PLASTICS ENGINEERING HANDBOOK

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of the

PLASTICS INDUSTRY,

Inc.

SPI

Fifth Edition

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of the Society of the Plastics Industry, Inc.

Foreword

I am pleased to present the Fifth Edition of the *Plastics Engineering Handbook*. Last published in 1976, this version of the standard industry reference on plastics processing incorporates the numerous revisions and additions necessitated by 14 years of activity in a dynamic industry.

At that last printing, then-SPI President Ralph L. Harding, Jr. anticipated that plastics production would top 26 billion pounds in 1976 (up from 1.25 billion in 1947, when the First Edition of this book was issued). As I write, plastics production in the United States had reached almost 60 billion pounds annually.

Indeed, the story of the U.S. plastics industry always has been one of phenomenal growth and unparalleled innovation. While these factors make compilation of a book such as this difficult, they also make it necessary. Thus I acknowledge all those who worked to gather and relate the information included in this 1991 edition and thank them for the effort it took to make the *Plastics Engineering Handbook* a definitive source and invaluable tool for our industry.

Larry L. Thomas
President
The Society of the Plastics Industry, Inc.

Preface

In this fifth edition of the *SPI Plastics Engineering Handbook*, we continue a tradition of providing readers with a comprehensive manual for plastics processing. Since the last edition was published in 1976, there have been many changes in the types of materials available for manufacturing plastic products. Likewise, there have been new processes introduced and substantial improvements in those that already existed. All in all, the plastics processing industry has become much more sophisticated than it was in the 1970s, making use of higher-performance materials and computer-controlled equipment to widen the range of applications for both thermoplastics and thermosets.

Extensive revisions have resulted in an up-to-date handbook that reflects the plastics industry's state of the art. Some changes in chapter order have been made to guide the reader through the maze of processes for these versatile materials. For example, the Extrusion chapter now precedes the other chapters on thermoplastic processing because extrusion is generic to most of them.

Chapter 1 provides a glossary of words and current expressions in use in the plastics industry. Specialized glossaries with illustrations are placed at the end of the chapters on extrusion and injection molding.

Chapters 2 and 3 cover the range of polymer materials in use in today's industry. The first provides an understanding of the basic chemistry of polymers; the second supplies a description of the families of plastics, their physical and chemical properties, and a brief discussion of the applications for which they are suited. The information has been updated to include descriptions of the newest, high-temperature plastics, e.g., liquid crystal polymers.

Chapters 4 through 20 are devoted to the most widely used methods of plastics processing. The chapter on extrusion has been completely rewritten and provides a thorough understanding of the theory and practice of melting and conveying thermoplastics. For easier reference, the three chapters on injection molding and tooling have been placed in sequence in the new edition. Coverage of blow molding has been expanded considerably to include discussions of new technologies such as injection stretch blow molding. The chapter on thermoforming has also been extensively revised to reflect the many changes in this ever more versatile processing method.

For each process, the *Handbook* covers all aspects of the technology: machinery and equipment, tooling, materials, process variables, and, in some cases, troubleshooting techniques.

Chapters 18 and 19, instead of concentrating on a single processing method, furnish a comprehensive presentation of the materials and methods used in two major industry segments. Chapter 18, on reinforced plastics, covers the full range of composite materials and manufacturing processes that are widely used in making products for automotive, aircraft and aerospace, marine, and construction applications. Chapter 19, on cellular plastics, covers both thermoset and ther-

moplastic foams as well as such new techniques as structural reaction injection molding, resin transfer molding, and gas-assisted injection molding.

Chapter 20, on radiation processing, begins the *Handbook*'s coverage of secondary processing techniques. Chapter 21 is devoted to descriptions of equipment for handling incoming raw materials, their distribution to individual processing machines, and for handling finished parts and scrap. Chapter 22 discusses preparation of the raw materials for processing.

In Chapters 23 through 26, the *Handbook* moves to secondary operations, with coverage of machining, assembly, and decorating.

Finally, in Chapter 27, there is a presentation of accepted testing methods for plastic materials and manufactured products.

The last portion of the *Handbook* is probably the most used section. Special attention has been paid to the index for the Fifth Edition to help the reader easily locate the information he or she needs.

Acknowledgments

In preparing this Fifth Edition of the *SPI Plastics Engineering Handbook*, we have built upon a base of information that has grown along with the plastics industry over the past 45 years.

As a work whose contents are largely contributed, the *Handbook* owes a great deal to the authors and reviewers whose time and efforts went into its publication. They all have our sincere appreciation.

In compiling the new work, much text from the previous edition has been retained, with the necessary revisions and updates provided by current industry experts. We therefore thank all the contributors and reviewers who participated in the Fourth Edition as well.

Acknowledgment is due once again to the many suppliers of plastic materials and processing equipment who have generously offered literature and illustrations. We have provided credit for those contributions throughout the handbook.

Thanks are also in order to the Society of the Plastics Industry, which supported the publication of the Handbook and supplied us with association literature, data, standards, and other information contained in this volume.

I would also like to give special thanks to Joel Frados, editor of the Fourth Edition and my mentor in the plastics publishing business, to Mel Friedman and Ed Galli of Edgell Communications for their help in gathering information, to Stephanie Seber for her long hours of manuscript preparation, to Emil Davidson for his inspiration and assistance, and to Tina Berins for her constant encouragement.

MICHAEL L. BERINS, *Editor*

Contents

1
Glossary

Over the years, the plastics industry has built up a language and a terminology of its own. In this chapter, the most commonly used words and expressions are classified and defined. Definitions of other terms can also be found in the text, and can be located by means of the index at the back of the book.

In many instances, the words being defined are peculiar to the plastics industry and the way in which it manufactures its products. In other cases, the expression used by the industry may derive from words commonly used in other branches of manufacturing (e.g., the concept of forging plastics from metalworking terminology); as applied to plastics, however, these definitions may differ from common usage.

Readers also are referred to the special glossaries included in the chapters on extrusion and injection molding.

A-stage—An early stage in the reaction of certain thermosetting resins, in which the material is still soluble in certain liquids and fusible. Sometimes referred to as resol. See **B-stage** and **C-stage**.

ablative plastic—Description applied to a material that absorbs heat (while part of it is being consumed by heat) through a decomposition process known as pyrolysis, which takes place in the near surface layer exposed to heat. This mechanism essentially provides thermal protection of the subsurface materials and components by sacrificing the surface layer.

accelerator—A chemical additive that increases the speed of a chemical reaction.

accumulator—An auxiliary cylinder and piston (plunger) mounted on injection molding or blow molding machines to provide fast delivery of plasticated melt. The accumulator cylinder is filled during the time between "shots" with melted plastic coming from the main (primary) extruder.

activation—The process of inducing radioactivity in a specimen by bombardment with neutrons or other types of radiation.

additive—Substance compounded into a resin to modify its characteristics (i.e., antistats, stabilizers, plasticizers, flame retardants, etc.).

adiabatic—An adjective used to describe a process or transformation in which no heat is added to or allowed to escape from the system under consideration. It is used, somewhat incorrectly, to describe a mode of extrusion in which no external heat is added to the extruder although heat may be removed by cooling to keep the output temperature of the melt passing through the extruder constant. The heat input in such a process is developed by the screw as its mechanical energy is converted to thermal energy.

aging—The process of exposing plastics to an adverse environment (i.e., heat, chemicals, light) for an interval of time, to determine the effect on properties.

air ring—A circular manifold used to distribute an even flow of the cooling medium, air, onto a hollow tubular film (bubble) passing through the center of the ring. In extrusion blown films, the air cooling provides uniform thickness.

air-slip forming—A variation of snap-back forming in which the male mold is enclosed in a box in such a way that when the mold moves forward toward the hot plastic, air is trapped between the mold and the plastic sheet. As the mold advances, the plastic is kept away from it by the air cushion formed as described above, until the full travel of the mold is reached, at which point a vacuum is applied, destroying the cushion and forming the part against the plug.

air vent—See **vent**.

ambient temperature—Temperature of the medium surrounding an object.

amorphous—Having no crystalline structure.

anchorage—Part of the insert that is molded inside of the plastic and held fast by the shrinkage of the plastic.

anisotropy—The tendency of a material to react differently to stresses applied in different directions.

anneal—To heat an article to a predetermined temperature and slowly cool it to relieve stresses. Annealing is employed on parts produced from both metals and plastics. (Annealing of molded or machined parts may be done dry as in an oven or wet as in a heated tank of mineral oil.)

antiblocking agent—A substance added to plastic resin to prevent adhesion between touching layers of film caused by pressure, heat, and contact during fabrication and storage.

antistatic agent—A substance that can be applied to the surface of a plastic article, or incorporated in the plastic from which the article is to be made. Its function is to render the surface of the plastic article less susceptible to accumulation of electrostatic charges which attract and hold fine dirt or dust on the surface of the plastic article.

aramid fiber—Lightweight, high strength polymeric fibers used as ballistic armor and as reinforcements for plastics.

arc resistance—Time required for a given electrical current to render the surface of a material conductive because of carbonization by the arc flames. Ref.: Standard Method of Test for High-Voltage, Low-Current Arc Resistance of Solid Electrical Insulating Materials (ASTM Designation: D 495).

atactic—Description applied to a random arrangement of units along a polymer chain. See **isotactic**.

autoclave—A closed vessel for conducting a chemical reaction or other operation under pressure and heat.

autoclave molding—Procedure used in reinforced plastic molding, in which, after layup, the entire assembly is placed in a steam autoclave at 50 to 100 psi. Additional pressure achieves higher reinforcement loadings and improved removal of air. (Modification of pressure bag method.)

automatic mold—A mold for injection, compression, or transfer molding that repeatedly goes through the entire molding cycle, including ejection, without human assistance.

average molecular weight—Term used to indicate the chain length of the most typical chain in a given plastic. Molecular weight of polymers is determined by measuring the viscosity of the material in solution at a specific temperature. The value is independent of specific chain length and falls between weight average and number average molecular weight.

B-stage—An intermediate stage in the reaction of a thermosetting resin in which the material softens when heated and swells in contact with certain liquids but does not entirely fuse or dissolve. Resins in thermosetting molding compounds usually are in this stage. See also **A-stage** and **C-stage**.

back pressure—Resistance of a material, because of its viscosity, to continue flow when mold is closing.

back-pressure-relief port—An opening from an extrusion die for the escape of excess material.

back taper—Reverse draft used in a mold to prevent the molded article from drawing freely. See **undercut**.

backing plate—In injection molding equipment, a heavy steel plate used as a support for the cavity blocks, guide pins, busings,

etc. In blow molding equipment, it is the steel plate on which the cavities (i.e., the bottle molds) are mounted.

baffle—A device used to restrict or divert the passage of fluid through a pipe line or channel. In hydraulic systems, the device, which often consists of a disc with a small central perforation, restricts the flow of hydraulic fluid in a high pressure line. A common location for the disc is in a joint in the line. When applied to molds, the term is indicative of a plug or similar device located in a stream or water channel in the mold and designed to divert and restrict the blow to a desired path.

bag molding—A method of applying pressure during bonding or reinforced plastics molding in which a flexible cover, usually in connection with a rigid die or mold, exerts pressure on the material being molded through the application of air pressure or the drawing of a vacuum.

Bakelite—A proprietary name for phenolic and other plastics materials, often used indiscriminately to describe any phenolic molding material or molding. The name is derived from that of Dr. Leo Hendrik Baekeland (1863–1944), a Belgian who developed phenolic resins in the early 1900s.

Banbury—An apparatus for compounding materials composed of a pair of contra-rotating rotors that masticate the materials to form a homogeneous blend. This is an internal-type mixer that produces excellent mixing.

band heater—Electrical heating units fitted to extruder barrels, adaptors, dies, nozzles, etc., utilized for heating the polymer to a desired temperature.

barrel—The tubular portion of an extruder in which the conveying screw rotates.

barrier plastics—A general term applied to a group of lightweight, transparent, and impact-resistant plastics, usually rigid copolymers of high acrylonitrile content. The barrier plastics generally are characterized by gas, aroma, and flavor barrier characteristics approaching those of metal and glass.

beta gauge—A thickness-measuring device used for sheeting or extruded parts. The device operates by beta radiation being emitted on one side of the part and a detector placed on the opposite side. When a part is passed through the beam, some of the beta radiation is absorbed, providing an indication of the part's thickness.

biaxial orientation—The process of stretching a hot plastic film or other article in two directions under conditions resulting in molecular orientation in two directions.

binder—A component of an adhesive composition that is primarily responsible for the adhesive forces that hold two bodies together. See **extender**, **filler**, and **matrix**.

biscuit—See **preform**.

blanking—The cutting of flat sheet stock to shape by striking it sharply with a punch while it is supported on a mating die. Punch presses are used. Also called **die cutting** (which see).

bleed—(1) To give up color when in contact with water or a solvent. (2) Undesired movement of certain materials in a plastic (e.g., plasticizers in vinyl) to the surface of the finished article or into an adjacent material; also called migration. (3) An escape passage at the parting line of a mold, like a vent but deeper, that allows material to escape or bleed out.

blind hole—Hole that is not drilled entirely through.

blister—Undesirable rounded elevation of the surface of a plastic, whose boundaries may be indefinitely outlined, somewhat resembling in shape a blister on the human skin. A blister may burst and become flattened.

blocking—An adhesion between touching layers of plastic, such as that which may develop under pressure during storage or use.

bloom—(1) A noncontinuous surface coating on plastic products that comes from ingredients such as plasticizers, lubricants, antistatic agents, etc., which are incorporated into the plastic resin. It is not always visible. Bloom is the result of ingredients coming out of solution in the plastic and migrating to its surface. (2) Also, term used to describe an increase in diameter of the parison as it comes

from the extruder die(s) in the blow molding process.

blow molding—A method of fabrication in which a warm plastic parison (hollow tube) is placed between the two halves of a mold (cavity) and forced to assume the shape of that mold cavity by use of air pressure. Pressurized air is introduced through the inside of the parison and thereby forces the plastic against the surface of the mold that defines the shape of the product.

blow pin—Part of the tooling used to form hollow objects or containers by the blow molding process. It is a tubular tool through which air pressure is introduced into the parison to create the air pressure necessary to form the parison into the shape of the mold. In some blow molding systems, it is a part of, or an extension of, the core pin.

blow pressure—The air pressure required to form the parison into the shape of the mold cavity in a blow molding operation.

blow rate—The speed or rate at which the air enters or the time required for air to enter the parison during the blow molding cycle.

blowing agent—A substance that alone or in conjunction with other substances is capable of producing a cellular structure in a plastic mass.

blown film extrusion—Technique for making film by extruding the plastic through a circular die, followed by expansion (by the pressure of internal air admitted through the center of the mandrel), cooling, and collapsing of the bubble.

blown tubing—A thermoplastic film produced by extruding a tube, applying a slight internal pressure to the tube to expand it while still molten, and subsequent cooling to set the tube. The tube is then flattened through guides and wound up flat on rolls. The size of blown tubing is determined by its flat width in inches as wound, rather than by the diameter (which is used for rigid tubing).

blow-up ratio—In blow molding, the ratio of the diameter of the product (usually its greatest diameter) to the diameter of the parison from which the product is formed. In blown film extrusion, the ratio between the diameter of the final film tube and the diameter of the die orifice.

bolster—Space or filler in a mold.

boss—Projection on a plastic part designed to add strength, to facilitate alignment during assembly, to provide for fastenings, etc.

bottom blow—A specific type of blow molding technique in which hollow articles are formed by injecting the blowing air into the parison from the bottom of the mold (as opposed to introducing the blowing air at a container opening).

bottom plate—Part of the mold that contains the heel radius and the push-up.

branched—Chemistry term referring to a configuration having side chains attached to the original chain (in a direction different from that of the original chain) in the molecular structure of a polymer.

breakdown voltage—The voltage required, under specific conditions, to cause the failure of an insulating material. See **dielectric strength** and **arc resistance**.

breaker plate—A metal plate installed across the flow of the stock between the end of an extruder screw and the die, with openings through it such as holes or slots. It usually is used to support a screen pack.

breathing—The opening and closing of a mold to allow gases to escape early in the molding cycle. Also called degassing. When referring to plastic sheeting, breathing indicates permeability to air.

brinell hardness—Similar to **Rockwell hardness** (which see).

bubble—A spherical, internal void or globule of air or other gas trapped within a plastic. See **void**.

bubbler—A device inserted into a mold force, cavity, or core that allows water to flow deep inside the hole into which it is inserted and to discharge through the open end of the hole. Uniform cooling of molds and of isolated mold sections can be achieved in this manner.

bulk density—The density of a molding material in loose form (granular, nodular, etc.) expressed as a ratio of weight to volume (e.g., g/cm^3 cubed or lb/ft^3 cubed).

bulk factor—Ratio of the volume of loose molding powder to the volume of the same weight of resin after molding.

bulk molding compound (BMC)—Thermo-