Plastics Engineering Handbook

of the Society of the Plastics Industry, Inc.

fourth edition

edited by **Joel Frados**

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FOREWORD

It is a great pleasure to present herewith the Fourth Edition of the Plastics Engineering Handbook. This new edition reflects substantial revisions and updating throughout. We are indeed indebted to the many contributors to this edition, especially to Joel Frados, Publisher of *Plastics Focus*, who served as Editor, and authored several sections.

When the Handbook was first published in 1947 the total reported production of plastics was 1,252,000,000 pounds. Currently, in 1976, we are likely to exceed 26 billion pounds. It is reasonable to believe that the earlier editions contributed in no small way to that fantastic growth through its emphasis on quality, sound engineering, and good design.

Today, plastics products are being used substantially in every industry, and the need for an authoritative and reliable Handbook like this has never been greater. It is essential that the designers and users of plastics recognize not only the potential capabilities but also the limitations of our materials.

Looking ahead, we can anticipate continuing rapid growth for plastics. There will inevitably be new and improved materials and dramatic innovations in production techniques, as well as thousands of new applications. Thus, plans must be made immediately for the publication of the Fifth Edition a few years hence.

All of us in plastics today owe a special acknowledgment to all of the men who worked on the earlier editions of this handbook. The most notable and most unsung of these is Charles L. Condit, now Staff Vice President of SPI, whose untiring devotion to our industry's progress continues to be an inspiration for all of us.

RALPH L. HARDING, JR.
President of SPI

PREFACE

The plastics industry has changed in many ways since the last edition of the *SPI Engineering Handbook* was published—so much so that it becomes difficult to make comparisons. Where thermosets dominated the Third Edition, the thermoplastics move to the fore in this one. The blow molding process, as another example, had only a few paragraphs of description in the Third Edition—it has a chapter of its own in this volume. And no one had even heard of rotational molding or structural foam molding when the Third Edition was published.

In fact, to keep pace with the fast-moving industry, virtually every chapter from the Third Edition has either been completely rewritten or revised extensively and a number of new chapters have been added.

However, the basic format and coverage that has made the *SPI Engineering Handbook* so important to the plastics industry has been retained. The general flow of the book continues to duplicate the general flow of plastics through the manufacturing operation—from original materials selection to processing to secondary finishing to final use.

Chapter 1 provides an up-to-date glossary of the words and expressions in common use in the plastics industry (including a special illustrated section on injection molding and extrusion nomenclature).

Chapters 2 and 3 form a basic guide to plastics materials highlighting their chemistry, their characteristics, and their applications. These two chapters are new to the *SPI Engineering Handbook*, but because the family of plastics has become so diverse over the years, this information is essential to a full understanding of the various manufacturing operations covered in the Handbook.

Chapters 4 through 18 are devoted to the most popular methods of plastics processing. The three major processing techniques—injection molding, extrusion, and thermoset processing—are covered first (Chapters 4 through 11). Next, thermoforming, including the relatively new concept of "cold stamping" (Chapter 12), and blow molding (Chapter 13) are reviewed. Chapters 14 through 18 cover those processing techniques that involve the use of plastics in various powder, paste, and liquid grades: rotational molding (Chapter 14), calendering (Chapter 15), processing vinyl dispersions (Chapter 16), powder coating (Chapter 17), and casting (Chapter 18).

In most instances, each chapter covers all aspects of the individual process: machinery and equipment, molds or dies, processing variables, etc. However, for injection molding and thermoset processing the subjects of mold design are discussed in separate chapters (Chapters 6 and 10, respectively). The reasons for this lie both in the complexity of the subjects and in the fact that many of the basic rules and principles outlined in these two chapters serve as a good starting point for understanding mold design as it applies to all the processes covered in subsequent chapters. Similarly, we have also devoted a separate chapter (5) to the subject of controls for injection molding. Again, this is intended as a review of the basic principles of process control as it applies to all processes (each subsequent chapter, however, does cover the type of controls used for the particular techniques being discussed).

Chapters 19 and 20 are devoted to two forms of plastic–reinforced plastics and foamed or cellular plastics–that are so unique and so widely used that they have virtually spawned entire industries of their own. Chapter 21 on radiation processing is another subject that is entirely new to an Engineering Handbook.

The next three chapters–mold making and materials (Chapter 22), designing molded products (Chapter 23), and standards for tolerances of molded articles (Chapter 24)–should more logically have been placed in the front of the Handbook, since they cover procedures that are generally undertaken after the basic plastic has been selected and before processing begins. However, we have carried them in the middle of the Handbook, after processing and before secondary finishing, because we feel that the success of these activities, especially design, will depend to a large extent on a complete understanding of the process to be used. As the reader will quickly note, when working with plastics, there are strong interrelationships between the basic material, the process, the design, and even finishing and assembly. This latter subject is covered in the four chapters that follow the sections on design–Chapter 25 through Chapter 28.

Finally, there is a chapter on Compounding and Materials Handling (Chapter 29) and one on Performance Testing of Molded Products (Chapter 30).

ACKNOWLEDGMENTS

Previous editions of the SPI Engineering Handbook were prepared by SPI-appointed subcommittees who were responsible for reviewing and up-dating each of the chapters of the book under the very able direction of Charles L. Condit (now Staff Vice President of SPI). Their efforts have provided the current Editors with an invaluable base of information with which to work—and we are deeply indebted to them.

As will be evident to readers of this edition, we have also been fortunate in having the assistance of a number of leading industry experts in compiling this Handbook. Wherever possible, we have acknowledged their contributions directly with a credit line, but since we are very much aware of the effort that went into the preparation of this material, we wish to extend to them our personal thanks.

Acknowledgment should also be made to the many materials suppliers in the plastics industry who have built up over the years a sizable body of literature relating to the use of plastics and who granted permission to use various sections in this Handbook. It would be impossible to list them all individually, since they span the entire gamut of current resin suppliers, but again, we have provided appropriate credit in the Handbook for their contributions.

Because of my own personal association with the publishing industry, I also found numerous occasions to call on my friends at the various plastics magazines for their advice and assistance on various sections of the Handbook. Since the plastics industry is serviced by a number of high-caliber publications, I was fortunate in obtaining permission to use editorial material here that originally appeared in those publications. I am especially indebted to Malcolm W. Riley and Lowell L. Scheiner of *Plastics Technology,* Sid Gross of *Modern Plastics,* Len Berringer and Bernie Miller of *Plastics World*, George Smoluk (ex-Editor) and Abe Schoengood (current Editor) of *Plastics Engineering*, Charles Cleworth of *Plastics Machinery & Equipment*, and Don Swanson of *Plastics Design and Processing*. And another note of thanks to J. O'Rinda Trauernicht from our own *Plastics Focus* staff, particularly for permission to use excerpts from her award-winning series on the bonding and decorating of plastics (as it originally appeared in *Plastics Technology*).

And finally, my very special gratitude to Julia Frados and Robin Frados for their assistance and encouragement.

JOEL FRADOS

CONTENTS

1 GLOSSARY

Over the years, the plastics industry has built up a language and a terminology of its very 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 derives from metalworking terminology); as applied to plastics, however, these definitions may differ from common usage.

Readers are especially referred to the illustrations that accompany the definitions of extrusion terminology, injection molding terminology, and mold terminology.

The Editor wishes to extend special thanks and appreciation to the following for permission to reprint various definitions: *Modern Plastics Encyclopedia* (published by McGraw-Hill, Inc.); Phillips Petroleum Co.'s "Glossary of Plastics Terms"; SPI's Machinery Division's "Standard Nomenclature for Single Screw Extruders"; SPI's Machinery Division's "Standard Nomenclature and Specifications for Plastics Injection Molding Machines"; SPI's Plastics Pipe Institute's "A Glossary of Plastics Piping Terms"; SPI's Bottle Division's "Bottle Glossary"; SPI's Custom Molders Division's "Standards and Practices of Plastics Custom Molders."

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, C-stage.**)

ablative plastics–This description applies to a material which 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.

accumulator–An auxiliary cylinder and piston (plunger) mounted on injection molding or blowing machines. It is used to provide extremely fast molding cycles. In blow molding, the accumulator cylinder is filled (during the time between parison deliveries or "shots") with melted plastic coming from the main (primary) extruder. The molten plastic is stored or "accumulated" in this auxiliary cylinder until the next parison is required. At that time the piston in the accumulator cylinder forces the molten plastic into the dies that form the parison.

acid-acceptor–A compound which acts as a stabilizer by chemically combining with acid which may be initially present in minute quantities in a plastic, or which may be formed by the decomposition of the resin.

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

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.

adsorption, n.–A concentration of a substance at a surface or interface of another substance.

aging, n.–**(1)** The effect of exposure of plastics to an environment for an interval of time. **(2)** The process of exposing plastics to an environment for an interval of time, resulting in improvement or deterioration of properties.

air ring–A circular manifold used to distribute an even flow of the cooling medium, air, onto a hollow tubular form passing through the center of the ring. In blown tubing, the air cools the tubing uniformly to provide uniform film 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–Small outlet, usually a groove, to provide a path for air to flow out of a mold cavity as the material enters.

ambient temperature–Temperature of the medium surrounding an object.

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

angle press–A hydraulic molding press equipped with horizontal and vertical rams, and specially designed for the production of complex moldings containing deep undercuts.

anneal–**(1)** To heat a molded plastic article to a predetermined termperature and slowly cool it, to relieve stresses. **(2)** To heat steel to a predetermined temperature above the critical range and slowly cool it, to relieve stresses and reduce harness. (Annealing of molded or machined parts may be done dry as in an oven or wet as in a heated tank of mineral oil.)

antioxidant–A chemical substance that can be added to a plastic resin to minimize or prevent the effects of oxygen attack on the plastic (e.g., yellowing or degradation). Such chemical attack by oxygen may render a plastic brittle or cause it to lose desired mechanical properties.

antistatic agent–A chemical 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.

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).

artificial aging (see also **aging**)–The exposure of the plastic to conditions which "accelerate" the effects of time. Such means include heating, exposure to cold, flexing, exposure to chemicals, ultraviolet lights, etc. Typically the conditions chosen for such testing reflect the conditions under which the plastic article will be used. The length of time the article is exposed to these test conditions is generally relatively short. Properties such as dimensional stability, mechanical fatigue, chemical resistance, stress crack resistance, etc., are evaluated.

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

autoclave molding–As used in reinforced plastic molding. After lay-up, entire assembly is placed in 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–Plastics (polymers) are long, chain-like structures. The number of units which comprise an individual chain varies from chain to chain. Average Molecular Weight indicates chain length of the most typical chain in a given plastic; it is neither the longest chain nor the shortest.

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 are usually 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 escape of excess material.

back taper–Reverse draft used in mold to prevent molded article from drawing freely. (See **undercut.)**

backing plate–In injection molding equipment, a heavy steel plate that is used as a support for the cavity blocks, guide pins, bushings, 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 flow 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 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 1900's.

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

barrel–See **extruder.**

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 are generally characterized by gas, aroma, and flavor barrier characteristics approaching those of metal and glass.

binder, n.–A component of an adhesive composition which is primarily responsible for the adhesive forces which hold two bodies together. (See **extender; filler; matrix**).

biscuit–See **cull** and **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.**

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, which allows material to escape or bleed out.

blind hole–Hole that is not drilled entirely through.

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

bloom–(1) A non-continuous surface coating on plastic products that comes from ingredients such as plasticizers, lubricants, anti-static 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 the surface of the plastic. (2) Also 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. The air pressure 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.

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.

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 which is 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 the flat width in inches as wound rather than by the diameter as in the case of rigid types of tubing.

blueing–A mold blemish in the form of a blue oxide film on the polished surface of a mold due to abnormally high mold temperatures is termed blueing.

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 which forms hollow articles 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 which contains the heel radius and the push-up.

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 perforated plate located at the rear end of an extruder or at the nozzle end of an injection cylinder. It often supports the screens that prevent foreign particles from entering the die, and is used to keep unplasticized material out of nozzle and to improve distribution of color particles.

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 (q.v.).

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

bubbler–A device inserted into a mold force, cavity or core, which allows water to flow deep inside the hole into which it is inserted and to discharge through the open end of hole. Uniform cooling of the 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 or lb/ft^3).