance to fatigue. The long-term stability of parts made from acetals in terms of retention of dimensions and strength have been proved over the years. They are odorless, tasteless, and non-toxic. Acetals are highly resistant to organic solvents, but are generally not recommended for contact with strong acids or strong bases.

Acetals are available as compounds for injection molding, blow molding, and extrusion. Grades reinforced with glass fibers (higher stiffness, lower creep, improved dimensional stability) or TFE-fluorocarbon fibers (improved frictional and wear properties) are also on the market for special uses.

ACRYLICS

Thermoplastic. These plastics, introduced in 1936 in the form of hard, rigid, and transparent materials, are well-known both to industry and to the public, although they are often referred to by the tradenames under which they are sold rather than by their correct generic title. Major applications are: safety glazing; lighting diffusers (particularly enclosures

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for outdoor street lights); aircraft canopies and windows; outdoor signs; automobile tail lights; escutcheons and nameplates for appliances; washbasins and sinks; safety shields; TV shields; furniture (e.g., tables); skylights; and food and drug packages (using the new acrylic multipolymers). They are also finding increasing use in the building field in large-area enclosures for shopping centers, swimming pools, restaurants; etc., and as room dividers.

The acrylics are transformed into end-products in several ways. They are most widely used in the form of sheets. Products can also be cast directly from the liquid into molds, although acrylic molding compounds are available for injection molding, extrusion, blow molding, and other standard processing methods. It is further possible to produce acrylic in film form for use as a protective surfacing over more weather-susceptible plastic sheets.

This outstanding resistance to long-term exposure to sunlight and weathering is one of the more important characteristics of acrylic. Also notable is the exceptional clarity and good light transmission it offers (cast acrylic sheet transmits about 92% total light). In crystal-clear form, acrylics can pipe light—that is, pick it up at one end and transmit it unseen, even around curves.

Acrylics are strong, rigid, and more resistant to impact than glass. Modified acrylics and acrylic multipolymers that offer even higher impact strengths and toughness are also now available. However, acrylics are not as resistant to surface scratching as glass, although new surface coatings are being formulated to overcome this limitation.

Acrylics have low water absorption, good electrical resistivity, and fair tensile strength. Service temperatures range from 120 to 200 F, depending on the load involved and the grade used.

ALKYDS

Thermoset. This plastic was developed in 1926 and was promptly put to work in liquid form as enamels, paints, lacquers, and similar coatings for automobiles, refrigerators, stoves, and similar products—still the largest use for the alkyds. In 1948, however, an alkyd compound was introduced as a molding material for compression molding electrical applications like

circuit breaker insulation, coil forms, capacitor and resistor encapsulation, cases, housings, and switchgear components.

Major properties, of course, are in the electrical area where alkyd molding materials offer excellent dielectric strength (will resist more than 350 volts per mil), high resistance to electrical leakage, and excellent arc resistance. Alkyds also have excellent heat resistance and are dimensionally stable under high temperatures.

ALLYLICS

Thermoset. Allylics were developed after World War II. From the plastics standpoint, however, the important innovation came in 1949 when diallyl phthalate (DAP), the most widely used compound in the allylic family, was introduced for electronic parts, electrical connectors, bases, and housings.

Two of the most outstanding features of DAP are excellent dimensional stability and a high insulation resistance (5×10^6 megohms) which is retained to an extremely high degree after exposure to moisture. Also: high dielectric strength, low dielectric loss, low dielectric constant over a wide frequency range, and excellent arc resistance. DAP has a service temperature up to 350 F., but another variation in the allylic family, diallyl isophthalate (DAIP), can be used at temperatures up to 450 F. All allylics are highly resistant to decomposition by practically all chemicals and offer superior resistance to the adverse effect of weathering.



A TYPEWRITER BALL molded of phenolic typifies high level of impact resistance in modern-day applications for various plastics materials.

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In addition to availability as a molding material, the allylics are used in powder and liquid form as coating and impregnating materials.

CELLULOSICS

Thermoplastic. Cellulosics go back to the very start of the plastics industry when John Wesley Hyatt created the first commercial U. S. plastic, cellulose nitrate, in 1868. Several other important members of the cellulosics family, each with its distinct properties, were introduced in the 1900s.

Cellulosics as a group are characterized by good strength, toughness, and high surface gloss. In addition, they have good chemical resistance. There are, however, important differences among the various types.

Cellulose acetate. Good toughness and rigidity. Resistant to most household chemicals, oil, gasoline, and cleaning fluids, but should be kept away from alcohol and alkalis. Unaffected by normal moisture and moderate heat and will withstand normal usage at below freezing. Forms: molding compounds for injection molding, extrusion, blow molding, etc.; sheets, films, rods, tubes, shapes; coatings. Applications: rigid packaging, recording tape, photographic film, knobs, appliance housings, handles, toys.

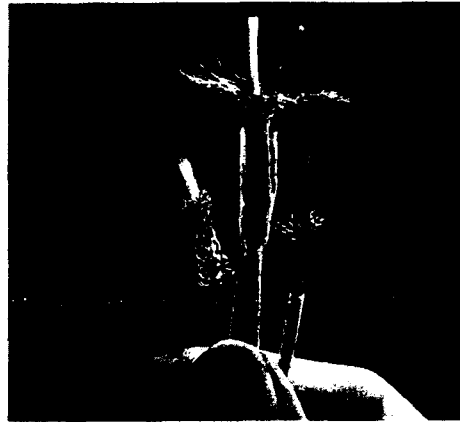
Cellulose acetate butyrate. Tougher than acetate and with lower moisture absorption. Resists weathering and has excellent transparency. Resistant to most household chemicals but adversely affected by alcohol, alkalis, paint removers, and acetones. Forms: molding compounds for injection molding, blow molding, extrusion, etc., sheets, rods, tubes, shapes; coatings (including powder coatings). Applications: tool handles, knobs, dials, appliance housings, steering wheels, signs, and light globes.

Cellulose propionate. Similar in properties to butyrate, but with somewhat higher tensile strength, modulus, and impact strength. Forms: molding compounds for injection molding and extrusion; film and sheet. Applications: automobile arm rests, pen and pencil barrels, appliance housings, and toys.

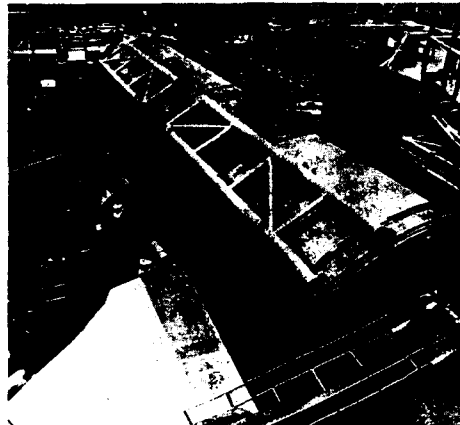
Ethyl cellulose. Excellent toughness and higher impact than other cellulosics. Can best maintain toughness and resiliency at



GREENHOUSES: Many plastics, including glass-reinforced polyester (above), acrylic, polycarbonate, films, etc., are used in glazing.



ELECTRICAL: Cables and wiring rely on superior electricals of plastics insulation based on vinyl, polyethylene, fluoroplastics (above), etc.



AEROSPACE: Largest graphite-epoxy composite structures made are these 60-ft. long cargo bay doors for the Space Shuttle Orbiter.

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sub-zero temperatures. Good dimensional stability over a wide range of temperatures and humidity conditions. Unaffected by alkalies, weak acids, but should be kept away from cleaning fluids, oils, and solvents. Forms: molding compounds (granules or flake); sheet, film, rod, tubes, and shapes. Applications: flashlight housings, tool handles, roller wheels, refrigerator breaker strips.

Cellulose nitrate: Available only as sheet, film, rod, and tube, and in solution for coatings, because it is flammable and cannot be molded. Offers a wide range of colors and variegated color effects. Applications: can be fabricated into decorative and functional products such as personal accessories, toilet articles, etc.

EPOXY

Thermoset. These plastics offer excellent electrical properties and dimensional stability, coupled with high strength, low moisture absorption, and superior adhesive characteristics for bonding metals, plastics, ceramics, glass, hard rubber, etc. Epoxies also have excellent chemical resistance.

Epoxies are used by the plastics industry in several ways. One is in combination with glass fibers (i.e., impregnating fibers with liquid epoxy resins) to produce high-strength composites or reinforced plastics that provide heightened strength, electrical and chemical properties, and heat resistance. Typical uses for epoxy-glass reinforced plastics are in aircraft components, filament wound rocket motor casings for missiles, pipes, tanks, pressure vessels, and tooling jigs and fixtures.

Epoxies are also used in the encapsulation or casting of various electrical and electronic components and in the powder coating of metal substrates. Molding compounds are also available for transfer and injection molding and most recently, liquid epoxy resins have proven adaptable to a take-off on injection molding known as liquid resin molding. Major outlets for the epoxies would also include adhesives, protective coatings in appliances, industrial equipment, gymnasium floors, etc., and sealants.

FLUOROPLASTICS

Thermoplastic. Also known as 'fluorocarbons.' Properties of this family, in general, include inertness to most chemicals, re-



BUILDING INSULATION: Urethane foam (above) and expanded styrene foam roof insulation are builder's newest tools in conserving energy.



STORAGE TANKS: Huge corrosion-resistant reinforced plastics tanks for chemicals can be produced at half the price of stainless steel.



BOTTLES: Major outlet in packaging area is plastics bottles for detergents, shampoos, milk, drugs, salad oils, syrups, cosmetics, etc.

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sistance to high temperatures, extremely low coefficients of friction, and excellent dielectric properties which are relatively insensitive to temperature and power frequency. Mechanical properties are normally low, but this changes dramatically when the fluoroplastics are reinforced with glass fibers or molybdenum disulfide fillers.

There are, however, several members of the fluoroplastics family that differ in properties and, more markedly, in processing characteristics. This group includes the following:

Tetrafluoroethylene (TFE). Very heat resistant (up to 500 F), outstanding chemical resistance, and the lowest coefficient of friction of any plastic. Can be used unlubricated. Tensile and impact strength are also good and it has outstanding low temperature characteristics. Processing: TFE cannot be processed by conventional techniques since it does not soften like other thermoplastics; it therefore must be formed by processes similar to powder metallurgy (i.e., powders are compacted to the desired shape and sintered). Applications: no-stick coatings for frying pans, non-lubricated bearings, chemical-resistant pipe and pump parts, high-temperature electrical parts, packings, gaskets, seals, and rings.

Chlorotrifluoroethylene (CTFE). Heat resistance up to 390 F., good tensile strength and impact. Chemically resistant to all inorganic corrosive liquids, including oxidizing acids and resistant to most organic solvents except certain halogenated materials and oxygen-coating compounds (which cause a slight swelling). Processing: unlike TFE, it can be molded and extruded by conventional processing techniques. Applications: coil forms, pipe and pump parts, valve diaphragms, fuel sight lenses, electrical insulators inserts and other industrial parts.

Fluorinated ethylene-propylene (FEP). This plastic shows the same properties as TFE, but exhibits a melt viscosity low enough to permit it to be molded by thermoplastic processing techniques. Applications: wire insulation and jacketing, high-frequency connectors, coils, gaskets, tube sockets.

Vinylidene fluoride. High tensile strength, low cold flow characteristics, thermally

stable at 650 F for short periods of time, 300 F for longer durations. Applications: insulation, seals and gaskets, diaphragms, chemical process equipment.

Ethylene trifluoroethylene (ETFE). Good high temperature and chemical resistance. Can be processed by conventional techniques. Applications: molded labware, valve liners, electrical connectors, coil bobbins.

Ethylene chlorotrifluoroethylene (E-CTFE). Strong, highly impact-resistant material that can also be molded or extruded on conventional thermoplastics equipment. Applications: wire and cable coatings (for applications requiring high-performance wire), chemically-resistant linings and coatings, molded labware, and film for laminates used in aircraft interiors, flexible circuitry and medical packaging.

IONOMERS

Thermoplastic. This family of plastics resins was developed in the United States in 1964. The name 'ionomer' was coined to indicate that the polymer contains inorganic as well as organic materials linked by both covalent and ionic bonds.

Ionomer film is used in the skin packaging of a number of products (i.e., the clear film is drawn over the product and a backing board to lock the two together) and as a durable heat-seal layer in composite structures (i.e., two or more different films combined together) used in the vacuum packaging of processed meat. It is also used in the extrusion coating of foil or paper for food and drug packaging and multi-wall bags. Molded ionomer products include: golf ball covers, top lifts for women's shoes, athletic shoe soles, and bumper guards for automotive exterior trim. In powder form, it can be applied as a protective covering for glass bottles.

Ionomers combine transparency with toughness, especially at low temperatures and are more resilient than polyethylene. They are virtually unaffected by oils and greases and are resistant to bases, dilute acids, hydrocarbons, ketones, alcohols, and esters. Resistance to liquid absorption is high by comparison with other plastics of comparable transparency. The ionomers are also distinguished by excellent adhesive characteristics and an ability to be easily sealed to other materials with heat.

MELAMINES

Thermoset. This plastic is a member of the amino family (which also includes urea) and is probably best known to the public as colorful, rugged dinnerware. However, it also finds use in many household goods and in various electrical applications. In liquid form, it has many applications outside of the molding area, including adhesives, coating resins, and laminating resins (e.g., decorative laminates for applications like counter tops are generally made by subjecting melamine resin-impregnated papers to heat and high pressure).

In servicing these markets, melamine resins offer extreme hardness, excellent colorability, and arc-resistant nontracking characteristics. Chemical resistance is relatively good, although the material is attacked by strong acids and alkalis. The resins perform satisfactorily over a wide temperature range from as low as -70 F to as high as 250 (cellulose- or flock-filled) to 400 F (asbestos- or glass-filled).

NITRILE BARRIER RESINS

Thermoplastic. This family of resins started to appear in the late 1960s and early 1970s. While many of the exact formulations involved are often the proprietary information of the suppliers and have not been divulged, most are characterized by the inclusion of a high degree of acrylonitrile materials. They are called barrier resins since one of their prime attributes is their resistance to the transmission of gas, aroma, or flavor. They are thus far intended primarily for use in packaging.

NYLONS (POLYAMIDES)

Thermoplastic. The nylon fiber industry was born in 1939 when 64 million pairs of nylon stockings were sold—and to this day, most people still associate nylon with fibers. However, in the '40s and '50s work continued on developing nylon compounds that could be molded and extruded or otherwise processed like plastics.

Today, the nylons comprise an important member of the plastics family. Actually, there are several different grades that are included under the family name of polyamide resins—each with related but not identical chemical compositions. Most are available in the form of compounds that

can be molded into products like gears, cams and other sliding contact devices, slide fasteners, door hinges, boat propellers, and appliance parts or extruded into film (for packaging and specialty uses such as "boil-in-the-bag" applications), sheet, or monofilament for brushes, fishing leaders, printing plates, racket strings, and sutures. Nylon can also be blow molded or rotationally molded. In liquid monomer form, it can be cast into parts that polymerize into solids as the part takes shape.

Nylons as a family are characterized by high tensile strengths, high modulus, and good impact strength. Abrasion resistance is high, resistance to heat can go to 250 F, and electrical properties and chemical resistance are good.

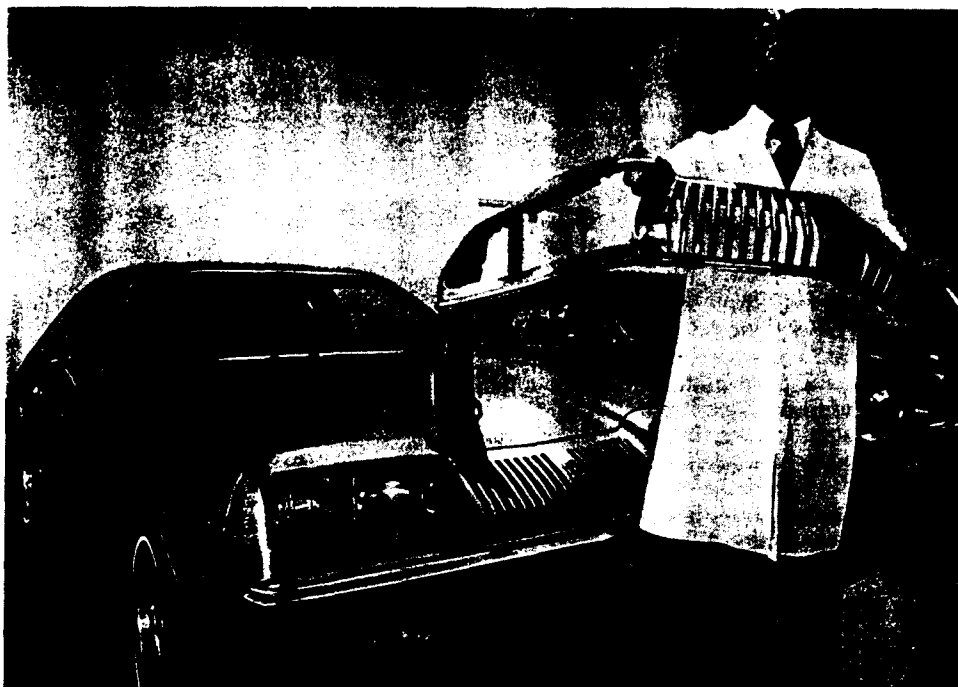
The various types of nylon that belong to the family are generally labelled according to their molecular structure. Nylon 6, for example, derives from the polymerization of caprolactam, a lactam that contains 6 carbon atoms. Nylon 6/6 has a chemical structure in which both amine and acid segments have 6 carbon atoms. Other types: nylon 8, nylon 11, nylon 12.

PHENOLIC

Thermoset. The second major plastic to be commercialized in the U. S. (in 1909), phenolics are still considered to be the workhorse of the thermosetting materials. They are found most commonly in such applications as: automotive (distributor caps, rotors, fuse blocks, and connectors); appliances (pot handles, knobs, and appliance bases); and electrical/electronic (connectors, wiring devices, and circuit breakers). Chances are most of the electrical switches in your home are based on phenolic. Like other thermosets, liquid phenolic resins also find wide outlet as bonding and adhesive resins for abrasives, brake linings, insulation, foundry and shell moldings, and laminates. It is the most popular binder for holding the various plies of wood together in plywood.

With the number and variety of types available, it is difficult to characterize phenolics as a whole. But, in general, they provide good electrical properties, excellent heat resistance, and good mechanical properties, coupled with excellent moldability. They are generally limited in color (usually black or dark brown) and color stability.

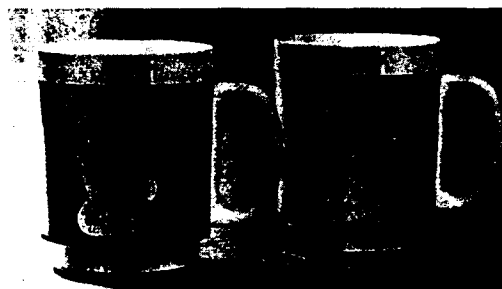
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AUTOMOTIVE EXTERIORS: Exciting potential for plastics: front end panels (shown above, in urethane elastomer), rear ends, grilles, fender extensions, hoods, doors, trunk lids, tops. Car models are already commercial with entire bodies based wholly on plastics materials.



LEISURE-TIME PRODUCTS: Molded polypropylene cooler is a familiar product. So are sporting goods like rods, golf clubs, skis, rackets, etc.



HOUSEWARES: Styrene mugs—plus plastics bowls, pitchers, canisters, thermos jugs, etc.—are standard fixtures in American homes.



CONDUIT: Major part of the pipe market is serviced by lightweight polyethylene conduit (above, for a gas and electric power plant).

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General-purpose molding grades are usually wood-flour and flock-filled. They provide a good all-around combination of moderately good mechanical, electrical, and physical properties at low cost. They are generally suitable for use at temperatures up to 300 F.

Impact grades vary with the reinforcement. In order of increasing impact strength, paper, chopped fabric or cord, and glass fibers are used. Glass fiber grades also provide substantial improvements in strength and rigidity.

Other popular variations include electrical grades and heat resistant grades (usually mineral- or glass-filled compounds that can take temperatures in the 400 to 500 F range). Special heat resistant phenolics (such as the phenyl silanes) provide good long-term stability at 500 to 550F and shorter term stability at 600F. Some types are usable for up to 1 hr as high as 1000F.

POLYPHENYLENE OXIDE-BASED RESINS

Thermoplastic. Introduced in 1964 as part of the family of engineering thermoplastics, these resins are characterized by outstanding dimensional stability at elevated temperatures, broad temperature use range, outstanding hydrolytic stability, and excellent dielectric properties over a wide range of frequencies and temperatures. Stability under long-term loading is outstanding.

Based on the grades chosen, resistance to heat (continuous) ranges from 175 to 265 F. Temperatures beyond these may be used for occasional short-time exposure. It also resists steam, aqueous chemicals, acids and bases, but will soften or dissolve in many halogenated or aromatic hydrocarbons.

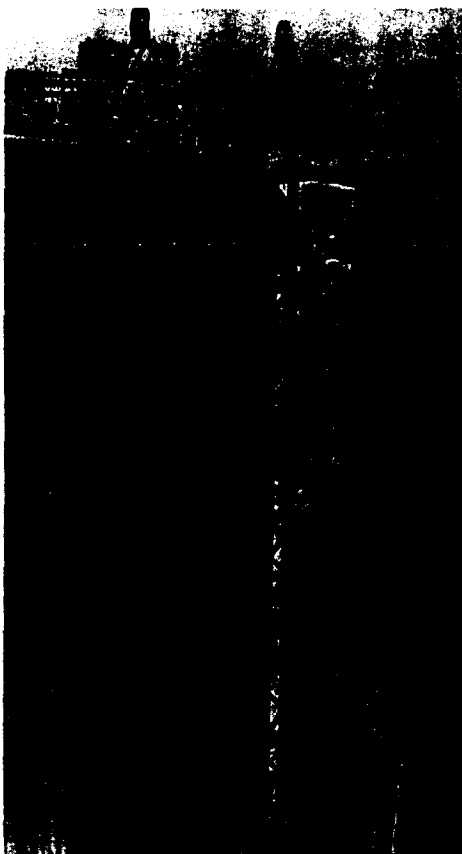
Molding, extrusion, and foam grades are available. In line with its ability to compete directly with metals, typical applications might include: automotive dashboards, electrical connectors, TV tuners and deflection yoke components, pumps, plumbing fixtures, small appliance and business machine housings, and automotive trim.

POLYARYL ETHER

Thermoplastic. Polyaryl ether is a high-heat engineering thermoplastic distinguished by three important properties: a



SMALL APPLIANCES: Polypropylene components in automatic coffee makers dramatize fast-growing use of plastics of all kinds in appliances.



CONSTRUCTION: Building panels, up to 8 by 24 ft. in size, and based on glass-reinforced plastics, are intended to cover wall surface of a building.

heat deflection temperature of 300 F, very high impact strength, and excellent chemical resistance to organic solvents (except chlorinated aromatics, esters, and ketones). It can be injection molded and is recommended for automotive, appliance, and electrical applications. In the automotive industry it can be used for painted exterior trim (since it can take the heats of paint baking ovens) or for under-the-hood applications requiring outstanding heat resistance.

POLYARYL SULFONE

Thermoplastic. This is another high-heat engineering thermoplastic that is characterized by a very high heat-deflection temperature (525 F at 264 psi). At normal ambient temperatures, polyaryl sulfone is a strong, stiff, tough material with properties comparable to other engineering thermoplastics. Its uniqueness, however, lies in the fact that even at elevated temperatures, the material can perform without any sacrifice of mechanical or electrical properties. Polyaryl sulfone has good resistance to a wide variety of chemicals, including acids, bases, and common solvents.

This plastic is designed to meet the need for higher thermal capabilities for aerospace, industrial, and consumer use. It can be molded or extruded on conventional equipment, although care must be taken to insure that sufficient pressures and temperature capabilities are provided.

POLYCARBONATE

Thermoplastic. Polycarbonates were developed commercially in 1957 and are one of the pioneering members of the family of engineering thermoplastics created to compete with die-cast metals.

They are among the stronger, tougher, and more rigid thermoplastics. In addition, they have a ductility normally associated with the softer, lower-modulus thermoplastics.

These properties, together with excellent electrical insulating characteristics, are maintained over a wide range of temperatures (-60 to 279F) and loading rates. Although there may be a loss of toughness with heat aging, the material still remains stronger than many thermoplastics. The creep resistance of these materials is one of the best for thermoplastics.

Polycarbonates are transparent materials and resistant to a variety of chemicals. They are, however, attacked by solvents.

Tensile yield strength and impact strength are also quite high. Moisture resistance is low and equilibrium is reached rapidly. The materials, however, are adversely affected by weathering (slight color change and slight embrittlement can occur on exposure to ultra-violet rays).

Polycarbonate compounds are available for injection molding, extrusion, blow molding, and rotational molding. Foamable grades for structural foam molding are also being marketed. In sheet form, polycarbonate is finding use in safety glazing, safety shields, and similar applications. Injection molded applications include: gears, lenses, electrical relay covers, helmets, cams and gears, automotive fender extensions, bezels, telephone switchgear, boat propellers, and housings for hand-held power tools and small appliances. Blow molded applications being marketed are nursing bottles, milk bottles, and clear containers for bottled water.

POLYESTERS, AROMATIC

Thermoplastic. Introduced in the early 1970's as a high-temperature engineering thermoplastic, this material shows excellent stability in air at over 600 F and combines inherent self-lubricating properties with high stiffness, thermal conductivity, electrical insulating properties, and solvent resistance. Because of its toughness and high heat resistance, it was originally fabricated by metallurgical-type processes. However, an injection moldable version was introduced in 1974. This grade can be processed with conventional equipment.

Typical applications include: self-lubricating bearings; seals, rotors, or vanes of process pumps; high temperature circuit boards; insulation components; encapsulation of diodes, transistors, and integrated circuits, and handles and slip-free coatings for frying pans.

POLYESTERS, THERMOPLASTIC

Thermoplastic. Although this material is also called a polyester, as above, and is also a thermoplastic, as are the aromatic polyesters described above, in chemical

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structure and properties it is quite different. In the form of film, the thermoplastic polyesters were introduced in 1962 for such applications as photography (microfilm, X-ray film); magnetic tape (audio, video, computer); packaging; metallized film; and various tapes and labels. As molding and extrusion compounds introduced in the early 1970s, they quickly became important new members of the family of engineering thermoplastics.

As molding materials, these linear polyesters are highly crystalline, with a melting point near 435 F. They are hard, strong, and extremely tough. Other characteristics include: high resistance to abrasion, a low coefficient of friction, high resistance to cold flow, good chemical resistance, good dielectric properties, and low moisture absorption. Thermoplastic polyesters can be extruded, injection molded, or blow molded.

Applications include: gears, bearings, housings for pumps and appliances, impellers, pulleys, switch parts, furniture, fender extensions, and other products in competition with metals or high-performance plastics. The resin is also recommended for packaging applications, especially for products (i.e., food and medical goods) that are to be sterilized by radiation. It is also being used for blow molded carbonated beverage bottles.

POLYESTERS, UNSATURATED

Thermoset. Again, while this family of plastics also go under the name of 'polyesters,' they are quite distinct from the polyesters described above. In fact, they are thermosets, as opposed to thermoplastics, and are probably most familiar to the public for their role in "reinforced plastics."

These materials were introduced for military use (i.e., naval craft) in 1942. After World War II, their characteristics proved extremely appealing to such non-military markets as automotive, marine, corrosion-resistant structures, building, electrical applications, and such consumer goods as luggage, fishing poles, and cases and housings of every type and description.

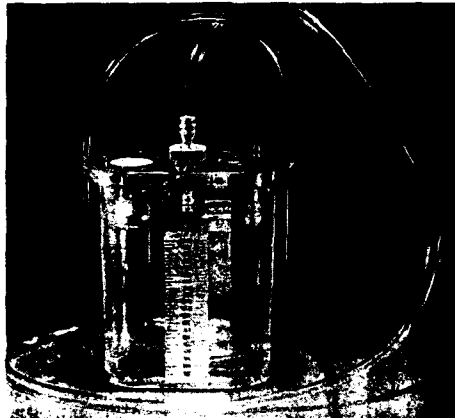
Polyester resin is a difficult plastic to define since it is so extremely versatile in terms of the forms in which it finds use in the industry. Polyester resins can be for-

mulated to be brittle and hard, tough and resilient, or soft and flexible. In combination with a reinforcement like glass fibers, they offer outstanding strength, a high strength-to-weight ratio, chemical resistance, and other excellent mechanicals.

Although polyesters are finding a growing market as a liquid resin for casting furniture parts (e.g., simulated wood doors, drawer fronts, lamp bases, wall plaques, etc.) their prime outlet is in combination with glass fibers in high-strength composites (or "reinforced plastics"). Using various lay-up, spray-up, and matched metal molding techniques, polyester-glass is being used for such products as automotive body parts, boat hulls, building panels, housings, bathroom components, tote boxes, appliances, and electronic and electrical applications.

Special equipment is also available to injection mold polyester-glass formulations. Most recently, one-component molding systems, combining resin, reinforcement, and other additives, have been made available to molders. These materials, known as SMC (sheet molding compounds) are easy to handle and are adaptable to automated processing.

Another popular technique of molding involves premix compounds, which are dough-like materials prepared by combining polyester, glass, catalyst, etc. prior to molding. This technique is currently being used to make automotive heater housings and air conditioner components.



MEDICAL: Clarity, non-toxicity, sterilizability, stability—all combine to promote plastics for medical devices, like this chest drainage unit.

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Also available for use with polyester resins is an extrusion-like technique known as pultrusion in which glass fibers are pulled through a resin bath to make continuous profiles, pipe, or other shapes.

POLYETHYLENE

Thermoplastic. This plastic came to the fore during the World War II years, first as an underwater cable coating, then as a critical insulating material for such vital military applications as radar cable. It was not until the end of the war that the plastic was taken off allocation and freed for consumer use. From that point on, its rise in popularity for both consumer and industrial uses was so spectacular that polyethylene became the first plastic in the U. S. to sell more than 1 billion pounds a year. Today, it is the largest volume plastic in the United States; in fact, it is the largest in the world.

Again, although the public is most familiar with the so-called "low-density" polyethylene in such forms as film for packaging, trash bags, garment bags, etc., and molded housewares, toys, containers, and the like, the polyethylene family encompasses a number of different materials with widely varying properties.

In general, polyethylenes are characterized by toughness, near-zero moisture absorption, excellent chemical resistance, excellent electrical insulating properties, low coefficient of friction, and ease of processing.

The low-density polyethylenes were the first member of the family to be developed and still dominate in terms of volume sales. These plastics are flexible, with high impact strength and relatively low heat resistance (140 to 175 F, although special grades can go up to 200 F). In the 1950's, polymer chemists developed techniques for providing polyethylenes with higher densities (by packing molecules more closely together). These new variations, appropriately called "high-density" polyethylene, showed greater stiffness and rigidity as compared to low-density, improved heat resistance, and increased resistance to permeability. High-density polyethylene's major use is in blow molded bottles for bleaches, liquid detergents, milk, and other beverages. It can also be blow molded into automotive gas tanks, drums, and carboys, or injection molded

into materials handling pallets, stadium seating, trash and garbage cans, automotive parts. High-density polyethylene film is used in shopping and merchandising bags.

Other members of the polyethylene family include: cross-linked polyethylene—a special grade that's treated either chemically or by irradiation to turn polyethylene, which is a thermoplastic material, into what is essentially an infusible thermosetting material with outstanding heat resistance and strength; and high-molecular-weight polyethylene, which has extremely high impact strength, excellent low temperature properties, and outstanding wear and abrasion resistance. To give you some idea of how tough this high-molecular-weight material is, it is used as the guide rail for ball returns in a bowling alley—an application in which it can outwear many other materials, including some exotic metals.

As indicated, polyethylene is adaptable to most thermoplastic processing techniques. It can be extruded (into film, sheet, pipe, profiles, etc.), extrusion coated onto many substrates (like paper for milk cartons, foils for packages, etc.), injection molded, blow molded, rotationally molded, etc. A powdered form of PE is available for use as a textile impregnant or as a protective coating for glass bottles. Flexible polyethylene foam (for electrical insulation) and rigid PE foam (for protective packaging) are also on the market.



MATERIALS HANDLING: Palletized containers thermoformed of ABS sheet, are rigid and tough enough to handle rigors of shipping and storage.

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POLYIMIDES

One of the newer plastics materials, the polyimides were introduced in the 1960s. They are unique in that, like the polyesters, there is one type of polyimide that acts like a thermoset (in that it exhibits no distinct softening point below its thermal degradation temperature) and one that acts like a thermoplastic (in that it softens and can be processed on conventional equipment).

The thermoset-type polyimides were the first members of the family to be introduced. They are among some of the most heat-resistant plastics known and can take temperatures up to 500 F and above for several thousand hours and intermittently at temperatures as high as 900 F. They also have very good electricals, excellent frictional characteristics, very good wear resistance, superior dimensional stability and excellent bearing qualities. Because of their thermosetting qualities, they cannot be processed by conventional techniques and must use other systems, such as powder-metallurgical methods. They are, therefore, more generally not supplied as compounds for processing, but instead are made available to end-users in the form of finished precision parts, as wire enamels, laminates, adhesives, and film (insulation for electric motor, aircraft wire cable, etc.). Typical applications for polyimide parts: gears, covers, bushings, turbo-fan engine backing rings, insulators, washers, etc., for such industries as aircraft and aerospace, nuclear power, office equipment, and electrical/electronics.

In the early 1970s, thermoplastic polyimides were introduced that were processible by standard processing techniques such as molding, film casting, solution fiber spinning. Temperature resistance is obviously not as high as for the thermoset-type materials, but still higher than most thermoplastics. Molding compounds are used for parts like piston rings, valve seats, bearings, seals, and structural components. The resin in solution form is also used as a laminating varnish.

POLYPHENYLENE SULFIDE

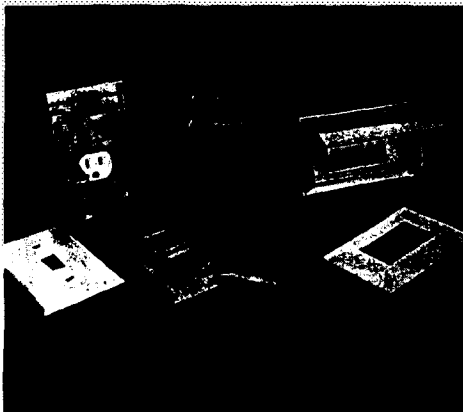
Thermoplastic. Polyphenylene sulfide is another one of those new plastics categorized as high-temperature, high-strength engineering thermoplastics. It offers outstanding chemical resistance, high stiff-



HOME EXTERIORS: Polystyrene shutters that can take punishment, weathering, and aging join products like vinyl siding and gutters in exteriors.



PIPE: Large-diameter pipes in reinforced plastics or polyethylene open new opportunities in chemical plants and sewage and water treatment systems.



ELECTRICAL USES IN THE HOME: Face plates, covers, and receptacles of polycarbonate (above) or other plastic are among the more familiar uses.

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ness, and good retention of mechanical properties at elevated temperatures. Melting point is 550 F. It is resistant to a broad range of solvents, mineral and organic acids, and alkalis.

Polyphenylene sulfide is available as compounds for injection molding or compression molding into hard, stiff, strong, and temperature-resistant parts such as valves, pump housings, pump impellers, conveyor rollers, spur gears, etc. It is also marketed in different grades suitable for slurry coating, fluidized bed coating, electrostatic spraying, etc. Corrosion-resistant, thermally-stable protective coatings based on this resin go into oil-field pipe, valves, fittings, couplings, and other equipment for the petroleum and chemical processing industries. It is also used as a release coating for molds, cookware, and industrial containers.

POLYPROPYLENE

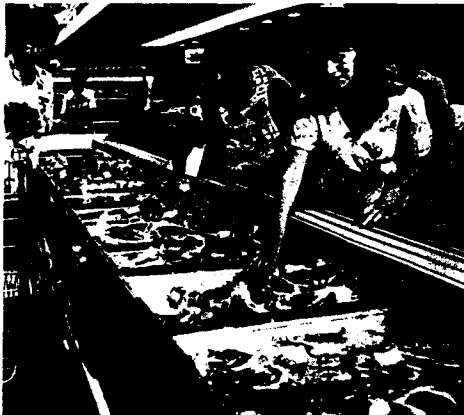
Thermoplastic. Polypropylene was developed out of the Nobel award-winning work of Karl Ziegler and Professor Natta in Europe and came to the United States in 1957.

It belong to the olefins family, which also includes the polyethylenes, but it is quite different in properties. It has a low density, is fairly rigid, has a heat distortion temperature of 150 to 200 F., and excellent chemical resistance (like all polyolefins). Polypropylenes also have negligible water absorption, excellent electrical properties, and are easy to process. The ability to carry light loads for long periods and over wide temperature ranges is an important characteristic. Polypropylenes do not have outstanding long-term creep resistance, but fatigue endurance limits are excellent and impart superior flex properties to the material.

In common with the polyethylenes, polypropylene is readily processed by all conventional systems, including solid and foam molding, extrusion, rotational molding, powder coating, and thermoforming. Considerable work has also gone into solid-phase forming of polypropylene, which is similar to the "cold" stamping of metals. Another processing system of importance to the polypropylenes is known as orientation (i.e., stretching the plastic to align the molecules and impart superior toughness); it is applicable to film, fibers,



PLUMBING: Having made a mark in sinks, basins, pipe, toilet floats, etc., plastics are now moving in on faucets (molded of acetal).



PACKAGING: Pick any section of the supermarket and you'll find plastics. Typical: film overwrap and formed trays for meat.



GLAZING: Lightweight and tough, transparent plastics panels meet stringent regulations on safety glazing for various rooms in the house.

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and blow molded products. Polypropylene foam is also available.

As far as end-uses are concerned, polypropylene is a most versatile material. Consumers are familiar with such molded polypropylene products as bottles for syrups and other foods, closures, automotive parts (fender skirts, battery cases, fan shrouds), appliances (agitators in washing machines), toys, housewares, etc. Polypropylene foams are also being molded into furniture frames.

Polypropylene can be extruded into fibers and filaments for carpets and rugs, carpet backing, woven bags, and cordage. In the form of film and sheeting, it's the overwrap for cigarettes, records, toys, and housewares items. Pipe and profiles, wire and cable coatings, and other extrusions (including such unusual products as corrugated polypropylene sheet that competes directly with traditional corrugated paper board, especially in the packaging of food) round out the list of applications.

POLYSTYRENE

Thermoplastic. Styrene monomer and the polystyrene resin made from the monomer remained as chemical curiosities for 80 years following their discovery in 1845. It wasn't until 1925 when commercial production of styrene monomer began in Germany and the U. S. that polystyrene attracted interest, and it wasn't until after World War II when monomer capacity could be diverted from its essential wartime use for styrene-butadiene synthetic rubber that polystyrene became an important plastic.

Today, polystyrene is the third largest volume plastic and certainly one of the two or three plastics that consumers know best.

Polystyrene, or styrene as it is more apt to be known by the public, can be molded, extruded, or otherwise processed by conventional thermoplastics techniques. It is available also as liquid solutions, adhesives, and coatings. Polystyrene foams can readily be prepared and are characterized by having excellent low thermal conductivity, high strength-to-weight ratio, low water absorption, closed cell structure, excellent energy absorption, and good chemical resistance. These attributes have made polystyrene foam of special interest as insulation board for construction, as a protective packaging material (e.g., egg

cartons), in hot and cold insulated drink cups, in marine applications, toys, displays, and housewares.

As a family, polystyrenes are characterized by hardness, excellent dielectric properties, and ease of processing. Products made of most polystyrene grades hold their dimensions well under conditions of normal use, but should not be exposed to continued outdoor use. Most foods, drinks and usual household acids, oils, alcohol, vinegar, have no effect on polystyrene, but the general run of polystyrenes are affected by citrus fruit rind oil, cleaning fluids, gasoline, turpentine and nail polish and remover.

However, it is difficult to characterize polystyrenes since one of their advantages is that they can be tailored to provide a wide range of mechanical, thermal, and chemical properties.

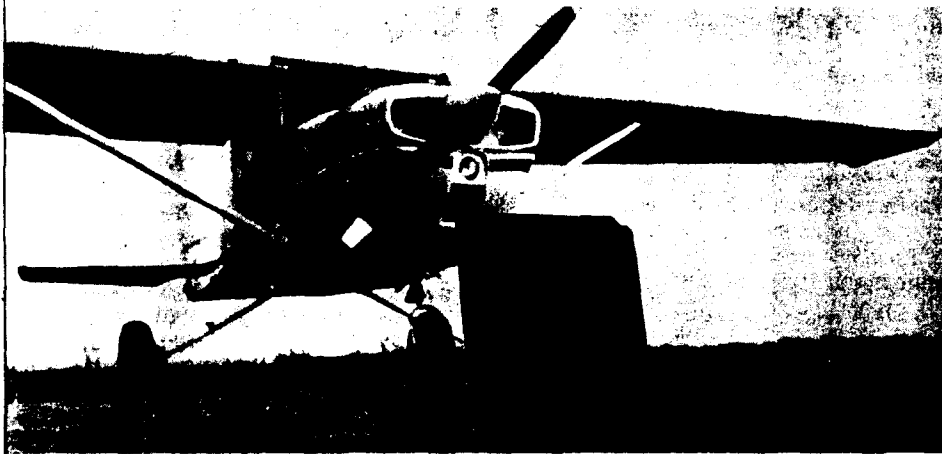
At the low end of the scale are the general-purpose polystyrenes—transparent materials with the lowest impacts in the family, but with lower costs and good hardness and rigidity. At the upper end are the high-impact and extra-high-impact polystyrenes which, as their name implies, are opaque materials that offer high impact, rigidity, and toughness. In-between are special grades of polystyrene formulated to be light stable (for use in lighting fixtures, diffusers, etc.), or more heat-resistant or more chemically resistant.

Molded applications for the various polystyrenes include: toys, automotive parts, housewares, kitchen items, appliances, wall tiles, refrigerator food containers, radio and TV housings, small appliance housings, furniture, packages, and construction applications such as shutters. A good deal of polystyrene sheet is thermofomed into products for packaging (dairy tubs), appliances (refrigerator liners), boats, luggage, disposable plates, etc.

POLYSULFONE

Thermoplastic. A mid-sixties development (1965), polysulfone is another of those rigid, strong, and heat-resistant plastics that were the focus of so much activity during the sixties and early 1970s.

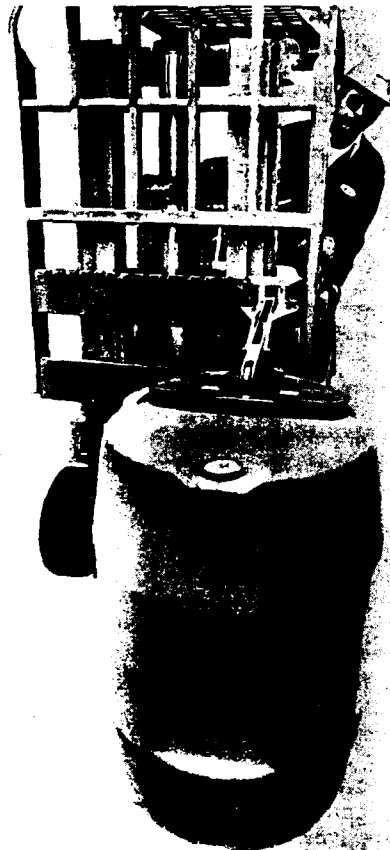
Polysulfone possesses a very high use temperature and very low creep under load. It maintains a high degree of its mechanical and electrical properties in



AIRCRAFT: Component plastics parts like this thermoplastic polyester-framed filter are common in small passenger planes. More recent activity is in adapting plastics to exterior parts—including several planes with all-plastics bodies (wings and fuselage).



ART: Calder's Universe, a sculpture based on acrylic, typifies art world's interest in plastics for unique self-expression.



SHIPPING DRUMS: Polyethylene can replace steel in 55-gal. drums, like that shown above, and is equally as applicable for 5-gal. pails.

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continuous service at temperatures ranging from -150 to 300 to 345 F. Tensile stress and modulus are high, and electrical properties are excellent over a wide temperature range and even after immersion in water or exposure to high humidity.

Polysulfone resins may be used as adhesives and can be fabricated by extrusion, injection molding, blow molding, and thermofforming. Foamed grades are available. Typical applications include connectors, coil bobbins, meter housings, circuit carriers, and other electrical/electronic components; in the automotive field, it is used for under-the-hood switch and relay bases and dome light bazels. Polysulfone also has found a market in medical equipment where sterilization by steam, dry heat, or ethylene oxide is required. Consumers are aware of it primarily in the form of component parts for such appliances as coffee-makers, humidifiers, high-intensity lamps, and kitchen-range hardware.

POLYURETHANE (URETHANE)

Introduced commercially only in 1954, the urethanes have already made an impact on a broad spectrum of U. S. industry. They are an extremely versatile plastic in terms of the forms in which they are available—flexible or rigid foams, solid elastomers (or rubbers), coatings, adhesives, and sealants. Their versatility also extends to chemical structure in that, although the urethanes are generally considered to be thermosets, there are grades of urethane elastomers that are thermoplastic in nature and are supplied in pellet form for molding, calendering, or extrusion.

Urethane's major and best known form, however, is a foamed or cellular material. Like all urethanes, the foams are prepared by first reacting two liquid components—polyols and isocyanates—together. In the presence of a blowing agent, this reaction will produce a foamed material having excellent thermal insulating properties. It is, however, possible to use water to generate the blowing agent. Water readily reacts with the isocyanate-containing components to form carbon dioxide which, in turn, becomes the blowing agent.

Depending on the reaction and the chemicals or additives used, the foams can either be a soft, flexible material or a tough, hard, rigid material, with all the variations

possible in-between. Flexible foams have outstanding cushioning characteristics, excellent energy-absorbing properties, and long life. They are used in furniture cushioning, carpet underlay, bedding, packaging, textiles, automotive seating, and safety padding. Rigid foams offer outstanding insulating values, excellent compressive strength, good dimensional stability, and outstanding buoyancy. They are used for insulating buildings, refrigerators, trucks, and cold-storage buildings, as a flotation medium for boats, and in the construction of furniture components such as drawers, table tops, head boards, chair frames and shells.

The processing techniques available for use with the foams are equally as varied. Flexible foams are produced in the form of slab stock or buns that can be subsequently fabricated or they can be molded directly into an end-product. Rigid foams can be foamed-in-place (poured in liquid form into an open cavity where foaming then takes place), sprayed onto a surface, or also molded into products. A newer technique known as reaction injection molding (RIM) or liquid injection molding (LIM) can produce parts with nonporous, relatively solid-surface skins (known as integral skin foams). The technique involves injecting under pressure the isocyanate and the polyol directly into a mold where the reaction takes place. It has been used for making automotive body parts, furniture, large housings, and similar products.



FURNITURE: Shell of chair is molded in one piece of phenylene oxide. Other plastic uses in furniture: tables, sofa frames, head boards, case goods, upholstery, cushioning.

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is coatings, urethanes impart outstanding protective and decorative effects to wood, metals, rubber, textiles, concrete, paper, leather, plastics, and many other materials.

In the form of elastomers, urethanes offer superiority to other elastomers in abrasion resistance and toughness, and are used in applications in which good performance and long service life are important. Printing rolls, gaskets and seals, cable insulation, drive and conveyor belts, solid tires, and automotive parts are typical applications. The thermoplastic elastomers can, of course, be molded or extruded by conventional means. The elastomers can also be processed by reaction injection molding (RIM) and this has become an important technique for producing automotive filler panels, front ends, and bumpers that are capable of meeting new automotive safety standards.

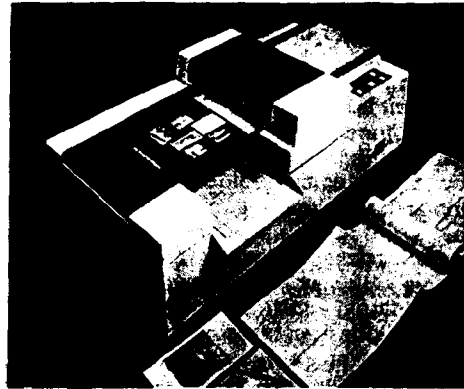
POLY (VINYL CHLORIDE)

The birth of poly (vinyl chloride) or PVC or vinyl as it is better known to the public, dates back to a German patent in the 1910s, but it was not until the late 1920s that a technically useful product was introduced in the U. S. By the start of World War II, the significance of plasticizing PVC (that is, adding a chemical known as a plasticizer to make PVC flexible and processible) was fully realized. It was during the war that the real importance of this polymer became apparent when, due to the acute shortage of rubber, many companies turned to PVC and began to realize its advantages. Since that time, the consumption of PVC has grown dramatically until today it is second only to polyethylene in volume use.

Because of its wide use in applications that are close to consumers, like upholstery, flooring, apparel and accessories, records, and wire insulation, vinyl is one of the better-known plastics.

As a family, vinyls are used mainly for their chemical and weathering resistance, high dielectric properties, or abrasion resistance. Chemical resistance is excellent. Vinyls also enjoy a very slow rate of water absorption. In general, they are recommended for use at temperature ranges from -65 to 175 F.

Actually, poly (vinyl chloride) or PVC, is only one member of the vinyls family, although the most important one. The two



BUSINESS MACHINES: Housings are prime market area. The molded structural foam model (above) replaces one previously die cast of



AUTOMOTIVE INTERIORS: Dashboard is plastic; so's steering wheel, knobs, glove compartment, floor mat, upholstery, foam cushioning, trim, etc.



DISPOSABLES: Styrene foam cups symbolize growing consumer and institutional demand for disposable dinnerware, utensils, plates.

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major sub-classifications in PVC are flexible PVC and rigid PVC. Flexible PVC is a plasticized material (i.e., made flexible with chemical additives called 'plasticizers') that is used for wire and cable insulation, apparel, flooring, wall coverings, upholstery, automotive seats, garden hose, toys, and medical tubing. Rigid PVC is an unplasticized, hard, tough thermoplastic that is used in applications like doors and window frames, pipe and fittings, building panels and siding, rainwater systems, credit cards, and flooring. Major processing methods are extrusion, injection molding, blow molding, and calendaring (for flexible PVC).

In cellular or foamed form, rigid PVC copolymer is being used for decorative moldings and trim to compete with wood. These foamed vinyl profiles can actually be cut and fabricated in much the same manner as their wood counterparts and will accept nails and other fasteners.

PVC is also available in a liquid form, known as plastisols or organosols, that can be used for coating fabrics, paper, and metal, or rotationally cast into dolls, balls, and automotive arm rests, dip molded into gloves, or slush molded into boots. Foamed plastisols are an important part of dispersion resin technology and are used for calendered flooring, leather-like upholstery, shoe fabrics, and carpet backing.

Other types of vinyls are PVC copolymers like vinyl chloride-vinyl acetate resins that are used for phonograph records; polyvinyl acetate, widely used as emulsions for paints, adhesives, textile sizings, and coatings; poly (vinyl alcohol), a water-soluble film; polyvinyl acetals (formals and butyrals), widely used to provide adhesion and good mechanical properties in a variety of systems; and poly (vinylidene chloride), a tough, abrasion-resistant vinyl with better than ordinary heat resistance (212 F maximum service temperature) and used for packaging film, coatings, and monofilaments. Poly (vinyl butyral) is used in safety glass innerlayer for automotive windshields.

SILICONES

Thermoset. Silicones were commercialized in the early 1940s and are characterized by long-term heat resistance (silicone insulation has shown itself highly stable up to 350 to 590 F), excellent electrical insu-

lating properties, good moisture and chemical resistance. Silicones are water repellent, weather resistant, and highly resistant to mineral acids, and also corrosive salt solutions.

Silicones are available as molding compounds, resins, coatings, greases, fluids, and as a room temperature vulcanizing rubber (used for making molds for the casting of various plastics like urethane). The big outlet for silicones are in the electrical industry where they are used for coil forms, switch parts, induction heating apparatus, as insulation for motors and generator coils, and in power cables. Silicone fluids are used in the plastics and rubber industry as mold release agents, lubricity and wear additives, lubricants, and in controlling cell structure in foamed plastics.

UREA

Thermoset. This plastic is another member of the amino family (as is melamine) and was developed in 1929. Like melamine, it is a very hard, scratch-resistant material with good chemical resistance, good electrical qualities, and heat resistance up to 170 F. They are available as molding powders or granules, as a foamed material, or in solution for lamination with wood and paper.

Ureas are compression molded into products such as decorative housings, jewelry casings, lighting fixtures, closures, wiring devices and buttons. In liquid resin form, it is used as baking enamel coatings, particle board binders, and paper and textile treatment.



LIGHTING: Office workers benefit from the improved lighting levels afforded by full-ceiling lighting diffusers based on acrylic.

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PROCESSING PLASTICS

The ways in which plastics can be processed into useful end-products are as varied as the plastics themselves.

While the processes differ, however, there are elements common to many of them. In the majority of cases, thermoplastics compounds in the form of pellets, granules, flakes, and powder, must be melted by heat so they can flow. Pressure is often involved in forcing the molten plastic into a mold cavity or through a die and cooling must be provided to allow the molten plastic to harden. With thermosets, heat and pressure also are most often used, only in this case, the heat (rather than cooling) serves to cure or set the thermosetting plastic, under pressure, in the mold. When thermoplastics or thermoset resins in liquid form are involved, heat and/or pressure need not necessarily be used, although in many casting techniques, intended for high-speed production, they do play a role. The descriptions of processes that follow cover the basics of the major manufacturing systems. It should be recognized, however, that there are variations in virtually every process, perhaps aimed at servicing a particular market or servicing a particular plastic, that represents some degree of deviation from the basics.

BLOW MOLDING

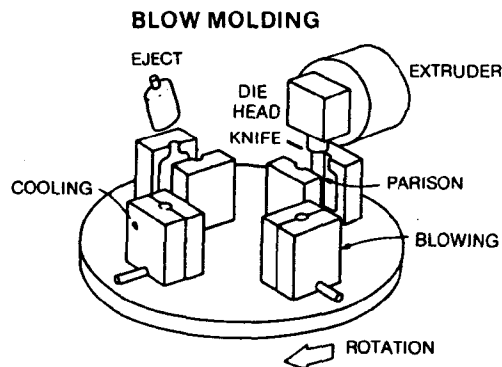
Generally used only with thermoplastics, this process is applicable to the production of hollow plastics products such as bottles, gas tanks, and carboys. Historically, blow molding began during World War II. However, it did not become an important process until well into the 1950s when high-density polyethylene (the rigid material used for bleach and detergent bottles) became available and commercial blow molding machines first started to be marketed.

Basically, blow molding involves the melting of the thermoplastics resin, then forming it into a tube-like shape (known as a parison), sealing the ends of the tube, and injecting air (e.g., through a needle inserted in the tube) so that the tube, in a softened state, is inflated inside the mold and forced against the walls of the mold.

On cooling, the part, now conforming to the shape of the cavity, is solidified and ejected from the mold as a finished piece.

A good analogy might be to trapping a balloon inside a mold, inflating it so that it sticks to the inside walls of the mold cavity, then somehow solidifying it in that shape before removing it.

There are many variations possible in the basic process, however. Where differences do exist is in the way the tube or parison is made (you can extrude it or injection mold it), whether the parison is to be used hot as it comes from the extruder or injection molding machine (as in conventional blow molding) or stored cold and then reheated (as in cold preforming molding), and the manner in which the parison is transferred to the mold for blowing or the mold is moved to the parison (using rotating wheels, rotating tables, rotating molds, etc.).



BLOW MOLDING: Diagram of continuous extrusion blow molding set-up, using a rotating horizontal table. Plastic parison (in cylindrical shape) is extruded from die into mold which closes on the parison (knife cuts the parison off from the extrudate). Mold then rotates to second station where air is injected into the parison (still hot and therefore formable) to blow it out to the shape of the inside mold cavity. At third station, the blown part is allowed to cool and set (i.e., harden). Mold finally rotates to last station where finished part (in this case, a bottle) is ejected from mold.

CALENDERING

Calendering can be used to process thermoplastics into film and sheeting, and to apply a plastic coating to textiles or other supporting materials.

In calendering film and sheeting, the plastic compound is passed between a series of three or four large, heated, revolving

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rollers which squeeze the material between them into a sheet or film. An analogy in this case might be flattening out a pasty dough mixture with a rolling pin. The thickness of the finished material is controlled by the space between the rolls. The surface of the plastic film or sheeting may be smooth or matted, depending on the surfacing on the rollers.

CASTING

Resins for casting emerged a little over a half century ago, but formulations suitable for increasingly widespread use date back only about 30 years.

Casting may be used both with thermoplastics and thermosets to make products, shapes, rods, and tubes, by pouring a liquid monomer-polymer solution into an open or closed mold where it finishes polymerizing into a solid. Film and sheeting can also be made in this way by casting directly into a flat open mold, casting onto a wheel or belt, or by precipitation in a chemical bath.

One essential difference between casting and molding is that pressure need not be used in casting (although large-volume, complex parts can be made by pressure-casting methods). Another difference is that the starting material is usually in liquid form rather than solid (such as pellets, granules, flake, powder, etc.). A third is that the liquid is often a monomer rather than the polymers used in most molding compounds.

A variation on casting is known as liquid injection molding (LIM) and involves the proportioning, mixing, and dispensing of liquid components and directly injecting the resultant mix into a mold which is clamped under pressure.

COATING

Thermosetting and thermoplastic materials may both be used as a coating. The materials to be coated may be metal, wood, paper, fabric, leather, glass, concrete, ceramics or other plastics.

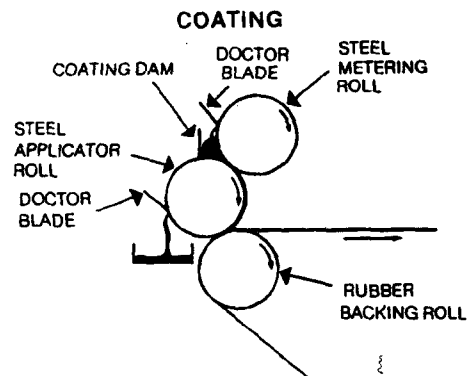
Methods of coating are varied and include knife or spread coating, spraying, roller coating, dipping, and brushing. Calendering of a film to a supporting material is also a form of coating.

In spread coating, the material to be coated passes over a roller and under a long

blade or knife. The plastic coating compound is placed on the material just in front of the knife, and is spread out over the material. The thickness of the coating is regulated by the speed at which the material is drawn under the knife, and the position of the knife.

In roller coating, two horizontal rollers are used. One roller picks up the plastic coating solution on its surface and deposits it on the second roller which, in turn, deposits the coating solution on the supporting material.

Most recently, plastics in the form of fine powders, have proved popular in the coating of a wide range of substrates. Two of the methods for applying powder coatings are fluidized bed and electrostatic spray coatings. In fluidized bed coating, the object to be coated is heated and then immersed in a dense-phase fluidized bed of powdered resin; the resin adheres to the heated object and subsequent heating provides a smooth, pinhole-free coating. Electrostatic spraying is based on the fact that most plastics powders are insulators with relatively high volume resistivity values. Therefore, they accept a charge (positive or negative polarity) and are attracted to a grounded or oppositely charged object (which is the one being coated).



COATING: A typical coating set-up, known as a 3-roll nip fed reverse roll coater. Plastic feeds from dam through nip between steel metering and applicator rolls, rotating in the same directions. At bottom of the applicator roll, plastic is laid on top of the substrate (e.g., fabric, paper, etc.) as it comes in contact with the substrate at nip between applicator roll and backing roll (which carries the substrate up from the bottom of set-up). Doctor blade is used to scrape off excess plastic from applicator roll.

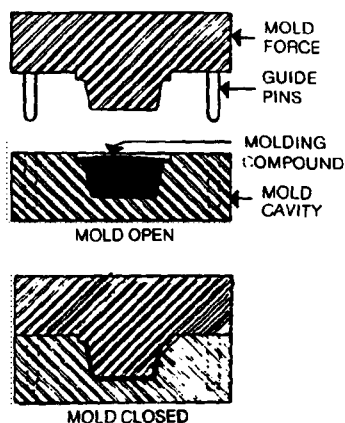
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COMPRESSION MOLDING

Compression molding is the most common method of forming thermosetting materials. Until the advent of injection molding, it was the most important of plastics processes. The earliest application of compression molding as a manufacturing process was early in the nineteenth century when Thomas Hancock patented a process for molding rubber. The first patent on using it to mold plastics was issued in the U.S. in 1870 to John Wesley Hyatt (developer of the first U.S. commercial plastic, celluloid) and Isaiah Hyatt.

Compression molding is simply the squeezing of a material into a desired shape by application of heat and pressure to the material in a mold.

COMPRESSION MOLDING



COMPRESSION MOLDING: Basics of a simple two-piece compression mold. Plastic molding material is loaded into lower half (cavity) of the heated mold (shown at top). Top half of the

halves

the mold. It is while the heated mold is closed that the thermosetting material undergoes a chemical change which permanently hardens it into the shape of the mold. The three compression molding factors—pressure, temperature and time the mold is closed—vary with the design of the finished article and the material being molded.

EXTRUSION

Extrusion is the method employed to form thermoplastic materials into continuous sheeting, film, tubes, rods, profile shapes, or filaments, and to coat wire, cable, and cord.

In extrusion, dry plastic material is first loaded into a hopper, then fed into a long heating chamber through which it is moved by the action of a continuously revolving screw. At the end of the heating chamber the molten plastic is forced out through a small opening or die with the shape desired in the finished product. As the plastic extrusion comes from the die, it is fed onto a conveyor belt where it is cooled, most frequently by blowers or by immersion in water. An over-simplified analogy would be to compare the technique to a household meat grinder or to squeezing toothpaste out of a tube.

In the case of wire and cable coating, the thermoplastic is extruded around a continuing length of wire or cable which, like the plastic, passes through the extruder die. The coated wire is wound on drums after cooling.

In producing wide film or sheeting, the plastic is extruded in the form of a tube. This tube may be split as it comes from the die and then stretched and thinned to the dimensions desired in the finished film.

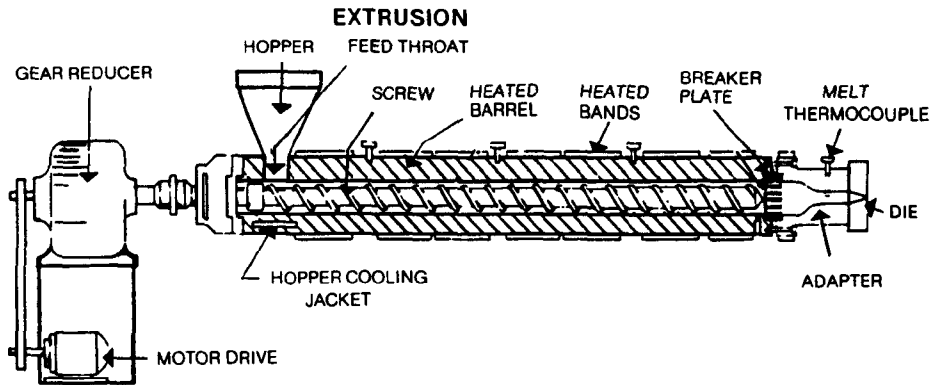
similar process,

as

dio frequency dielectric techniques.) The mold is then closed, pressing down on the marketplace, coextrusion has been adapted to the production of products like pack-

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EXTRUSION: In a basic single-screw extruder, plastics pellets (or powders) are fed through the hopper, through the feed throat, and into a screw that rotates in a heated barrel. The rotation of the screw (which is powered by the drive motor) conveys the plastic forward for melting and delivery through the breaker plate (reduces the rotary motion of the melt), through the adaptor, and into the die which dictates the shape and size of the final extrudate. Over-simplified analogies that can help in understanding extrusion are the operation of a household meat grinder or squeezing toothpaste out of a tube.

structure several layers of different plastics, each offering varying degrees of moisture resistance, gas barrier properties, adhesive qualities, economics, etc.

FABRICATING

Fabricating is an over-all description for the various operations performed on secondary shapes like sheet, film, rod, tube, or profiles, to turn them into finished products.

Fabricating divides into three broad categories: the machining of solid shapes; the cutting, sewing, and sealing of film and sheeting; and the forming of film and sheet.

Machining. Using techniques quite common to metal, wood, and other industries, plastics shapes can be turned into end-products by such methods as grinding, turning on a lathe, sawing, reaming, milling, routing, drilling, and tapping.

Cutting, sewing, and sealing of film and sheet. In this category of fabricating fall all the operations involved in turning plastics film and sheeting into finished articles like inflatable toys, garment bags, shower curtains, aprons, raincoat, and luggage. In making these products, the film or sheet is first cut to the desired pattern by hand, in die-cutting presses, or by other methods. The pieces are then put together using such assembly techniques as sewing,

or thermal, high-frequency, or ultrasonic sealing.

Forming. In working with thermoplastics sheets, several approaches are possible. In one, sheet can simply be bent and joined together by such techniques as hot gas welding to form structural products like hoods, venting systems, duct work, storage tanks, and allied products. Thermoplastic sheet can also be scored and fed into conventional paperboard creasing and folding equipment to make a standard plastic box or carton. The plastic blank can also be beaded for added strength before being creased and folded into a box.

The major method for forming film or sheet, however, is known as thermoforming (i.e., heating and sheet and then forming it while it is in its softened state by pushing it or pulling it into or over a mold). This technique has become a major processing method in its own right and is covered below.

FINISHING

The finishing of plastics includes the different methods of adding either decorative or functional surface effects to a plastic product. Plastics, of course, are unique in that color and decorative effects can be added to plastics prior to and during manufacturing. Pigments and dyes, for example, are compounded into the plastic before they are processed so that color is

integral to a plastic product and is continuous throughout the piece. Two-color plastics moldings are also possible, as is currently being done by molding typewriter keys in one piece. Decorative surface textures can also be incorporated into a plastic part by simply incorporating such textures in the surface of the mold.

However, plastics parts, whether film and sheeting or rigid products, can be post-finished in a number of ways. Film and sheet can be post-embossed with textures and they can be printed by letterpress, gravure, or silk screening. Rigid plastics parts can be painted or they can be given a metallic surface by such techniques as metallizing, barrel plating, or electroplating. Another popular method is hot-stamping, in which heat, pressure, and dwell time are used to transfer color or design from a carrier film to the plastic part.

A more recent decorating technique is known as in-mold decorating and involves the incorporation of a printed foil into a plastic part during molding so that it becomes an integral part of the piece and is actually inside the piece under the surface.

This technique was originally developed to decorate melamine dinnerware.

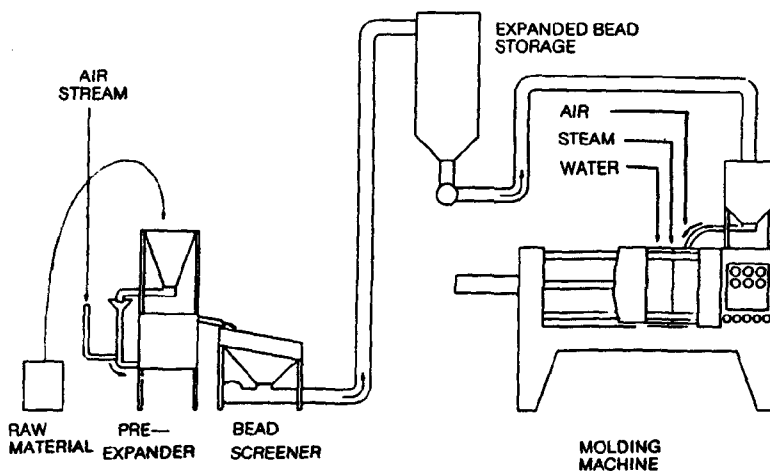
FOAM PLASTICS MOLDING

The manufacture of foam plastics parts cuts across most of the processing techniques covered in this section. Foams can be used in casting, calendaring, coating, rotational molding, blow molding, even injection molding and extrusion. Typical requirements in such instances are for the incorporation of blowing agents in the resin that decompose under heat to generate the gasses needed to create the cellular structure and for various controls to accommodate the foaming action.

There are, however, some techniques unique to foamed plastics. When working with expanded polystyrene beads, for example, to produce cups, picnic dishes, etc., various "steam-chest" molding methods are used. The application of steam causes the beads to expand and fuse together.

When working with urethane foams, it is possible to use spray guns or mixing-

STYRENE FOAM MOLDING



FOAM MOLDING: Among the many variations in molding foamed plastics is this set-up for steam chest molding expandable styrene beads into products like foam cups, novelties, ice buckets, picnic goods, building products, etc. In this operation, the expandable beads, containing a blowing agent, are pre-expanded with steam, then screened to remove large clumps. The expanded beads are next blown into a storage hopper and allowed to dry and stabilize. From here, they feed into the final mold where steam is again used to complete expansion of the beads so that they fill the mold and fuse together. Water is used for cooling, prior to opening the mold and removing the finished foamed styrene part.

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metering machines to mix the liquid ingredients together and direct them into a cavity or mold or surface objects with them. The mixed ingredients start to foam up after leaving the dispensing equipment.

There is a unique technology that has also sprung up in connection with the molding of structural foam—foams with integral skins (i.e., solid) and a cellular core and with a high strength-to-weight ratio. When processing structural foams, several techniques are in use, mostly related to injection molding. One such method is known as the "low-pressure" system because the molds are only partially filled with the plastic melt (using relatively low pressure). The pressures generated within the melt as the blowing agent decomposes and the melt expands are sufficient to fill the mold.

A second technique is known as the "high-pressure system." This differs from low-pressure in that the plastic melt (with the blowing agent incorporated in it) is injected under high pressure into the mold cavity to completely fill it. To accommodate the expansion of the melt as it foams, the mold itself is expanded.

A third technique known as "expansion casting" involves the use of closed metal molds that are filled with expandable pellets, then subjected to a heating cycle, during which the material expands and fuses.

Systems are also available to extrude structural foams with integral skins and cellular cores. Many of these involve conventional extruders and modified techniques. Others involve special systems that use unique die design and shaping dies to control the foaming action.

HIGH-PRESSURE LAMINATING

Thermosetting plastics are most generally used in high-pressure laminating which is distinguished by the use of high heat and pressure. These plastics are used to hold together the reinforcing materials that comprise the body of the finished product. The reinforcing materials may be cloth, paper, wood, or glass fibers.

The end product of high-pressure laminating may be plain flat sheets, rods, tubes or formed shapes.

In producing a flat surface, impregnated sheets are stacked between two highly polished steel plates and subjected to heat and high pressure in an hydraulic press which cures the plastic and presses the plies of material into a single piece of the desired thickness. In making high-pressure tubing, resin-treated reinforcing sheets are wrapped, under tension and/or pressure, around a heated rod. The assembly is then cured in an oven. In producing formed shapes, the reinforcing material is cut into pieces that conform to the contour of the product, fitted into the mold and cured under heat and pressure.

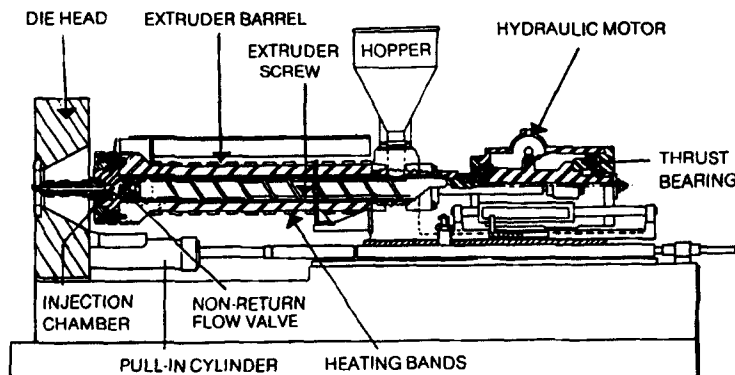
INJECTION MOLDING

The process of molding was patented by John and Isaiah Hyatt in 1872 to mold the cellulose nitrate material (known as celluloid) that they had developed. The first multi-cavity mold (i.e., to make more than one part at a time) was introduced by John Hyatt in 1878. Modern technology in injection molding, however, did not begin to develop until the late 1930s. Its growth was extremely rapid during the '40s and '50s and by the 1960s, it had already by-passed compression molding as the major plastics processing method. Originally used expressly for processing thermoplastics, the technique was adapted in the mid-1960s to also handle the thermosets and in the early 1970s to molding reinforced plastics (glass-thermoset resin combinations).

The basic concept of thermoplastic injection molding revolves around the ability of a thermoplastic material to be softened by heat and to harden when cooled. In most operations, granular material (the plastic resin) is fed into one end of the heating cylinder (usually through a feeding device known as a hopper), heated, and softened (plasticated or plasticized), forced out the other end of the cylinder (while it is still in the form of a melt) through a nozzle and into a relatively cool mold held closed under pressure. Here, the melt cools and hardens (cures) until it is fully set-up. At this point, the mold opens and the molded part in solid form is removed.

Originally, the favored technique for forcing the plastic through the heating cylinder and into the mold was with an injection plunger. Machines using this system are known as plunger machines. The more popular and dominant technique today,

INJECTION MOLDING



INJECTION MOLDING: Diagram of reciprocating screw injection molding machine. Plastics pellets feed through the hopper into the screw (much like the screw in an extruder) where they are compacted, melted, and pumped by the rotation of the screw past the non-return flow valve (allows material to flow right to left, but not from left to right) to the front of the screw where it is allowed to accumulate. At the proper time, the rotation of the screw is stopped and the amount of molten plastic in front of the screw is injected into the mold, using the screw as a plunger activated by the hydraulic injection cylinders. In the mold, the molten plastic flows throughout the cavity, completely filling it. The plastic is then allowed to cool and harden, the mold is opened, and the finished part removed. The back end of the machine shown above contains the motors and drives needed to power the machine.

however, is based on a rotating screw (like the screw used in extrusion) that moves back and forth within the heating cylinder to help soften the plastic and to force it along the cylinder and into the mold. Machines using this system are known as reciprocating screw machines.

The machines used for molding thermosets are called in-line screw injection machines or direct screw transfer machines. They involve basically the same system as in the injection molding of thermoplastics. Temperatures differ, however, as does the design of the screw. In addition, machines for thermosets are also designed so that the screw stops turning when the exact volume of plastic needed to fill the mold has reached the end of the cylinder. At this point, the screw then moves forward under hydraulic pressure to force the plastic, into the mold. Most of these changes are intended to accommodate the fact that thermosets, unlike thermoplastics, cure with the continued application of heat.

In the injection molding of reinforced plastics based on thermoset resins with glass fiber reinforcements, stuffer cylinders, rather than hoppers, are used to push the plastic into the machine. This is necessary since the reinforced plastics are in a

putty-like form that does not flow freely like pellets or granules do. The machines use either a screw or plunger to then force the heated reinforced plastic through the cylinder and into the mold.

REACTION INJECTION MOLDING (RIM)

This technique (also sometimes called liquid injection molding) has thus far been used primarily for molding polyurethane elastomers or foams into end-products with solid integral skins and cellular cores.

Basically, two or more pressurized reactive streams (in the case of urethane, this means an isocyanate and a polyol) are impinged together under high pressure in a mixing chamber. The resulting mixture is then injected, under low pressure, into the mold where the reaction begins and continues until the liquid mixture has set up into a solid or cellular finished product.

Until the advent of RIM, standard liquid casting systems for urethanes involved low feedline pressures and some means of mechanical mixing (e.g., rotating blades). In contrast to these systems, RIM offers such advantages as self-cleaning mixing heads, higher outputs, lower cycles, improved products.

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REINFORCED PLASTICS PROCESSING

Reinforced plastics are composites in which resins (acting as a binder material) are combined with reinforcing materials (usually in a fibrous form) to produce products that have exceptional strength-to-weight ratios and outstanding physicals. The resins may be either thermosets or thermoplastics. However, the thermosetting resins, which were the first plastics to be adapted to this concept (polyester resins, in particular), dominate the field to a large degree.

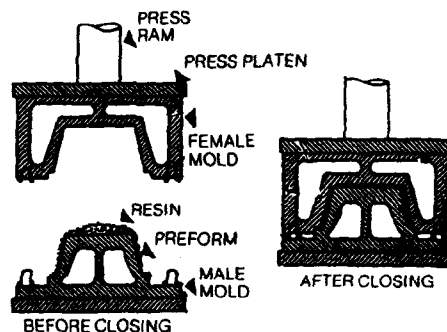
Reinforced thermoplastics can be injection molded, rotationally molded, or extruded on conventional equipment. There are even reinforced thermoplastics sheets that can be "cold" stamped into shape using matching metal molds that form the parts. It is called cold stamping because the molds are kept at or slightly above room temperature. The sheets, however, must be pre-heated.

It is also possible to use modified injection molding techniques with reinforced thermoset resins (see Injection Molding, above), although by and large, the processing of reinforced thermoset resins has developed a technology all of its own. For example, it is possible to process these reinforced plastics into extremely large parts (e.g., boat hulls, storage tanks, etc.), using little or no pressure. One such system is known as hand lay-up and simply involves the manual placement of the reinforcing fibers (in the form of fabrics, woven roving, or mat) into a mold, impregnating the lay-up with liquid resin, squeezing out entrapped air with a squeegee, and then allowing the part to cure, with or without heat, into a finished product. Other variations on this method aimed at improving surface finish and providing a more uniform product involve the use of plastic film or rubber bags placed on top of the lay-ups and forced against them by pulling a vacuum under the film or by applying air pressure over the bag.

Another approach to making a reinforced plastic product is known as "spray-up." In this process, chopped glass and resin are deposited simultaneously in a mold using special spraying equipment. The film-resin mix is then rolled by hand to remove air and allowed to cure at room temperature or heated to achieve an accelerated cure.

Most high-volume reinforced plastics processes in use today, however, do involve the application of pressure. The most popular of these is known as matched metal die molding and is basically a compression molding system in which the reinforced thermoset plastics are placed between matching heated molds and held under pressure until the fiber-filled resin polymerizes (i.e., hardens into a solid). Where differences do exist is in the way in which the reinforced plastic material is fed into the mold. The three forms available today include: 1) preforms shaped from the fibers to the approximate shape of the parts to be made and placed into the mold (more uniformity in product, less waste); 2) bulk molding compounds made up by mixing

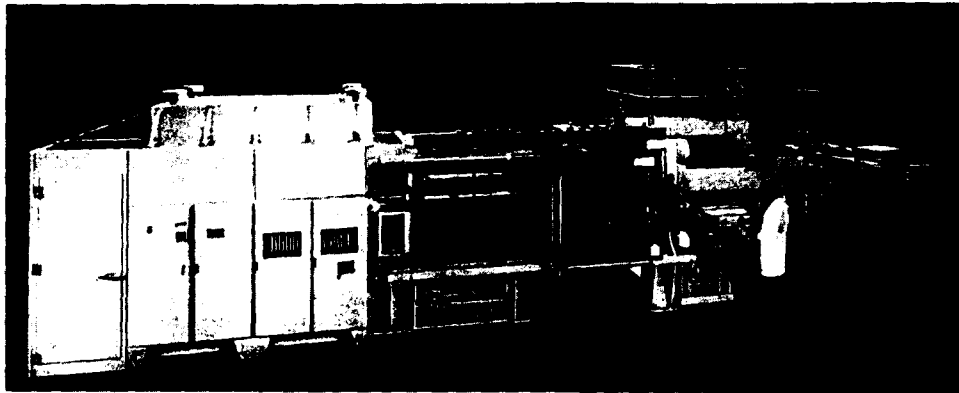
REINFORCED PLASTICS MOLDING



REINFORCED PLASTICS MOLDING: Matched-die molding is one technique for producing RP parts. Basically, it is a compression molding process (see Compression Molding), in which resin and glass fibers are shaped into the finished product under heat and pressure between the two halves of a mold (male and female halves). The glass fiber reinforcements are laid over the male mold in the form of a "preform"—a combination of glass and resin preformed before molding to the basic shape of the part to be molded. Additional liquid resin mix is added before mold is closed.

resin, fibers, catalyst, etc., together into a putty-like mass that can be placed in the mold as is or extruded into a rope-like form for easier handling; and 3) sheet molding compounds, in which fiber, resin, and other ingredients are precombined into a sheet form that can easily be loaded into the mold; either manually or with automatic techniques.

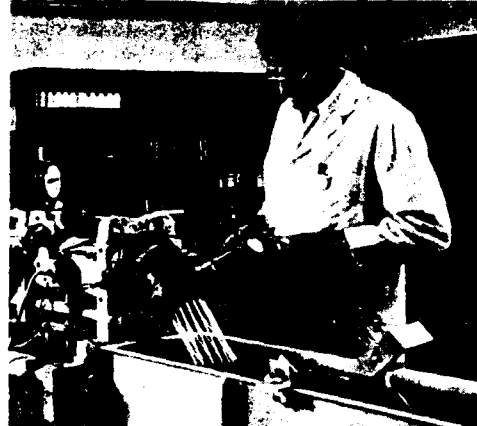
Other unique reinforced plastics processing methods include: pultrusion, a method



INJECTION MOLDING: Machine sizes available today can go up to 1500-ton clamping force (capable of molding a 25-lb. part) and higher (to 3000 tons or better). Hopper for receiving plastics pellets is to operator's right, mold area to his left, behind safety gates.



COATING: Passing through ovens and series of pressure rolls, an expanded vinyl coating is applied to a substrate. Technique can be used to produce products ranging from flooring to wallpaper to various kinds of wearing apparel.



EXTRUSION: Strands emerge from the die of a compounding extruder and pass into a water bath for cooling. Changing die size can vary extrudate from thin filaments all the way up to 48-in.-diameter sewage pipe.



STRUCTURAL FOAM MOLDING: Typical plant set-up shows two 150-ton presses molding plastics foam panels (stacked, foreground) for underground swimming pool. Because lower pressures are used in this process, these 65-lb. panels can be foam molded in a single shot.

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for making continuous shapes (e.g., stair railings) by pulling resin-impregnated fibers through shaping dies and curing operations (it's the reinforced plastics industry's counterpart to thermoplastic extrusion) and filament winding, a method for making cylindrical shapes (e.g., rocket motor cases) by winding resin-impregnated fibers around a mandrel, curing the part, and removing the mandrel.

ROTATIONAL MOLDING

This technique, like blow molding, is used to make hollow one-piece parts.

Essentially, rotational molding consists of charging a measured amount of plastic resin into a warm mold which is rotated in an oven about two axes. In the oven, the heat penetrates the mold, causing the plastic, if it is in powder form, to become tacky and stick to the mold surface, or if it is in liquid form, to start to gel on the mold surface. Since the molds continue to ro-

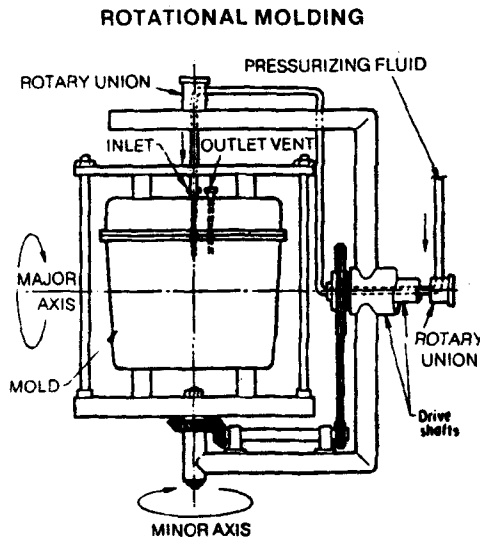
tate while the heating is going on, the plastic will gradually become distributed evenly on the mold cavity walls through gravitational force. As the cycle continues, the polymer melts completely, forming a homogeneous layer of molten plastic. After cooling, the molds are opened and the parts removed.

THERMOFORMING

Basically, thermoforming consists of heating thermoplastic sheet to its softening temperature and forcing the hot and flexible material against the contours of a mold by mechanical means (e.g., tools, plugs, solid molds, etc.) or by pneumatic means (e.g., differentials in air pressure created by pulling a vacuum between sheet and mold or using the pressures of compressed air to force the sheet against the mold). The various forming techniques are generally described in terms of the means used to form the sheet, such as vacuum forming, pressure forming, plug-assist forming, etc.

In the early days of thermoforming, the process involved heating the sheet in a separate oven and then transferring the hot sheet to the forming press. As the industry became more sophisticated, however, automatic machinery combining heating and forming in a single unit evolved. At the same time, the industry moved from the original concept of sheet-fed machines (i.e., feeding a single die-cut sheet into the forming press) to continuous operation feeding off a roll of plastic or directly from the mouth of an extruder.

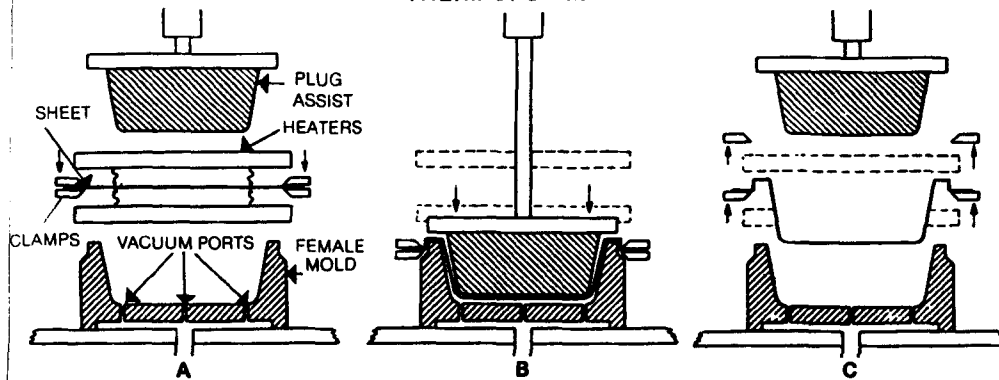
Most recently, the thermoforming industry has begun to evaluate the idea of reducing the amount of heat applied to a thermoplastic sheet, or even eliminating it entirely, and then using the higher pressures of stamping presses to form a part. These techniques are known as cold forming (in which certain plastics, like ABS, have been developed that can be formed at room temperatures, using standard metal working techniques and equipment), solid-phase forming (in which the material is heated below melt temperature and formed while in this heated, solid state), and compression molding (where glass-reinforced material is heated above its melt temperature but has the consistency of wet cardboard due to its reinforcement and can be formed in the compression press).



ROTATIONAL MOLDING: Diagram of basic system indicates how plastics (which feed in through the inlet) are formed into hollow products inside a closed mold while the mold is being rotated about two axes and heat is applied. Spindle is turned on a primary axis, while molds are rotated on a secondary axis. During rotation, the heated (molten) plastic is distributed evenly on the inside walls of the mold cavity through gravitational force. After cooling, the mold is opened and the finished part in the shape of the cavity is removed.

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THERMOFORMING



THERMOFORMING: This variation on the thermoforming of plastic sheet is known as plug-assist vacuum forming. In operation, the plastic sheet is clamped in place and heaters move in to heat the sheet top and bottom to soften it (A). Heaters are then withdrawn and the frame holding the sheet is lowered down to contact the mold. At this point, the plug-assist is lowered into the softened sheet, stretching it down to the bottom of the mold cavity (B). After the plug-assist has reached its closed position, a vacuum is drawn through the ports to pull the stretched sheet completely into the cavity and finish the forming. Next, the plug-assist is withdrawn, the formed sheet is cooled, and the clamps are opened to remove the formed part from the frame (C).

TRANSFER MOLDING

Transfer molding is most generally used for thermosetting plastics.

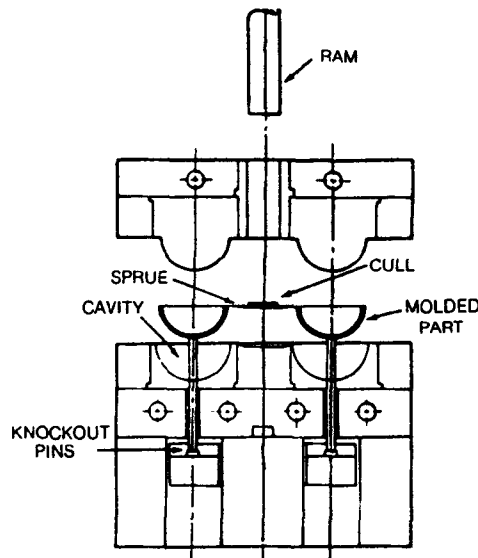
This method is like compression molding in that the plastic is cured into an infusible state in a mold under heat and pressure. It differs from compression molding in that the plastic is heated to a point of plasticity before it reaches the mold and is forced into the closed mold by means of an hydraulically-operated plunger.

Transfer molding was developed to facilitate the molding of intricate products with small deep holes or numerous metal inserts. The dry molding compound used in compression molding sometimes disturbs the position of the metal inserts and the pins which form the holes. The liquefied plastic material in transfer molding flows around these metal parts without causing them to shift position.

One popular method is known as plunger molding and is illustrated at right. A ram forces the plastic from the pot beneath it into the two cup-shaped mold cavities. Diagram shows mold as it is opened after cavities have been filled and parts have cured. Cull (the residual disc of material left in the pot) and the sprue (or runners that carry the plastic from pot to cavities)

remain with the molded pieces and must subsequently be removed.

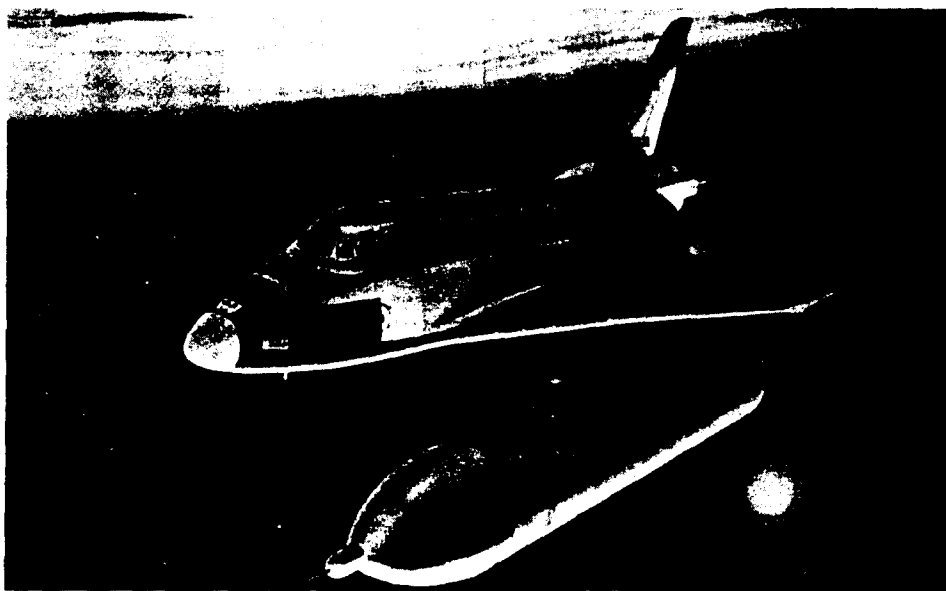
TRANSFER MOLDING



TRANSFER MOLDING: Plastic transfers from "pot" or "well" through runners and gates into cavities retained in a closed heated melt. System shown above is known as "plunger molding" and is described in accompanying text.

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PLASTICS IN OUR FUTURE



As man ventures further into space, aerospace engineers turn increasingly towards plastics to design the advanced vehicles that will be needed.

Materials shape the age in which we live. They determine the form and function of where we live and how we live and how we work and how we play. It is for good and significant reason that so many of the ages in the course of man's development are described in terms of the materials that guided these developments.

It thus becomes even more remarkable when we evaluate the impact that plastics have had on the world today to realize that their existence dates back to just a little over a hundred years ago. Plastics are still evolving, still changing, still improving. Their potential impact on society as we move into the twenty-first century looms larger and larger.

The seeds are already being sown. As we have tried to indicate in this brochure, it is probably impossible to define the totality of the plastics experience in our everyday lives. They are there in so many ways. . . . in apparel, in home furnishings, in construction, in lighting, in furniture, in transportation, in packaging, in medical use, in recreational activities, in communications, in electronics, in housewares, in appliances, in aerospace, in storage tanks and pipes, in luggage, in insulation, in the toys

our children play with, even the playground equipment they play on.

Yet the best is still to come. As a family, many plastics materials are light in weight, yet pound-for-pound much stronger than a number of conventional materials. Translated into the world of tomorrow, they provide the wherewithal for architects to move beyond the conventional box shape of today's homes to fulfill the dream of buildings with more curves and flowing forms, with more open spacing based on plastics members that can span large areas without buckling, with thinner exterior shells that provide unmatched flexibility in executing new and unusual designs.

We see it today in the extensive use of plastics in the futuristic structures at World's Fairs and Olympic sites, in modern-day sports stadia, in geodesic domes. Chances are that if the domed cities that have been standard science-fiction fare for decades ever do come to pass, it will be a plastic dome that will do the covering.

Plastics have more to offer. They can be shaped easily, inexpensively and accurately into large parts and transported economically. Modern concepts of pre-

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fabricated building components mass-produced in factories and trucked to the building site have evolved in part from this plastics capability. Tomorrow, it may be low-cost housing for underdeveloped countries that will benefit.

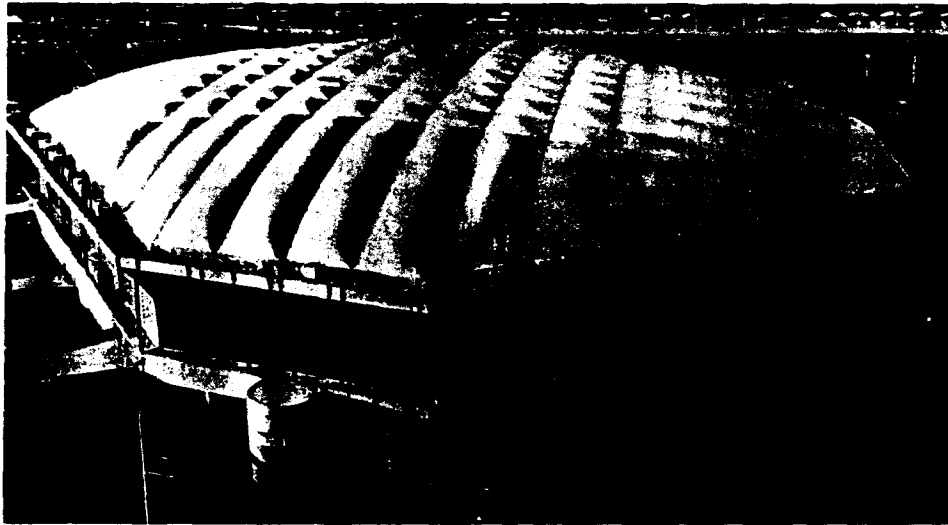
Another straw in the wind: already commercial today are plastics bathroom units, molded and formed in one piece complete with tub, surround, cabinet, sink, toilet. Tomorrow's beneficiary: urban renewal. Visualize a building completely gutted inside and then transformed into usable living space by hoisting a one-piece plastics room with a crane and lowering it in place within the building shell.

These same properties and characteristics of various plastics that could revolutionize building construction in the decades to come may exert an equally as strong influence on building interiors. Mobile plastics walls and room dividers will enable us to change living space as we need it, around a central utility core. Printed plastics surfacing films will help us change a room's color scheme just as quickly. And interior designers are only now just touching on the potential of plastics in furniture—not in imitation of the standard wood shapes we know today, but in the free-flowing shapes and combinations of transparency, color, and texture that only plastic can provide. Significantly, the revolution in furniture design that came out of Europe in the

1960s—inflatable chairs, transparent acrylic tables, stylish reinforced plastics chairs—were sparked by the availability of plastics.

Beyond the home, visionaries see strong roles for plastics in transportation. The same factors of light weight, strength, designability, and ease of maintenance will make plastics as important to the exterior of the automobile (hoods, trunk lids, entire bodies) as it currently is to the interior of the automobile. When automotive engineers finally do come up with the "safety car" of the future that will encase us in an energy-absorbing shell, chances are again good that plastics will be heavily involved. The futuristic cars that Detroit is showing to the public today already use reinforced plastics bodies, urethane bumpers and ends, break-away projections and non-shattering plastics windows.

Even more exciting are the opportunities for plastics in the "people movers" of tomorrow—the mass transportation concepts based on monorails, electric cars, guided autos. Again, you can see the future today in the large number of plastic-bodied vehicles in use at various amusement parks and airports in the U. S. And if you look a little harder you can find small passenger airplanes based almost entirely on plastics, including wings and fuselage. They've been commercial and in use since the late 1960s.



Ten-acre air-supported dome for sports stadium uses plastics to advantage, as do other avant-garde new building concepts.

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The exciting thing about plastics is that in the decades to come they will be working their magic equally as effectively in areas that are considered commonplace next to construction and transportation, areas that are accepted by the public and rarely questioned, areas like housewares and toys and packaging. It is difficult to pin descriptions like "revolutionary" on the influence that plastics has already had in these markets, but revolutionary it was. Just try to remember the limitations in function, form, and color that characterized many of these products before the advent of plastics. Accept the fact that the end is not yet in sight. This is especially true in the areas in which plastics packages will impact on the concept of a fully automated supermarket or other retail establishment—plastics packages that can be more easily, and more safely, handled, plastics packages that may offer longer shelf life without deterioration of the contents, superfunctional packages that bend or expand or otherwise change in size or shape to make storage, delivering, and dispensing functions that much easier.

To the plastic chemist it is all grist for the same mills. It is his job to come up with a material that will meet a need, whether that need is for a heat-resistant plastic that will protect an astronaut or for a plastic housewares item. But he also knows that when you're working with plastics, the avant-garde and the commonplace can become inter-related. The same heat-resistant plastic that protected the astronauts showed up years later in the bowl of a smoking pipe.

As impossible as it is to define today's plastics experience, it is even more difficult to describe its potential for the future. There are very few areas of technological development in which plastics are not involved. The biochemical techniques that have enabled doctors to replace diseased parts of the body is a plastics development—and still in its infancy. The science of fiber optics that has such disparate uses as lighting the dashboard in our automobile or allowing doctors to examine us internally in a way that was completely impossible before can be based on plastic filaments or plastic-coated glass filaments. Nuclear energy plants use lead-filled polyethylene slabs as protective shielding. The concept of miniaturization in electronics

that could someday give us the science-fiction wrist-watch TV leans heavily on plastics. And you will find plastics in the rockets and the exploring machines and the space stations that will be used in the decades to come as we move further and further out into space. It's already happening today.

Plastics are not the substitute that so many people still consider them. It is true they evolved as a substitute-type material (i.e., to replace ivory) and it is true that one period of great activity took place in World War II to replace unavailable materials that were needed to meet consumer and military demands. But that was the wonder of plastics—that man could create a synthetic to meet his needs. The age of synthetics never did mean that the older, more conventional materials had lost their value; rather, it simply meant that it was not available to the extent needed to cover our demands and that man's creativity and ingenuity had come up with alternate possibilities: plastics.

Of course, although the image still exists for plastics, the substitution syndrome has long since become a part of 'ancient' history. It does crop up from time to time, whenever a potential materials shortage looms and the polymer chemist unleashes his imagination to resolve the problem (e.g., concerns about paper shortages in England and Japan in the late 1960s led to the development of plastics 'papers' that could be used for packaging, in bags, to write on, to print on, etc.). But by and large, plastics have become prime materials—quite different, quite unique, and unlike many of the materials that have gone before.

And after 100 years, we're still learning how we can change them, how we can use them even better and more effectively. Plastics are already an expression of our times and certainly one of the means by which today's dreamers and planners will forge the world of tomorrow. It is probably most significant that in the world of modern art, so many artists and sculptors have turned to plastics as the most suitable means of self-expression. In a way, the artist, in his rejection of conventional shapes and forms and materials, is emphasizing plastics as a material with a life and individuality of its very own—and in harmony with the times in which we live.

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WHAT IS SPI?

The Society of the Plastics Industry, Inc., (SPI), represents some 1400 member companies who are responsible for about 75% of plastics sales in the United States. In effect, it is a member-run federation of many groups; through nearly 50 divisions, special purpose groups, market councils, regional sections, and service committees, SPI gives focus, perspective and direction to its members' specific interests.

Members include processors, machinery manufacturers, mold makers and resin producers. The processor, who converts plastic into a finished or semi-finished product, represents a two to one majority in the membership of SPI. The plastics processors are the backbone of the industry and their operations are proprietor controlled. Most are small businesses with a hundred or so employees.

Incorporated in 1937, SPI has grown with the dynamic industry it represents. In addition to the Society's New York office, there is a Mid-Western office, 3150 Des Plaines Avenue, Des Plaines, Illinois, 60018 (312) 297-6150; a Western office, Saddleback Sq., 12440 Firestone Blvd., Norwalk, CA, 90650, (213) 331-0340, an Eastern Office, 1575 Rte. 23, Butler, N.J. 07405 (201) 838-2222, and a Washington office, 1101 17th Street, N.W., Suite 204, Washington, D.C., 20036 (202) 331-0340.

Its 50 operating units work toward the basic SPI objective of "... providing lead-

ership for the responsible advancement of the entire plastics industry." SPI sponsors many special research projects in areas such as resource recovery, combustibility, the industry's future growth potential and worker safety at major private research organizations. SPI is also responsible for many information programs, literature, surveys, reports, newsletters, and handbooks for industry and public use. SPI's service committees provide liaison with government agencies, code and regulatory groups, and many other associations.

SPI also functions as the industry's spokesman on public issues, and serves as the focal point of organization of the industry for their solution.

Each year more schools, colleges and universities are adding instructions in plastics to their curricula. As interest grows, new courses are added, old courses realigned to better prepare students for the needs of the plastics industry.

A wealth of information is contained in trade and technical magazines and technical books for and about the plastics industry. A listing of these publications is available.

The Society of the Plastics Industry, Inc., has a speakers bureau with a number of slide presentations ready for use. Information on the bureau is available from SPI/New York.

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The information in the foregoing has been adapted from data obtained from a wide variety of sources. It is not intended to convey approval by the Society of the Plastics Industry for using any specific plastic in any specific application. Rather, it is intended to provide the reader with some measure of perspective in understanding the versatility inherent in the family of plastics and in the many, many different uses to which each can be put. The information has been gathered together in full awareness that the dynamics of the plastics industry can always lead to change both in materials and markets.

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Educational Facilities

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Trade Publications and Books

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Speakers Bureau

The Society of the Plastics Industry, Inc., has a Speakers Bureau with a number of speeches and slide presentations. Additional information and a list of the speeches and slides, with a brief description of content, is available.

For these lists write to

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