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The Development of Technical Instructional Materials for Industrial Technology Students

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THE DEVELOPMENT OF TECHNICAL INSTRUCTIONAL MATERIALS FOR INDUSTRIAL TECHNOLOGY STUDENTS

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** Note: This appendix is a stand alone teaching document, and is therefore independently paginated.

CHAPTER 1

INTRODUCTION

This research project arose as the result of an expressed need within the Department of Industrial Technology at the University of Northern Iowa (M. F. Fahmy, personal communication, January 1987). This need was expressed as the lack of a suitable textbook for an introductory level course in industrial plastics.

The curriculum structure in some programs requires a general familiarity with plastic materials and their major areas of industrial application. In other curricula a more detailed working knowledge of plastics technology is both desirable and essential, but not required (B. C. Rogers, personal communication, June 1987).

Currently, the materials science needs of students are being met through two courses. Metals, both ferrous and non-ferrous, are taught in 33:132g, Metallurgy. All other material systems are covered in the materials science survey course 33:172g, Industrial Materials (University of Northern Iowa Bulletin, University Catalog Issue, 1986 - 1988).

A plastics course, 33:177g, Industrial Plastics is listed in the University Bulletin, but has not been offered for some time. The reasons for this are:

1. The lack of an appropriate text for teaching the course (M. F. Fahmy, personal communication January 1987).

2. No faculty members have the background to teach such a course (M. F. Fahmy, personal communication, January 1987).

3. The necessary laboratory activities for the course remain to be developed and installed (M. F. Fahmy, personal communication, January 1987).

The foregoing suggests that if appropriate teaching materials were developed within the department, they would be useful in both a materials survey course, and in an introductory level course devoted entirely to plastics (T. Favre & J. Shultz, personal communication, March 1987). Moreover, the production of such materials as an initial effort would certainly suggest some appropriate laboratory exercises. Thus, the natural evolution of this project implies the development of an accompanying laboratory syllabus and manual (M. F. Fahmy, personal communication, May 1987).

The result of this project would be a stand-alone teaching aid and reference document developed and written within the Department of Industrial Technology. Hence, the document would specifically address the needs of <u>technical</u> students in materials science courses at the University of Northern Iowa. However, before writing such a document, the process and the procedures for developing technical instructional materials needs to be determined and documented.

However, preliminary readings yielded little usable information. Only a few contained specifically applicable information. The work of Andrews (1975) and Blicq (1986) was confined to technical writing; that of Jones (1981), Van Leunen (1978), and Carver (1984) addressed the reporting of scientific research (that is, "scholarly writing"); Turk's text (1982) covered general expository writing; Fischel's book (1884) dealt with writing and publishing professional books; and Wilson's work (1983) covered several viewpoints on the development of instructional materials. Since the information was so diverse, the development and presentation of the research is equally eclectic in nature.

Purpose of the Research

The purpose of the research was to develop a usable reference document for graduate students, graduate assistants, undergraduate students, and others who must write technical instructional materials.

The Research Problem

The problem in this study was to determine how technical instructional materials should be developed and written.

Research Questions

The specific questions in this research study are:

1. Is there a body of knowledge specifically related to the development of technical instructional materials?

2. Is there an overall process that is used to develop and write such materials?

3. Can the overall process be expressed as a procedure or protocol which is usable by a reasonably skilled writer?

4. What are the individual components or steps in the process?

5. Are there any other factors which should be considered in developing and writing technical instructional materials?

Limitations

The limitations pertaining to this study were:

1. The available references specifically addressing the development of technical instructional materials were limited, both in number and scope.

2. The number of experts with significant experience in technical or instructional writing were limited.

3. Only one computerized editing package was available for the expert panel to evaluate and comment upon.

Assumptions

In this study the assumptions made were:

1. The available knowledge regarding the process of writing technical instructional materials is not discrete, that is, it is not conveniently located in a single or a few references.

2. Once a suitable procedure has been identified and detailed, it will be usable by individuals in many fields who are required to develop technical instructional materials.

3. The process of communicating written technical information involves not only a set of discrete procedural steps, but many intangible factors as well.

4. The intangible factors, although important, will not be part of this research.

5. The instructional materials developed using the procedures outlined herein will be specifically for use within the Department of Industrial Technology.

6. The procedures developed and detailed will be specifically applicable in the post-secondary educational setting.

Definitions of Terms

The terms peculiar to this research are:

Body of knowledge -- an aggregate of information, both subject specific and subject related regarding a technical subject.

Development -- the process of defining and refining the the material to be taught according to established training or educational principles and practices.

Expertise -- a level of competence in a single technical subject (and related technical areas) which would permit an individual to teach the subject to undergraduate technology students.

Expository writing -- a straightfoward presentation and/or explanation of factual material.

Instructional writing -- the presentation of technical information to be learned in written form.

Intangible factors -- components of a process which are crucial to its successful functioning, but which are highly subjective and difficult to define or measure.

Mechanics -- the rules, conventions and practices related to writing technical instructional materials, such as syntax, grammar, style, spelling, punctuation, etc.

Technical instructional materials -- materials related to a specific technical subject which were developed using established educational or instructional principles, and which are specifically written for teaching technical students.

Technical students -- students in four year technology programs or two year technical programs.

Technical subject -- a course of study which is less theoretical and more applications oriented, and which has been specifically developed and written for technical students.

Technical writing -- the presentation of technical subject information in written form.

CHAPTER 2

REVIEW OF THE LITERATURE

This research was limited by a lack of available references specifically addressing the writing of technical instructional materials for the post-secondary student. Many volumes on the subject of conducting scholarly or purely academic research were available and consulted. There are many acceptable styles and techniques used to report the results of academic or empirical research ("scholarly writing") (Andrews, 1975).

Similarly, many reference works on technical writing were briefly consulted. The variability of styles and techniques was even more pronounced than in research writing. Indeed, the standards and formats for technical writing vary not only from industry to industry, but from company to company as well (Andrews, 1975; Israel & Wright, 1987).

Other more generic writing manuals or style manuals such as Effective Writing by Turk (1982), Strunk and White's The Elements of Style (1979), and Ross-Larson's Edit yourself (1982) were found to be applicable in some degree to many types or styles of writing. However, very little information which specifically applied to the writing of technical instructional materials was found. Due to their unique nature, the writing of these materials combines some of the techniques and practices of several kinds of writing (Wilson, 1983).

If their technical aspects are ignored, the most unique feature of these materials is their instructional design. In this context, any style of writing is acceptable provided that it contributes to the attainment of established instructional objectives (Miller & Rose, 1975). This "primacy of instructional objectives" was a recurring theme throughout the readings, and is the single most important measure of the correctness (and the effectiveness) of written instructional materials.

Clearly, the subject of writing technical instructional materials cannot be completely addressed from a single viewpoint. Nor can it be effectively executed using only a single style or kind of writing.

With this preliminary information and some guidance from several local experts (see Chapter 3 of this paper), the thrust of the literature review was redirected toward identifying those factors important to the preparation of technical instructional materials.

Preliminary Considerations

The preliminary considerations are those which are usually concerned with the "pre-writing" process. These considerations can also become important during the early stages of writing.

The Importance of Writer Interest

The importance of writer interest in the development of instructional materials cannot be ignored. At the heart of the issue is learner motivation (Miller and Rose, 1975). An interested writer is an enthusiastic writer, and this enthusiasm is translated as a motivating force in the establishment of instructional set (Wilson, 1983).

The Primacy of Instructional Objectives

The hallmark of all instructional writing is its specific objective oriented nature. Instructional objectives enable the learner to measure achievement, and the teacher to gauge effectiveness (Miller & Rose, 1975).

Defining the Audience

Every writer must determine the audience for which he or she is writing. This is true without exception, and it is the most essential step in the writing process (Andrews, 1975; Israel & Wright, 1987; Miller & Rose, 1975; Freitag, 1982).

Assumption of Prerequisites

The writer must also make some assumptions regarding the students' level of preparation for the course. This is especially true for courses of study at the post-secondary level. The most obvious (and valid) assumption is that students registering for a course have met all published prerequisites (Wilson, 1983).

Subject Area Expertise

It can be presumed that the writer of technical instructional materials is also a subject matter expert. However, it has been found that in both instructional and technical writing, considerable expertise is developed as a direct result of the writing process (Blicq, 1986). Thus, expertise proceeds along a continuum of development involving both acquisition and refinement of knowledge.

Considerations in Writing

The points discussed below loom large during the actual writing process. However, it is important to remember that many of the factors apply throughout both the development and writing processes.

Currency of Content

Currency of subject area content was not found to be an essential consideration in all cases. The need for currency was found to be closely and directly related to the needs of the audience (Warren, 1985). Israel and Wright (1987) make a particular point of audience identification and targeting.

Relevancy of Content

This area is highly subjective, and in many cases, addressed in absolute terms. The most frequent and the most relevant criteria for judging relevancy was: if it is not relevant, does it need to be written? (Blicq, 1986).

Linearity of Treatment of Content

Some degree of linearity was found to be necessary in all three types of writing (Bly, 1982; Rathbone, 1985; Van Til, 1981). In general, linear organization of content is appropriate insofar as it promotes the attainment of instructional objectives (Miller & Rose, 1975). An equally important function of linearity is to assist the writer in developing a balanced and integrated presentation of the material (Andrews, 1975).

Organization of Content - Learning Unit Structure

There are many acceptable methods for organizing learning units. However, the particular organizational structure of the learning units is not as important as the consistent use of the same format for all learning units. The consistent use of a single pattern of learning unit organization contributes to the establishment of instructional set, and promotes learning efficiency (Miller & Rose, 1975; Wilson, 1983).

Writing for the Reader - Level and Style

Both the level at which the material is written, and the way that it is written were found to be important in maintaining student interest and motivation (Miller & Rose, 1975). The selection of an appropriate level and style of writing is an important part of audience definition (Andrews, 1975; Freitag, 1982).

Final Considerations

The following considerations are typically encountered in the final stages of writing and publishing the document. However, the writer is advised to apply them where applicable throughout the writing process.

Graphics and Illustrations

The purpose of all graphics and illustrations is the clarification and amplification of textual material, and the demonstration of relationships. More simply, they amplify the writer's ability to describe, and thus improve process of communication (Andrews, 1975).

Technical Terminology

The development and use of an appropriate technical vocabulary is one of the most important functions of technical instructional materials (Warren, 1985). Again, this is a reflection of the needs of the student.

References

It is important to maintain the "flow" of information in technical instructional materials. In many cases, the citation of references in the text often interrupts the flow of the material and impedes effective learning (Blicq, 1986).

Bibliography

Some writers recommended that a bibliography be placed at the end of each unit (Wilson, 1983). Others opted for a comprehensive bibliography at the end of the document (Andrews, 1975). In either case, it was found that the purpose of the bibliography is twofold. First, it serves to document the writing. Second, it provides the student with additional sources of subject and level specific information.

Editing

Editing is regarded as a tool which is applied throughout the writing process (Van Leunen, 1978). In the writing of instructional materials, appropriate editing serves to enhance instructional effectiveness and the attainment of instructional objectives (Wilson, 1983).

CHAPTER 3

RESEARCH METHODOLOGY

The original methodology for this project was to be a content analysis of the existing literature. However, preliminary readings found the available literature on the subject of writing technical instructional materials to be lacking. The literature review was redirected toward finding factors common to, and essential in the three types of writing which apply to developing technical instructional materials. These factors were then used as a basis for conducting personal interviews with local experts.

Research Design

The desired result of the research was an exposition of the principles and practices used to write technical instructional materials. Therefore, the descriptive research design was chosen.

This project was a one-shot focused exploration of the writing process as it is applied to the development of technical instructional materials. Research questions were answered using the archival method (Israel and Wright, 1987) of a library literature review, and the observational method (Israel & Wright, 1987) of personal interviews with subject matter experts.

The direction of the research was determined by informal methods (Israel & Wright, 1987) through interaction with industrial technology faculty, staff and graduate students. As the research proceeded, this interaction became essential in keeping the project on track.

An informal (Israel & Wright, 1987) preliminary literature review was used to assist in defining the scope of the investigation. The literature review served to isolate those factors most important to the process of writing instructional materials for technical students. In addition, informal conferences with university experts minimized false starts and unproductive readings.

Selection of Local Experts

The process of selecting local experts for interview was essentially subjective, and was based on the following criteria:

1. Applicability of expertise
2. Position within the University
3. Publication and/or authoring experience
4. Consulting experience
5. Willingness to participate in the study

The following individuals were identified and interviewed or consulted during the conduct of the research:

1. Dr. Jan C. Robbins, Head of the Department of English Language and Literature; experienced technical writer; industry consultant on technical writing

2. Dr. Ervin A. Dennis, Professor of Industrial Technology; author of technology related textbooks

3. Dr. Charles R. May, Head of the Department of Curriculum and Instruction; expert in the development of instructional materials

4. Dr. M. F. Fahmy, Associate Professor of Industrial Technology; materials scientist; engineer; well published in the materials science field; materials technology teaching expert

5. Dr. Bruce C. Rogers, Assistant Professor of Industrial Technology; advisor on related programs and technologies

Data Gathering Strategy

Two methods were used to gather data for the study. They were the archival review and the opinion strategies (Israel & Wright, 1987). Due to the time factor, the size of the sample for both the literature review and the personal interviews was small. However, they are adequate for the limited scope of this study.

The archival review focused on an examination of the literature to determine if the subject of writing technical instructional materials was discretely covered.

This was not the case (see Chapter 2). However, the review of the literature did yield a number of factors common to technical, instructional and expository writing.

A listing of these factors was compiled for use in interviewing local experts. In essence, these points were used as an "instrument" for the format and conduct of the personal interviews (E. A. Dennis, personal communication, July 1987).

Conducting the Interviews

To establish the appropriate set, each interview began with a brief introduction to the topic of the interview and the specific purpose of the research. Special care was taken to ensure that each interviewee understood the nature of the information being sought. The subject was then asked if he had any questions on topic, purpose or information desired.

Each of the factors on the "instrument" was then individually presented to the subject. First, the subject was asked his opinion as to the applicability of the point to the subject of writing technical instructional materials. Only three grades of response were permitted. These were:

1. The factor is essential
2. No opinion
3. The factor is unimportant

If one of these three responses was not obvious, the subject was asked to respond specifically in these terms. A ranking of the factors relative to each other was not made, since this was not the purpose of the study. Hence, the "instrument" was similar in effect to a three point Likert Scale (Dominowski, 1980)

The content of the responses was not constrained by the interviewer. However, if necessary, the subject was guided back to the thrust of the factor under discussion.

Once the discussion of all the factors was completed, a final specific question was posed. This was: "Can you think of any factors that should be added to those already discussed?" The purpose here was to obtain an expert subjective evaluation of the researcher's review and analysis of the findings in the literature. The interview was concluded by asking the subject for any general or specific comments, observations, criticisms or suggestions.

Recording Interview Data

Neither written nor electronic verbatim transcripts of the interviews were made. The subject's responses were recorded in paraphrased form for later analysis and integration. In all paraphrasing, careful attention was given to retaining the subject's original meaning.

If any subject had particularly strong opinions regarding any factor, they were recorded. Verbatim quotations were recorded if requested by the subject, or if the researcher believed that they would be particularly applicable in describing the findings.

Analysis

Archival and observational data was subjected to qualitative analysis using both abstract-sequential and random-abstraction techniques (Israel & Wright, 1987). The content of the interview with each expert was subjectively analyzed for its relevance to, and importance in, the process of developing technical instructional materials. In addition, a pattern of occurrence (Israel and Wright, 1987) was determined for each factor.

CHAPTER 4

RESULTS OF THE INTERVIEWS

This chapter is a summary of the findings derived from the personal interviews. The opinions of the experts on each point are discussed in the same order as they were extracted from the literature review.

The interviewees for this study were:

1. Dr. Jan C. Robbins, Head of the Department of English Language and Literature; experienced technical writer; industry consultant on technical writing

2. Dr. Ervin A. Dennis, Professor of Industrial Technology; author of technology related textbooks

3. Dr. Charles R. May, Head of the Department of Curriculum and Instruction; expert in the development of instructional materials

Preliminary Considerations

The preliminary considerations are those which are usually concerned with the "pre-writing" process. These considerations can also become important during the early stages of writing.

Importance of Writer Interest

All agreed that some degree of writer interest is essential if the writing process is to be successful. Dennis observed that the writer does not necessarily need to be interested in the subject of the writing. However, he felt that an interest in, and a liking for the writing process itself is necessary. He felt this to be particularly true for graduate students and graduate assistants who are frequently given writing assignments that are not within their area of interest.

From an instructional point of view, May said that writer interest is critical in the development of effective instructional materials. He further stated that most people are poor writers, so they do not undertake writing projects. This lends support to Dennis' opinion that an interest in and a liking for the writing process can contribute to becoming a successful writer.

Primacy of Educational Objectives

There was unanimous agreement among the experts that the accomplishment of educational objectives is of prime importance in writing technical instructional materials. May indicated that specific instructional objectives are built upon the more general educational philosophy of the instructor. That is, the general philosophy serves as a framework into which the more specific instructional objectives are fitted.

Dennis said that it is important to let the student know what objectives have been established. He noted that the chapters of most textbooks begin with a narrative statement or an enumeration of what the student is expected to learn in reading the chapter. Dennis stated that instructional objectives also keep the writer focused on the subject matter.

Robbins observed that "most readers do not know that they need to know". He said that an up-front statement of the learning objectives and their importance to the student both stimulate the student's interest and enhance learner motivation.

He described two approaches to stating objectives. The first emphasizes the positive aspect by stating what the knowledge will enable the student to do. He typified this approach with the phrase "If you learn this material, you will be able to ...". The second approach is more negative in that it emphasizes the catastrophes which may befall the student if the material is not learned. This was typified by the phrase "If you do not learn the material, the following (usually negative) will result".

Assumption of Prerequisites

The experts concurred in the opinion that it is essential that the writer make some assumptions regarding the level of preparation of the audience for whom the materials are being written. Specifically, all agreed that the writer must assume that the student can read and write at the college level, and has met all published course prerequisites or their equivalent prior to enrollment.

Dennis noted that there are also some widely held implicit assumptions in materials written for students at the university level. These assumptions are general in nature, and include such things as general mental ability and adequate speed of comprehension.

Defining the Audience

All agreed that it is of critical importance to define the audience for whom the materials are being written. Where possible, it is also desirable to know some of the more important characteristics of the group.

Robbins noted that audience definition may be as simple as knowing the members of a small society for whom a highly esoteric research paper is being written. Conversely, it may be as complex as the detailed target population description typically developed in the technical instructional setting. Robbins further observed that the writer should draw upon the collective background of the intended audience, and look for the "common denominators" in that group.

Subject Area Expertise

Dennis maintained that the writer need not be an expert in the subject matter. However, he noted that a broad knowledge of the subject area coupled with a willingness to learn and a liking for writing are essential.

Robbins said that it important for the writer to "know as much as the reader wants to know". He indicated that a general knowledge of the subject area and a knowledge of where problems or errors are likely to occur are also important.

May maintained that expertise in the subject matter is critical. He also indicated that, from the reader's point of view, the writer's expertise is assumed. That is, "if you are writing about it, you must know enough about it to meet the student's needs".

Considerations in Writing

The points discussed below loom large during the actual writing process. However, it is important to remember that many of the factors apply throughout both the development and writing processes.

Currency of Content

Dennis maintains that the writer must strike a balance between relevancy, currency, and content. He noted that "cutting edge" topics have a shortened publication life since technology is evolving so rapidly.

May and Robbins maintained that currency of content must be defined in terms of the needs of the audience. Robbins characterized this as "writing for the state-of-the-art, as the reader knows it" (emphasis his).

Relevancy of Content

Dennis termed this is a judgement call on the part of the writer. He advised that the writer measure the relevance of a particular topic by considering its usefulness to the reader. He noted here that the student assumes that what the writer is presenting is either necessary for further understanding, or will be useful in the student's professional life.

Robbins maintained that the needs of the reader decide the relevancy of a topic. He also said that many readers may not know that a particular topic is relevant to them, or why it is relevant. In these cases, he indicated that the writer must indicate the importance of the material to the reader.

May noted that relevance of any topic must primarily be judged on a single factor. That factor is the topic's contribution to established instructional objectives.

Linearity of Content

Robbins typified this as "giving the reader what he needs to know when he needs to know it". Robbins further qualified this by saying that the reader should be told up-front what the end result of the process will be. He also makes a distinction between the "logic of the information and the psychologic [sic] of the reader". That is, presenting the information to serve the learning needs of the reader is more important than adhering to the structure of the information.

Dennis maintains that it is important to progress from the more basic to the more complex ideas of a particular topic. He felt that the student is better prepared psychologically if a topic is introduced by a brief review of "the basics".

May emphasized that students learn by "apperception". That is, the acquisition of new knowledge is based upon previous learning. He felt that a brief review of previously learned material serves as a foundation for the new learning that is to come.

Organization of Content - Unit Structure

May emphatically stated that learning units are not simply a series of lessons. He said that this is an error on the part of many writers of instructional materials. He defines learning units as complete stand-alone instructional units which contain all necessary supporting material from related subject areas. He maintains that students must have the "big picture", that is they must see how the current material fits into the subject as a whole. He advocates the presentation of the "big ideas" followed by the "small ideas", with the latter supporting and supplementing the former.

Dennis maintains that it is part of the writer's responsibility to organize the material into small increments which the student can easily grasp. He noted that this enhances learning and gives the student a psychological edge by building confidence.

Robbins said that the reader can better understand the material if the structure of the learning units is incremental. Here, he reiterated his advice that the writer present what the reader needs to know, when he needs to know it. He called this format "user driven".

Level and Style of Writing

Robbins advocates writing to the "LCD of the class". That is, the writer should use a level and style of writing that is appropriate to the least qualified reader. He advocated writing characterized by the "3 C's", or "clear, concise, and complete". He stated that simple and direct writing is more effective, and called this the "KISS philosophy", or "Keep It Simple, Stupid!". He recommended writing in the present tense, in the active voice, and the use of short sentences and paragraphs. Robbins maintained that appropriate level and style of writing will prevent the situation in which "the reader understands everything that you write, but doesen't know what you are talking about" from arising.

May indicated that the style of writing should be modeled after the accepted style of writers on "the cutting edge" in the field. He said that the level of the writing should be close to the reading and knowledge levels of the intended audience. He suggests that writing above this level leaves a gap between what the student knows and what is being presented. Writing below this level leads to reader boredom and sub-optimization of learning objectives.

Dennis believes that the level of writing should be kept as an overriding guideline for the writer. He agreed with Robbins with regard to style of writing, indicating that it should be straightforward, direct and factual. He agreed that Robbins' "3 C's" are appropriate in technical instructional materials. He advocated very little tangent in, and only limited repeating of the material.

Final Considerations

The following considerations are typically encountered in the final stages of writing and publishing the document. However, the writer is advised to apply them where applicable throughout the writing process.

Graphics and Illustrations

Dennis said that it is very important to use high quality graphics. He emphasized that graphics should not overpower the reader, nor should they detract from the textual presentation of the material. He also maintained that graphics can contribute to effective organization of the text material.

May stated that graphics serve to enhance learning through facilitating the sharing of ideas. He advocates the use of graphics in instructional materials to help the reader visualize concepts, to clarify explanations and to illustrate relationships.

Robbins maintains that graphics are used to do what the text of the material cannot do clearly. Hence, graphics always support textual material.

All agreed that graphics are never used on a stand alone basis, rather they support, supplement or enhance textual material. They further agreed that graphics should not be used to do that which can be done with text alone. A final point of agreement was that every graphic must be accompanied by a textual explanation.

Technical Terminology

Robbins maintained that correct and appropriate technical terminology should be used in all cases. He recommended that the term be defined at its first use in the text of the material. He also advocated the use of a carefully constructed glossary for both reference and review.

Dennis agreed that the appropriate terminology should always be used. He said that this assists the student in the acquisition of a technical vocabulary. He also advocated providing the reader with a brief definition of the term the first time it is used. Dennis recommended that technical terminology be used where essential, but only where essential. He said that this would prevent overpowering the reader with too many new terms.

May noted that the use of jargon is common in all technical writing. He stated that this was a consequence of the increasingly narrow focus of the technologies. He indicated that it is proper to use as much technical language as is necessary to adequately describe the subject. May made the point that technical terminology enables the writer to accurately and succinctly describe technical details using the least possible number of words. However, he stated that "readers demand meaning from technical communication, and the use of technical language should contribute to that meaning". May also agreed that once a new term has been defined, it is proper to use it from that point on. May recommended that the writer not allow the definition of terms to interfere with the flow of instruction. He also advocated using the "five percent frustration rule". This rule states that in any 100 word passage, the reader should find no more than five new or difficult words. Finally, May agreed that the writer should provide the reader with a complete glossary.

References

The experts agreed that the flow of the text of instructional materials should not be interrupted by the citing of references. Robbins advocated using the simplest possible method of documentation. He stated that the writer needs to "get the research out of the text of the instructional material and place it in an appendix".

May also advocated using few cites in text. He maintained that the writer should use references in text only "to write and to teach professionally". However, he did state that it is the writer's responsibility to "document all vital statements".

Dennis maintained that all documentation should appear at the end of each section of the instructional material. He said that no reference citations should occur in the text of the material.

Bibliography

Robbins stated that a complete bibliography must appear at the end of the document. He maintained that the bibliography should contain recommended references as well as consulted references.

May noted that a reference list should contain only those works which were actually cited in the text of the material. He contrasted this with a bibliography which contains supporting and unused references, as well as recommendations for further reading. He recommended that the bibliography contain several levels of expertise, for example, introductory, intermediate and advanced.

Dennis agreed that a complete bibliography should appear at the end of the document. He also felt that the bibliography should contain additional recommended readings at several different levels of student competence in the subject area.

Editing

May stated that the writer must accept the the fact that the first draft will seldom remain unchanged. He expressed the view that writers need to accept editing and rewriting as as a continuing process. He characterized this by quoting Zinsser's saying that "writing is rewriting".

Both Dennis and Robbins advocated the use of several levels of editing. They said that it is the writer's responsibility to edit the first draft as completely and as accurately as possible. After the first rewrite, they recommended that the material then be edited by an expert in the technical subject matter. They recommended further editing by another writer (Dennis) or a style editor (Robbins). Robbins suggested that a final editing by a reader inexperienced in the subject area is also valuable.

All three experts concurred in the opinion that any editing tool is appropriate for the writer if it assists him or her in meeting the needs of the reader. The experts also agreed that "tool" can include computer-based style and mechanics editing packages.

CHAPTER 5

ANALYSIS OF THE FINDINGS

Both the review of the literature and the interviews with university experts were subjected to qualitative analysis using abstract-sequential and random-abstraction methods. The desired result of the analysis was the determination and integration of existing information, and an accompanying synthesis of new information regarding the process of writing technical instructional materials.

Analysis of the Literature

An initial search of the available literature for references specifically addressing the subject of writing technical instructional materials produced only one usable reference. However, many references addressing other types of writing, such as technical writing, expository writing, and research writing were consulted. Textbooks, reference books and other teaching materials were evaluated for any "common denominator" techniques which were applicable to technical instructional materials.

Although there is a definite body of knowledge on the subject of writing technical instructional materials, that knowledge is not discrete. Moreover, it appears that the knowledge is eclectic in nature and is drawn from the principles and techniques of several types of writing. A second, more detailed, analysis of the appropriate literature revealed that the most important of these principles and techniques are:

1. Writer interest
2. The primacy of instructional objectives
3. Audience definition
4. Assumption of prerequisites
5. Subject area expertise
6. Currency of content
7. Relevancy of content
8. Linearity of treatment of content
9. Organization of content
10. Level and style of writing
11. Graphics and illustrations
12. Technical terminology
13. References
14. Bibliography
15. Editing

These factors were most often noted in technical writing, expository writing, and research writing. They were used as the framework (or "instrument") for the interviews with local experts.

Analysis of the Interviews

Analysis and integration of the literature provided the general principles and techniques of the three kinds of writing (technical, expository, and research) that were most often seen in textbooks, reference works, and other instructional materials. However, it was the interviews with local experts which focused those principles and techniques upon the specific process of writing technical instructional materials. As a result, it was possible to identify and elaborate upon 15 factors or components important in the development of technical instructional materials.

The interviews also proved the previous selection of the 15 important writing factors to be valid. In the conduct of the interviews, a 100 percent positive pattern of occurrence for each factor was noted. That is, all the experts agreed that every factor which was isolated in the literature review was important to the process of writing technical instructional materials. Moreover, none of the experts interviewed could suggest any additional factors. This implies that the 15 factors listed above constitute a complete enumeration of all the major considerations involved in writing technical instructional materials.

The analysis of the findings permits several statements to be made in response to the research questions: These are:

1. There is a body of knowledge which is specifically related to the development of technical instructional materials. However, the knowledge is not discrete, rather it contains components drawn from many related sources and subjects. Typically, the knowledge is

acquired by a process of trial and error writing, by the emulation of other successful writers, or by the simple process of accretion.

2. There is an overall process used to develop and write technical instructional materials. Like the body of knowledge, the steps in the process are usually learned by emulation or trial and error.

3. It is not possible to express the overall process of developing technical instructional materials as a simplified procedure or protocol. However, this research has identified and isolated 15 components which are critical to the process. These components can be used as guidelines for writing effective technical instructional materials in many areas.

4. The most important components in the process of developing technical instructional materials are those 15 which were previously listed.

5. In terms of the development and writing of technical instructional materials, the analysis of the findings indicates that there are no other significant factors to be considered.

CHAPTER 6

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

This chapter summarizes and integrates the findings of the study. It also provides answers to the research questions, and recommendations for further application of the results. Appendix A is a summary of the findings of the study in a form suitable for use by writers of technical instructional materials.

Summary

This research project is the result of an expressed need within the Department of Industrial Technology at the University of Northern Iowa (M. F. Fahmy, personal communication, January 1987). The specific need was to prepare introductory level teaching and laboratory materials for a course in industrial plastics technology.

The purpose of the research was to develop a simplified but complete reference document for writers of technical instructional materials within the Department of Industrial Technology. The specific problem to be solved by the research was to determine how technical instructional materials should be developed and written. The research questions were answered by analysis of archival and opinion data.

Once the process and procedures contributing to the development of technical instructional materials were determined, they were to be applied to the development of a stand-alone teaching aid and reference manual on industrial plastics. The document would have immediate utility since it was specifically written for industrial technology students at the University of Northern Iowa.

The research was exploratory and descriptive in nature, and facilitated innovation and development through content analysis (Israel & Wright, 1987). It was a one-shot focused exploration of the writing process as it applies to technical instructional materials.

The intent of the original research was to quantify and describe the writing process through a review and analysis of the literature. However, a preliminary search revealed a large gap in the available literature regarding the writing of technical instructional materials.

Several university experts were consulted for further guidance. The experts were not surprised at the paucity of information relating to the writing of technical instructional materials. Their advice was to conduct a review of textbooks, reference books, and other similar instructional materials with a view toward determining any factors common to all. In addition, Robbins (personal communication, July 1987) recommended that references on technical, expository and research writing also be reviewed for the purpose of isolating and identifying any commonalities shared by all three types of writing.

The first search of the literature was a review of several representative technical textbooks and reference books. This search produced 15 factors or components which were believed to be important in the process of developing technical instructional materials. A second search of the literature on technical, expository and research writing techniques found that all 15 components are present, in one form or another, in all three types of writing. These data were then used as a format for conducting interviews with university experts. The 15 components derived from the literature were:

1. Writer interest
2. The primacy of instructional objectives
3. Audience definition
4. Assumption of prerequisites
5. Subject area expertise
6. Currency of content
7. Relevancy of content
8. Linearity of treatment of content
9. Organization of content
10. Level and style of writing
11. Graphics and illustrations
12. Technical terminology
13. References
14. Bibliography
15. Editing

The intent of the interviews with university experts was to produce a consensus regarding the utility of each of the components isolated in the literature search. In addition, each expert was asked to provide specific recommendations concerning the application of each factor to the process of writing technical instructional materials.

The findings in the literature and the interviews were subjected to qualitative analysis using random-abstraction and random-sequential methods. The intent of the analysis was to integrate existing information, and to synthesize new information regarding the procedure for the development of technical instructional materials.

The interviews with the experts produced a 100 percent positive pattern of occurrence for the 15 factors. That is, all the experts agreed that all 15 factors are important in the development of technical instructional materials. In addition, none of the experts could suggest any other factors. This indicates that the literature search and evaluation was adequate in both scope and depth.

Conclusions

Based on the findings of the research, five conclusions were drawn. These were:

1. A body of knowledge specifically applicable to the development of technical instructional materials exists.

2. The knowledge is not discrete, but is drawn from many sources. Typically the knowledge is acquired through trial and error, by emulation of successful writers, or by accretion.

3. It is not possible to express the overall process of writing technical instructional materials as a simplified series of steps, or a procedure.

4. Fifteen critical factors were identified and elaborated upon through interviews with local experts. These factors can be used as guidelines for writers of technical instructional materials.

5. The 15 factors already identified constitute a complete enumeration of the components most important to the process of writing technical instructional materials.

Recommendations

It would appear that the information resulting from this study represents a valid generic approach to the writing of technical instructional materials. However, writers of these materials are reminded that they work within the milieu of an institution, and (often) under the direction of a particular professor. Therefore, it is *always* appropriate to incorporate institutional and individual preferences in the developmental and writing processes.

This research was specifically conducted to facilitate the development of a teaching document for use in industrial plastics technology. It is recommended that this proceed without delay. In addition, the planning for the second part of the document, a laboratory syllabus, should also be undertaken immediately. It is further recommended that the results of this research be made available to graduate students who may be required to write technical instructional materials.

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APPENDIX A

APPENDIX A

RECOMMENDATIONS FOR WRITERS

As educators, one of our primary functions is to communicate usable knowledge to students. One of the most important and prevalent ways of doing this is through the medium of writing. Because writing is a tool which we will use throughout our careers, learning to do it well is an investment in ourselves as well as an obligation to our students.

The pertinent information derived from this study is synthesized point by point in the pages which follow. For convenience in writing, the material is divided into three broad categories; preliminary considerations, considerations in writing, and final considerations. However, it is well to remember that the process of writing proceeds along a continuum. You will find that the steps of the process are not discrete, rather they merge into each other, and ultimately lead to a coherent whole. Therefore, do not take this summary as the *sine qua non* for writing instructional materials, but as a place to start. The rest is up to you.

Preliminary Considerations

These items are typically concerned with the preliminary or "pre-writing" processes such as planning, outlining, defining the audience, and the like. They may be important during the early writing stages as well.

Importance of Writer Interest

You need to have some degree of interest in the subject about which you are writing. Most important, however, you need an interest in, and a liking for the writing process itself. When you are thinking about writing, keep Epictetus' advice in mind: "If you want to succeed at writing: write." (Staff, 1987). Your own interest in the subject contributes to the development of student interest, and is a significant factor in establishing instructional set.

Primacy of Instructional Objectives

All writing has a purpose; to inform, to entertain, to teach, to describe, and so on. Your reason for writing is to teach the student. What you want the student to learn defines the instructional objectives. Keep in mind that the student probably has no idea what he or she needs to know about the subject. Students rely upon you to know this and to meet their needs. Hence, _you_ must know what you want to teach before you can write.

Instructional objectives allow the student to measure achievement, and the writer to measure effectiveness. Your objectives must be expressed as specific measurable goals which the student can work toward, and against which you can evaluate student performance. Well defined objectives will also help you to keep your writing focused on the subject matter.

Let the reader know what he or she is expected to learn from reading your material, and why it is important to learn it. This is best accomplished by providing a brief introductory statement indicating what the learning unit will cover, and its importance to the student. A long listing of the objectives can seem formidable to the reader. It is better to use the narrative form to provide a brief overview which arouses curiosity and heightens interest.

Assumption of Prerequisites

As a writer of instructional materials, you need to make some assumptions about your audience before beginning to write. Since you are writing for students at the college level, you can assume the following:

1. The student can read college level writing.
2. The student can produce college level writing.
3. The student has adequate general mental ability.
4. The student has learned to overcome or compensate for any disadvantages, disabilities, or handicaps.
5. The student has an adequate speed of comprehension of the material to be presented.

6. The student has met all published prerequisites for the course.

Defining the Audience

This is the most essential step in the writing process because it enables you to target a defined group of readers for your writing. While assuming prerequisites deals with general assumptions about the readers, audience definition enables you to determine some of the more specific and important characteristics of the group. Try to draw upon the collective background of the audience, and find the "common denominators" in the group. You can then use these "common denominators" as shared points of reference for presenting the instructional material.

Subject Area Expertise

Students expect the writer to know as much as they want or need to know about the subject. From the reader's point of view, you are already an expert in the subject matter. Otherwise, why would you be writing about it? However, remember that expertise proceeds along a continuum of development involving both acquisition and refinement of knowledge. You may not be "the expert" now, but when your writing is completed you will be. Thus, expertise develops as a direct result of the writing process. This is why a broad knowledge of the subject area, a willingness to learn, and a liking for writing, are more important than narrowly developed technical knowledge.

Considerations in Writing

The points mentioned below are usually confined to the writing phase of the project. However, one or more of them may be useful throughout the process of development and writing.

Currency of Content

The need for currency in subject matter is determined by the needs of the audience. There is a simple reader oriented rule which can be used here: write for the state-of-the-art, as the reader needs to know it. Note that "cutting edge" information typically has a very short publication life, since technology is evolving so rapidly.

Relevancy of Content

You must judge the relevance of content against two criteria. These are the contribution made to established instructional objectives and usefulness to the reader.

The reader is working under the assumption that what you are presenting is either necessary for further understanding, or is essential in professional life. Many of your readers will not know what is, or what is not, relevant to the subject matter. In these cases, it is up to you to indicate the importance of the material to the reader. A useful form of "Occam's razor" for relevance is: if it is not relevant to the subject, does it need to be written?

Linearity of Content

Generally, a linear progression of the material from the basics to the more advanced topics is desirable. However, any form of organization of the material must promote the attainment of instructional objectives.

Students learn by "apperception". That is, the acquisition of new knowledge is based upon previously learned material. Thus, you need to make a distinction between organization which is information oriented, and organization which is learning oriented. You should present the material to serve the learning needs of the student whenever possible. In short, give your readers what they need to know, when they need to know it.

Organization of Content - Learning Unit Structure

Many writers make the mistake of regarding learning units as a series of lessons, much like the chapters in a book. This is information centered organization, and does not account for the needs of the learner.

Learning units are complete stand-alone instructional units which contain both the primary learning material, and all necessary supporting material from related areas as well. Such instructional units give the student the "big picture" by relating the present material to that already learned, and to that which is to come. In this type of organization, larger concepts are presented first, followed by the smaller supporting and enhancing ideas.

Whatever form of organization you decide to use, be consistent. Use the same format for all learning units. This assists the reader in assuming instructional set, and promotes efficient learning.

Level and Style of Writing

Your audience will determine both the level of writing and the style of writing which you use. You must use a level and style of writing that is appropriate to the least qualified member of the class. Writing above this level leaves a gap between what the reader knows and what is being presented. Writing below this level leads to reader boredom.

Your writing should be guided by the three "C's", that is, clear, concise and complete. Make heavy use of the "KISS" philosophy; "Keep It Simple, Stupid!". Write in the present tense, use the active voice, and use short sentences and paragraphs. Use the same level and style of writing throughout the material so that the reader always knows what to expect. It is appropriate to model your writing after a style which is accepted in the field in which you are writing. However, remember that the style which you use must assist the learner in attaining the instructional objectives.

Final Considerations

The points discussed below are generally found in the final stages of writing. However, they can be applied at any appropriate point in the writing process.

Graphics and Illustrations

Graphics serve to enhance learning by facilitating the sharing of ideas. Mink (1987) reminds us that graphics enable us to "speak without words." They amplify our ability to describe, and thus improve the process of communication.

Graphics are used in instructional materials to clarify explanations, to help the reader visualize concepts, and to illustrate or demonstrate relationships.

Graphics are used to do what text alone cannot do clearly. Thus, graphics are never used on a stand-alone basis, rather they always supplement, support, or enhance written material. Do not use graphics to do what can be done by text alone. When you do use a graphic, make sure that it is accompanied by an adequate textual explanation.

Technical Terminology

The development of an appropriate technical vocabulary is one of the most important functions of technical instructional materials. Technical terminology enables you to accurately and succinctly describe technical details using the least possible number of words. However, remember that your readers must be able to derive meaning from your communication. For communication to be effective, technical terminology must contribute to or enhance that meaning.

It is appropriate to use the correct technical terminology in all cases. Define the term the first time it is used, and use it freely thereafter. Also provide the reader with a carefully constructed glossary for reference and review. Do not allow the use of technical terms to interfere with the flow of learning. As a rule, the student should not encounter more than five new or difficult words for every 100 words of text.

References

The primary purpose of instructional materials is to teach. The rigorous documentation necessary in research writing is inappropriate in instructional materials. However, as the writer, it is your responsibility to author professionally, and to document all vital references according to accepted standards.

Try to keep citations in the text to a minimum, since these tend to distract the student's attention and interrupt the flow of instruction. Footnoting is not recommended. All your documentation should appear in a "References" section at the end of the learning unit.

Bibliography

A bibliography serves to document your writing as well as provide the student with additional sources of relevant information. Your bibliography should contain both consulted references and recommended references.

Make sure that the bibliography conforms to the same order as the learning units. This makes it easy for the student to find relevant information. In addition, include several levels of expertise in every section of the bibliography. This will ensure that students at every level of achievement have access to appropriate information.

Editing

You need to accept the fact that the first draft will seldom remain unchanged. Your material should be edited constantly, both while you write, and when writing is completed. As Zinsser says, "Writing is rewriting."

Once your writing is complete, it should be subjected to several levels of editing. As the author, it is your job to completely and accurately edit the first draft. After the first rewrite, have the material edited by a subject matter expert. This should be followed with a review of the manuscript by a another experienced writer, or a style editor if available. It is also useful to have the material reviewed by a person who is inexperienced in the subject matter.

APPENDIX B

INDUSTRIAL PLASTICS

A Guide for the Student TECHNOLOGIST

D. D. Bradney

May 11, 1987

TABLE OF CONTENTS

INDUSTRIAL PLASTICS

Section A

Introduction

The student technologist is becoming foremost a **materials user**. Users of materials require a basic knowledge of the commonly used material systems, i.e., metals, plastics, ceramics, glasses and composites.

Moreover, they must be able to describe and compare the properties, applications and limitations of representative members of each system. In short, they must develop a "working repertoire" of materials from which intelligent selections can be made. My research for this guide was directed by these needs.

This guide is more qualitative rather than analytical or quantitative. This is a reflection of the needs of the technical student. My approach was to research the available data, extract the information most useful to the student technologist and synthesize the material into a useful whole.

In writing this guide, my goal was to produce a **useful** teaching document on the basics of plastics. It is aimed at students in two or four year technical programs who require a general working knowledge of plastics and their general industrial applications. It is suitable for use in a materials science survey course, or in a first course in plastics.

I have assumed that the student has completed at least a survey course in materials science, and is familiar with the basic ideas and language of chemistry.

For simplicity of presentation, references are not cited in the text of the guide. Rather, they are listed in the final section of the document. In some sections, I have cited extensively from a single source. In these cases, the reference is acknowledged where it is used.

To provide instructional flexibility, the contents of this guide are arranged in sections, each of which addresses a particular topic. Each section can be used to supplement regular course materials, or the entire document can be used as a stand-alone teaching aid. For these reasons, each section is independently paginated.

For continuity of presentation and clarity in reading, new terms have been placed in boldface type, and are explained or defined as they are introduced. To assist the student in developing and using a plastics vocabulary, a brief glossary of the terms used herein is provided.

I am indebted to my friends and fellow graduate students Mike Courbat, Tony Favre, John Shultz, and Don Cassel for their advice, support and encouragement.

Many thanks are due Drs. E. A. Dennis, Jan Robbins, Charlie May, and Bruce Rogers for willingly (and patiently!) sharing their considerable expertise.

Most of all, I am grateful to Dr. M. F. Fahmy, advisor and mentor, for always having a minute.

INDUSTRIAL PLASTICS

Section 8

Industrial Material Selection Process

INTRODUCTION

The selection of a given material for a specific application can range from being a "piece of cake" (the ideal compromise material is already in use) to an outright nightmare (no material can fulfill design conditions at competitive cost).

However, most design application problems fall somewhere between these two extremes. We will see that the choice of a material is ALWAYS a compromise between three primary categories of selection criteria. These are material availability, material properties and economic constraints.

GENERAL SELECTION CRITERIA

Material availability addresses such questions as: Is the material on hand in our own facilities? Will we need to order the material from a supplier? Are there minimum order requirements? What is the lead time? Is the selected material proprietary (limited suppliers)? Is special processing required before we can use it (value added)? What is the storage life? Are there special storage requirements? The design team must establish the time constraints for the procurement of materials.

Material properties are all the distinguishing characteristics of the material, including mechanical properties, physical properties, processing characteristics, chemical properties, thermal properties, electrical characteristics, radiation resistance and dimensional stability. In material selection, the goal of the design team is to provide a product having all ESSENTIAL properties and as few of the undesirable properties as possible.

Economic constraints are always the prime selection factors given a choice of materials which will perform the desired function. Here must be considered a plethora of details, e.g., what is the demand for the material? Is current production meeting demand? What is the political situation in the source nation? What is the price history of the commodity? What is the cost per unit volume of the material? How fabricable is the material, i.e. what will it cost to make and join the components of the finished product? How much value added markup will the product sustain and still be marketable? How much inspection and quality control is necessary to ensure acceptable quality? What is the likely service life of the product in the intended service environment? These questions and others like them must be asked, and answered at every step in the design and production process.

The design team is expected to produce a product which will maximize profitability as well as meet or exceed solid engineering standards. Material evaluation and selection is an integral part of the design and development process. It is appropriate to examine the role of material selection within this context.

DESIGN PROCESS

Most design is accomplished by a team composed of engineers and/or designers from relevant disciplines, manufacturing and production specialists, materials specialists, and quality assurance technologists. It is important to realize that the process is a GROUP effort.

The first phase in the design process is the expression of need for a new product or redesign of a product currently in service. This need can come from many sources, e.g. customer complaints, the competition, internal reviews and evaluation, failure data and the like.

Once the need is expressed the members of the team begin a "thinking" process (both individual and collective). This brings together the collective experience and expertise of the team. During this stage reading, research, modeling, consultation, rough sketches and calculation are the primary activities. In this stage, a rough list of possible materials is developed. The desired result of these activities is a DESIGN CONCEPT.

From the design concept comes sketches and further calculation. Actuation and drive mechanisms are envisioned. Some preliminary material evaluation takes place on a broad scale. The exterior appearance of the product may be envisioned and drawn. A full scale mock-up may be made and the customer's approval sought. The number of possible candidate materials is narrowed. The end result here is a DESIGN WHICH PERFORMS ALL REQUIRED FUNCTIONS.

The next stage is the development of assembly drawings, both orthographic and pictorial. Stress analysis, motion analysis, vibration analysis, lubrication requirements, failure modes, material compatibility, operating environment and the effect of component failure are all considered. Materials are considered against GO or NO-GO criteria. The result should be a WORKABLE, PRODUCIBLE AND COST EFFECTIVE DESIGN.

Now operational conditions for each part must be determined. Included here are speeds, acceleration, stress, tolerances and fits, service environment, production costs, life-cycle costs, maintenance factors, hardness, surface treatments, wear limits and rates, and safety. The goal of this phase is to ESTABLISH ALL THE OPERATIONAL REQUIREMENTS FOR EACH COMPONENT IN THE DEVICE.

When the requirements for each part are known, the detailing phase can begin. Working from the assembly drawings, designers make detailed working drawings for every component of the device. Such drawings show shape, size, tolerance, allowances, fit, material, machining, finishing, surface treatment, and necessary heat or chemical treatment. The material selection process moves from GO NO-GO criteria to comparative evaluation and selection. The result is a COMPLETE SET OF DRAWINGS FROM WHICH THE PRODUCT CAN BE PRODUCED.

Once detailing is completed, either a prototype is completed or a limited production run is made. Sufficient units are required to permit complete evaluation of the product in the intended service environment. Debugging, the elimination of problems in the construction or operation of the product, begins in this phase and continues throughout the evaluation of the product. The goal of this phase is a product that is MARKET READY.

MATERIAL SELECTION

Material requirements and selection factors are crucial elements of the design process. Although it might seem that material selection is confined to the assembly and detail drawing portions of the process, this is not the case. Even in the earliest stages of design some consideration is given to candidate materials on a broad and generalized basis. As the development of the design proceeds, material considerations become progressively narrower.

Material selection begins with a thorough analysis of the function the part is to perform, and the environment in which it is to function. Using these criteria, a list of essential properties and characteristics for the part is developed. These become the GO NO-GO material selection factors. In a sense, these are screening items which narrow the field of possible candidate materials. For further consideration, any material MUST meet or exceed ALL these requirements, otherwise it is rejected. It is worth noting that any excess of some property beyond the established minimum level is of no value, and indeed, may be detrimental in terms of cost.

At this stage, any material is a candidate if it can meet the GO NO-GO criteria. The GO NO-GO criteria are derived from a few primary areas. These are material availability, processing facilities, material cost, processing costs, marketability, the material properties themselves, and disposability or recyclability of the product. Of all these, COST is most often the deciding factor in selecting a given material. The reality of competitive manufacturing is highest quality at lowest cost and minimum value added.

Once the GO NO-GO factors have been established, the design team then proceeds to develop the DIFFERENTIATING factors, or those attributes which permit relative choices to be made among the candidate materials. Here, tradeoffs can be made in terms of the RELATIVE importance of each factor to the overall performance of the design in the intended service environment. The application of differentiating factors to those materials which have met the GO NO-GO screening criteria results in either a single best candidate material or a list of several candidate materials that meet all criteria.

Increasingly, SYSTEMATIC methods of material selection are being used. An example of such a method is WEIGHTED PROPERTY INDICES. The development of selection factors and the application of GO NO-GO criteria is as previously described. The application of differentiating criteria is accomplished by assigning each selection criterion a degree of importance (WEIGHT FACTOR) relative to the other criteria. Each property is then rated on some arbitrary numerical scale (e.g., 1 for poorest to 5 for best). This rating is then multiplied by the appropriate weight factor to arrive at a rating number for the particular criterion. The sum of the rating numbers is then divided by the sum of weight factors used. The optimum material is the one with the highest numerical score.

INDUSTRIAL PLASTICS

Section C

Nature & Structure of Plastics

INTRODUCTION

Materials differ from each other not only because of their composition, but because of the organization of their constituent units as well. More importantly, it is this structure which determines the properties of the material.

This section will briefly review the general structure and nature of plastics with a view toward explaining their unique properties.

DEFINITION OF PLASTIC

We may state a descriptive definition of plastic as follows: A polymeric material which is composed of simpler molecular units, either organic or inorganic, covalently bonded together. Every plastic contains carbon, oxygen, and hydrogen atoms as part of the molecular units (i.e., they are "hydrocarbons"). All plastics are liquid at some stage in their manufacture, and can be formed into complex shapes which are retained in the finished form. Forming of a plastic material always involves the application of heat, pressure or both.

MAJOR CHARACTERISTICS

All plastics share some common properties which are typical of the group. Plastics are essentially non-crystalline, although they can exhibit some long range order. They are nonconductors of electricity, generally resistant to chemical and environmental attack, are low in heat conductance, have low softening temperatures, are easily formed into complex shapes and exhibit **viscoelastic behavior.** This is continued deformation over time after removal of an applied load.

NATURE AND STRUCTURE

Materials such as plastics are called **molecular** because their basic structural units are molecules called **mers**, monomer molecules, or more simply **monomers**.

Every monomer consists of a number of individual atoms that are strongly bonded together, usually **covalently**. In most plastics, the constituent monomer molecules are always **hydrocarbon** based. That is, they are composed of hydrogen atoms bonded to carbon atoms. A notable exception is the silicones, which are composed of oxygen atoms bonded to silicon atoms.

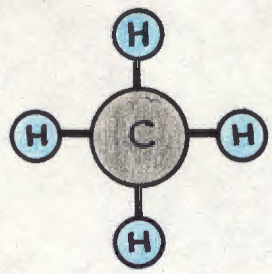

Fig. 1. Hydrocarbon Monomer

A **polymer** is an agglomeration of monomers covalently bonded together to form a long-chain molecule. In general, when we speak of a "polymer" we mean long chains of monomers covalently bonded together, end-to-end.

Polymers can have two geometric forms. **Linear polymers** are composed of many monomers covalently bonded together "end-to-end" to form long chain-like structures. **Branched polymers** have numerous side chains of various lengths attached to the main linear polymer.

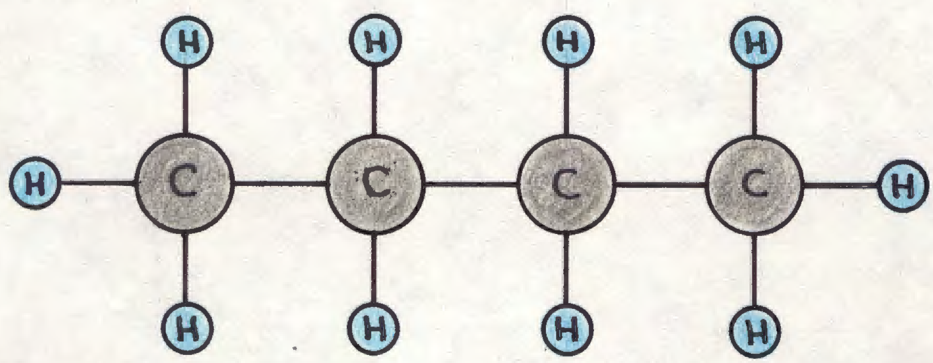

Fig. 2. Linear Polymer Chain

The side chains of branched polymers may be attached to the main polymer in several different ways. If the side chains are randomly attached, the polymer is **atactic**; if the side chains are coplanar AND branch out on only one side of the main chain, the polymer is termed **isotactic**; if the side chains are coplanar AND alternate from one side to the other, the polymer is called **syndiotactic**.

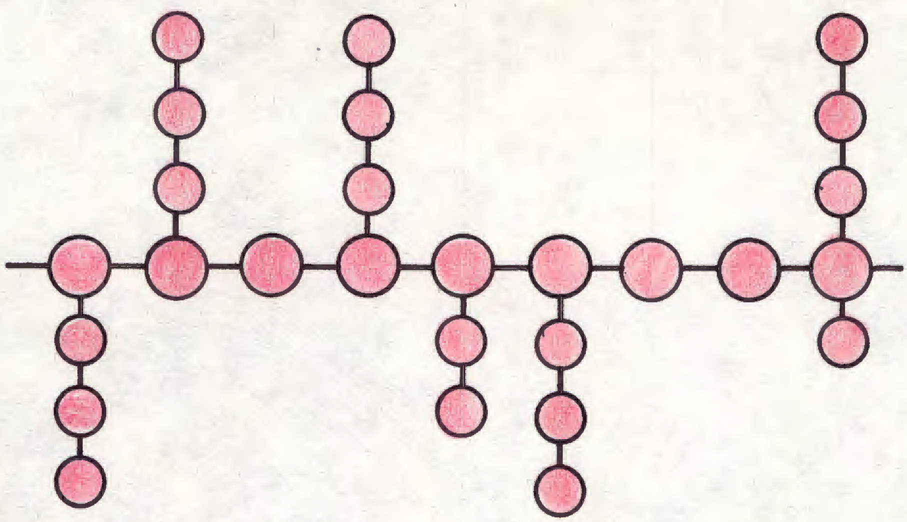

Fig. 3. Atactic Branched Polymer

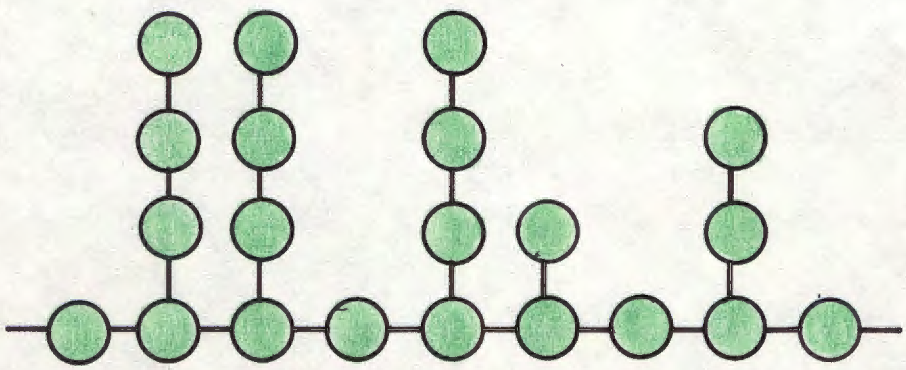

Fig. 4. Isotactic Branched Polymer

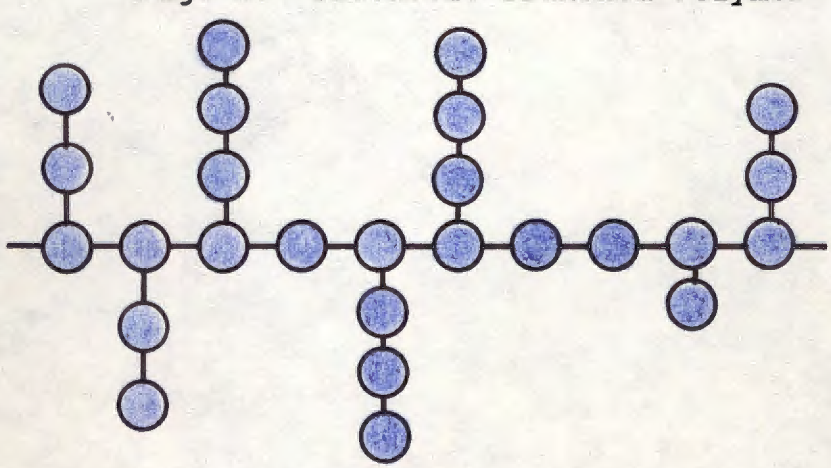

Fig. 5. Syndiotactic Branched Polymer

The process of joining monomers together to form polymers is **polymerization**. This is a chemical reaction brought about by **catalysis** with appropriate chemicals, the application of heat and pressure or both.

The two primary polymerization reactions are **addition** and **condensation**. In **addition polymerization**, the monomer, usually in solution, is subjected to catalysis or heat and pressure. The polymer thus formed has the same repeating unit as the starting monomer.

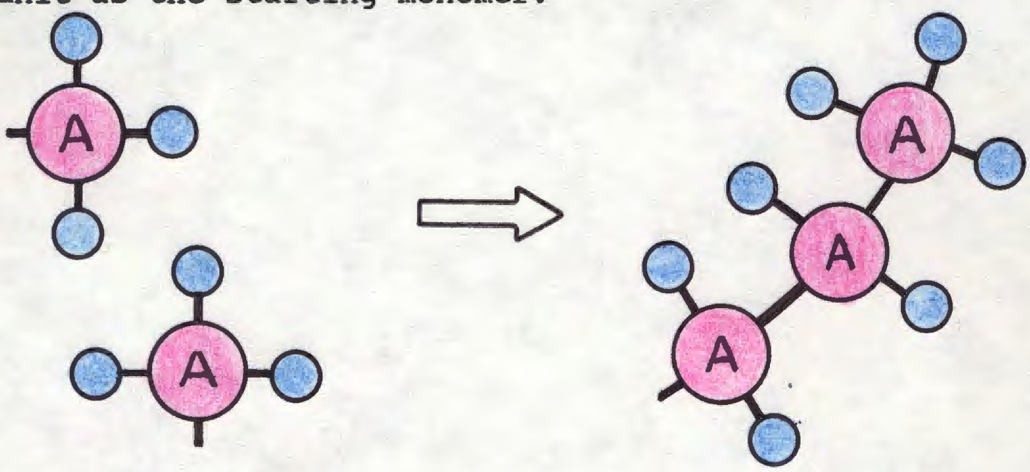

Fig. 6. Addition Polymerization

In **condensation polymerization**, the repeating molecule in the polymer chain is different than the starting monomers. The reaction is termed condensation because water is a by-product of the polymerization.

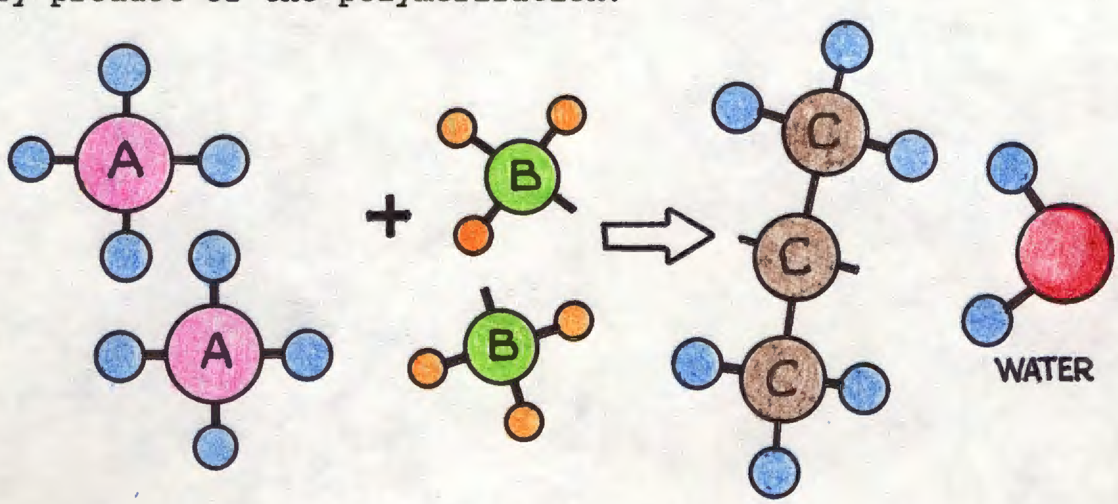

Fig. 7. Condensation Polymerization

A **homopolymer** is a polymer consisting entirely of the same kind of monomer structural units. A **copolymer** is formed from two different types of monomers. **Terpolymers** are made up of three or more kinds of monomers. The term **resin** refers in general to the basic chemical polymer compounds.

Plastic polymers demonstrate some special characteristics as a result of molecular organization and interactions within molecular structure. Both have a pronounced effect upon the properties of the plastic. Each is mentioned briefly below in order of increasing organization.

LINEAR POLYMERS

Linear polymers demonstrate the simplest type of organization. As previously mentioned, the monomer units of a linear polymer are covalently bonded end-to-end to form a large chain structure or **macromolecule.**

The chains are quite long in relation to their breadth, and there is minimal attraction or bonding between the chains. Bonds formed between chains are weak, typically either van der Waals forces, hydrogen bonds or interaction of polar groups. The weakness of the bonds permits flexibility, and the chains tend to intertwine, and lie in the same plane. The result is a random spatial arrangement giving rise to an amorphous structure.

COLOR ADDED FOR CLARITY ONLY

Fig. 8. Linear Polymer

BRANCHED POLYMERS

As previously mentioned, branched polymers result when a chain continues concurrent growth as two or more chains. Branching causes stiffening and strengthening since the side chains become intertwined and entangled with each other, and with the parent chain. This is a mechanical phenomenon due to spatial location and molecular geometry.

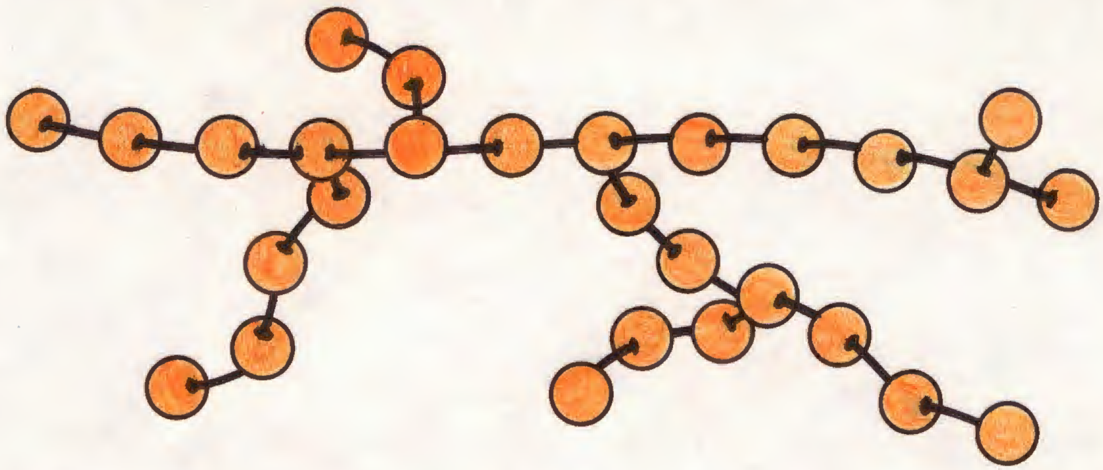

Fig. 9. Branched Polymer

CROSS-LINKED POLYMERS

Cross-linking (or cross-bonding) involves the formation of primary (covalent) bonds between the side chains of the polymer macromolecules. The many side chains in a branched polymer contribute to the formation of cross-links between the polymer chains. The greater the degree of cross-bonding, the greater the strength and rigidity of the polymer. Moreover, increased cross-bonding decreases solubility and increases high temperature stability.

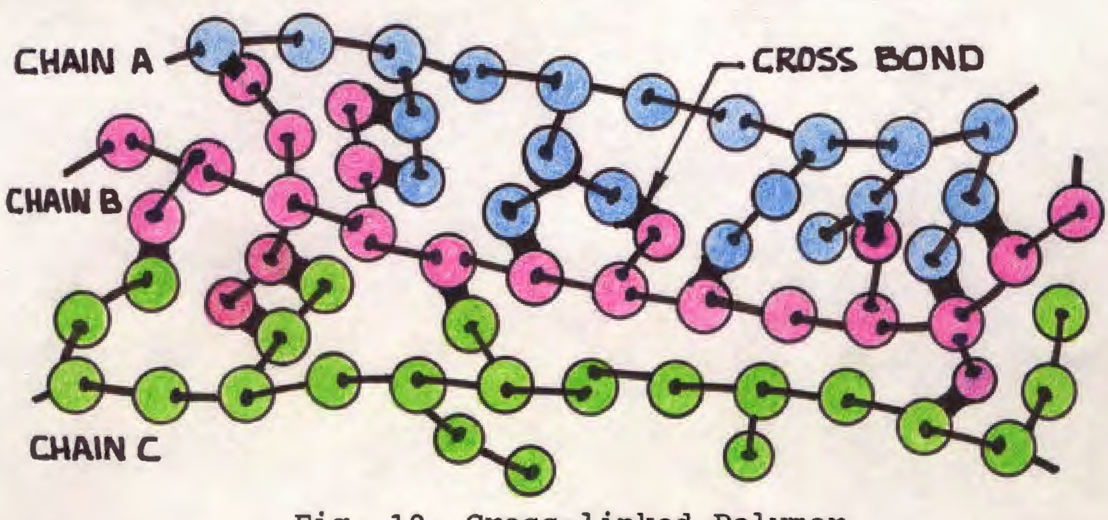

Fig. 10. Cross-linked Polymer

CHAIN STIFFENED POLYMERS

This is a mechanical strengthening which is caused by the incorporation of large substituent groups onto the monomers comprising a polymer chain. Usually, the primary carbon-to-carbon bonds are pivot points of chain flexure, permitting the chains to intertwine and bend around each other. But, when the physically large and unsymmetrical substituent groups attach to the monomers, the ability of the chains to flex is impaired. The result is increased rigidity and brittleness. An example of this mechanism is the large benzene ring molecule which is attached to the monomers of polystyrene.

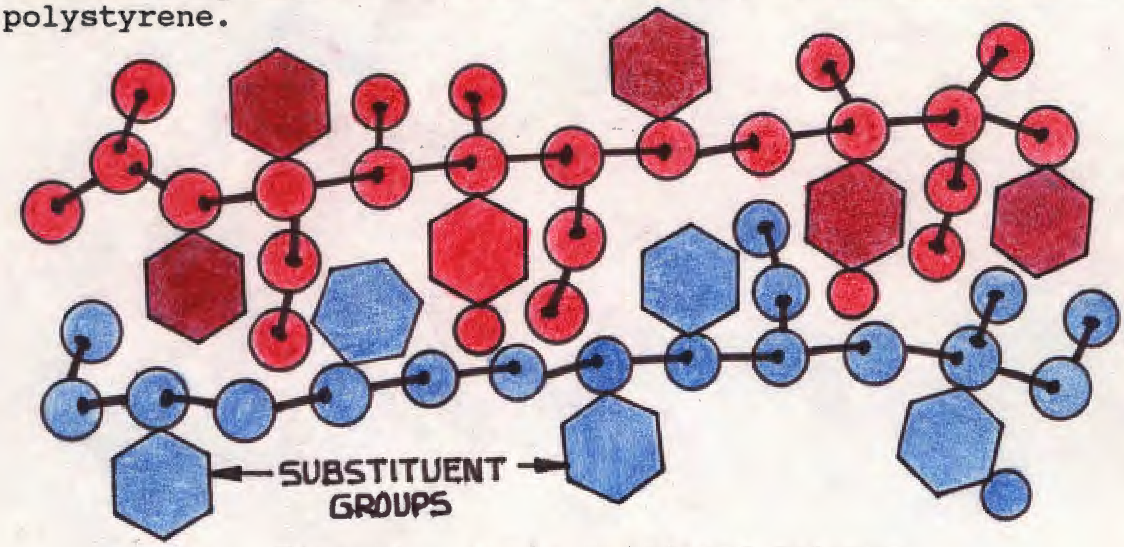

Fig. 11. Chain Stiffened Polymer

THERMOSETTING POLYMER

A thermosetting polymer is one which permanently holds its original shape. In most thermosetting polymers, a high degree of cross-linking between polymer chains is present. Since cross-linking results from the formation of primary covalent bonds under heat and pressure, thermosetting polymers will not melt upon reheating. Indeed, temperatures in excess of 400° F. are necessary to produce heat effects on a thermoset. A thermoset will burn, char or in some cases, sublime. But, it will not melt.

THERMOPLASTIC POLYMER

Thermoplastic polymers exhibit little or no cross-linking between macromolecule chains. Consequently, the bonds between these molecules are weak. The application of low heat (not in excess of 250° F.) causes sufficient molecular agitation to cause the bonds to break, and the polymer melts. When cooled, it hardens again as the bonds are re-established. This occurs no matter how often the process is repeated.

MOLECULAR WEIGHT

The properties and characteristics of a polymer are to some degree, dependent upon the molecular weight of the polymer. By **molecular weight** we mean the aggregate weight of the atoms making up a monomer multiplied by the total number of monomers in the polymer. Note that this is a function of chain length (the longer the chain, the higher the molecular weight). Due to variations in polymer chain length, molecular weight is usually given as **average molecular weight.** As previously noted, the general rule is that mechanical, thermal and other properties increase with increasing molecular weight.

CRYSTALLINITY

We have previously noted that most polymers are not crystalline, i.e., they do not possess a long range order to their structure as do the metals and the ceramics. However, radiographic diffraction studies have demonstrated a tendency in some polymers, most notably those of high molecular weight (density), to display a degree of organization in spatial geometry. We may regard polymeric crystallinity as regions of highly ordered structure within an amorphous matrix of the same material.

This organization is typically an alignment of the long molecular chains within the polymer, and is precipitated by molding or slow cooling from the molten state.

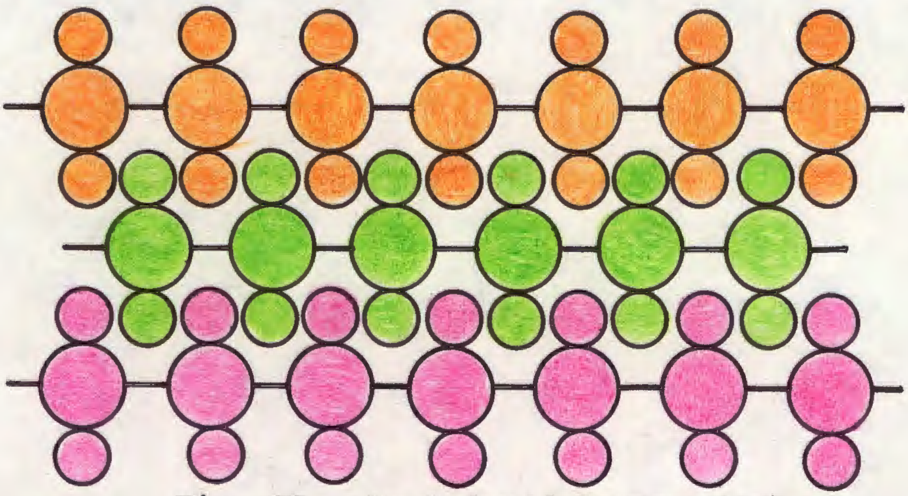

Fig. 12. An Ordered Arrangement of Chains Leading to Crystallinity

Finally, we note that the space available between the molecular chains is also a function of crystallinity. Thus, permeability to moisture and gasses decreases as density increases. This explains why many high density polymers are resistant to chemical and environmental attack.

Density increases with increasing crystallinity, thus density is often used to describe the degree of polymeric crystallinity. Moreover, intermolecular bonding forces are also proportional to the degree of crystallinity present. Thus, strength and temperature stability increase with crystallinity, while ductility and impact resistance decrease.

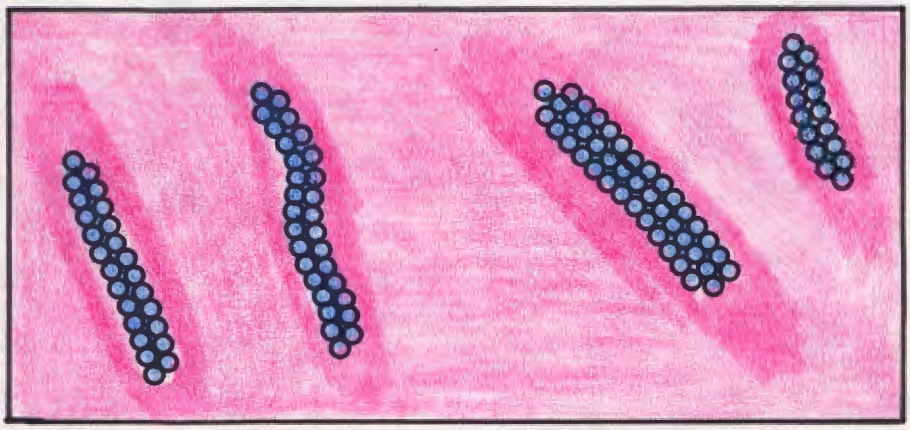

Fig. 13. Areas of Crystalline Structure in Amorphous Polymer Matrix

GLASS TRANSITION TEMPERATURE

The behavior of thermoplastic polymer molecules is highly temperature dependent. Above the lower end of a narrow range of temperatures, a thermoplastic changes from a brittle rigid state to a softer and more flexible condition. The lower limit of this temperature range is the glass transition temperature.

The glass transition temperature is a function of secondary bonding between the polymer chains. When secondary bonds are numerous the polymer chains are stiffer, and the glass transition temperature is higher. With few secondary bonds, the polymer is less dense, more flexible and the glass transition temperature is much lower.

Here, crystallinity (i.e., density) plays a large role in determining properties. If a degree of crystallinity is present, the forces accounting for this structure hold the molecules together, providing useful strength at room temperature. Those plastics with only slight crystallinity depend entirely upon the rigidity of their polymer chains for strength above the glass transition temperature.

INDUSTRIAL PLASTICS

Section D

Property Definitions and Standardized Testing Methods

INTRODUCTION

The property definitions and testing methods herein will supplement and clarify the tabular property values in the sections which follow. The intent is to permit the reader to more readily interpret the tabular data, and to use it in a particular applications problem.

As with all such data, the student should regard it as a general guide to material properties. In determining the properties of a material necessary for a specific application, it may be necessary to consult standard industrial reference texts or manufacturers' product information literature, rely upon expert industry or academic consultants, or to gather the necessary data in-house using empirical methods.

Many properties and the methods of testing them are industry standardized, either by definition or by long usage. Others are more esoteric, having been specifically developed for, and applying only to, a limited portion of the field of plastics. However, to be a valid measure of the property in a particular specimen, each test must be conducted using a consistent methodology which is applied within a narrow range of permissible test conditions.

The technologist must always be aware of the danger of applying representative data to a specific situation.

PROCESSING PROPERTIES

MOLDING QUALITIES

This is a "composite" term which derives its definition from many of the properties of a plastic, including viscosity, density, molecular weight, softening temperature, linear shrinkage, compression ratio, specific heat and thermal expansion.

We may say a plastic has good molding qualities if it exhibits high flowability, good compressibility and low linear shrinkage.

COMPRESSION MOLDING TEMPERATURE AND PRESSURE

An optimum range of temperature and pressure within which the polymer may be readily compression molded with good results. This property is dependent upon such factors as viscosity, molecular weight, specific gravity and specific heat.

INJECTION MOLDING TEMPERATURE AND PRESSURE

The optimum range of temperature and pressure for injection molding. Also highly dependent upon molecular weight, viscosity and specific gravity.

As a rule, temperatures for injection molding are from 50° to 100° F. higher than those for compression molding. The pressure range for injection molding is from two to 20 times higher than those for compression molding.

COMPRESSION RATIO

This is a measure of the **compressibility** of a plastic. It is a comparison of the volume occupied by a polymer at two different pressures and temperatures. Usually the reference points are atmospheric pressure and ambient temperature. The final temperature and pressure are those of the mold.

This property is influenced not only by molecular weight and density, but by temperature, volume and mold time as well.

LINEAR SHRINKAGE

A relative measure of variance in linear dimensions between actual mold size and molded product size. In metalcasting the analogous term is **mold shrinkage**. It is usually expressed as either **inches per inch** or as a percent.

SPECIFIC GRAVITY OR DENSITY

ASTM 792-66 and D1505-68

Specific gravity and density are used interchangably, although there is a slight difference between the two.

Specific gravity is the ratio of the weight of a given volume of the material to the weight of the same volume of water, at 23° C. (73.4° F.). It is properly expressed as "Specific Gravity, 23/23°C."

Density is the **weight** per unit volume of the substance. Here, we refer to **weight density** rather than **mass density**. Weight density is expressed as "D23C, g/cm^3."

The discrepancy between specific gravity and weight density arises because at 23°C, water has a density that is slightly less than 1 (0.99756). If an exact figure is required, density may be derived from specific gravity as follows:

D23C, g/cm^3 = specific gravity, 23/23°C x 0.99756

Specific gravity is important in the price factor, as well as in production control. Typically, the higher the specific gravity, the denser (and heavier) the material and the higher the unit cost.

In production, density is important because a polymer may exhibit varying degrees of packing during the molding process, depending upon molecular weight and structure, mold time, temperature, pressure and mold volume.

SPECIFIC VOLUME

This is numerically equal to the reciprocal of weight density, i.e., it is volume per unit of weight. Typical customary units are cubic inches per pound (in^3/lb). It is an indicator of the volume occupied by a given weight of the polymer.

MACHINING QUALITIES

This is another "composite" term that is used to describe the overall effect of many individual factors. We may generalize and say that a polymer machines well when: the greatest amount of material is removed in the shortest possible time; there is minimal distortion of the workpiece; tool replacement or redressing is not required; a satisfactory surface finish is produced; and low overall costs are maintained.

We note that this is a relative adjective comparison between two or more materials or polymers. Like material selection, machining qualities are always a compromise. For a given cutting operation, one polymer may take a better surface finish than another, and yet exhibit poor dimensional stability or cause high rates of tool wear at the same time.

MECHANICAL PROPERTIES

TENSILE STRENGTH

ASTM D 638-72

This is the single most important measure of the strength of a material. Since most design loads are at or below the elastic limit, we may define tensile strength as the uniaxial tensile loading required to exceed the material's elastic limit. Recall that below the elastic limit,

Hooke's Law applies, and the degree of deformation (**strain**) is proportional to the applied stress.

Usually, tensile stress is **normalized**, i.e., the load is divided by the original cross-sectional area of the specimen. Likewise, deformation is also normalized by dividing it by the original gage length. The normalization of load and deformation eliminate the effects of specimen size, and gives us **unit stress** and **unit strain**. Unit values are often termed **engineering stress** and **engineering strain**, and they permit direct comparison of the tensile properties of different materials.

If a load is applied which does not exceed the material's elastic limit, the material will resume its original shape and dimensions when the load is removed. However, if the load exceeds the material's elastic limit, recovery is not possible, and the deformation becomes permanent. Deformation produced by loads in excess of the elastic limit is termed **plastic set, plastic deformation,** or **plastic flow.**

ELONGATION

ASTM D 638-72

This is deformation produced by tensile loading measured in inches of deformation. This value is usually normalized by dividing it by the original gage length on the test specimen.

Elongation, along with **percent reduction in area**, are two important measures of **ductility**, or the ability of a material to be plastically deformed without rupture.

As might be expected, the thermosetting plastics are quite brittle and show little **elastic behavior**. Conversely, the thermoplastics, due to their molecular structure and spatial geometry, are both highly plastic and highly elastic.

In practice, many thermoplastics do not exhibit a definite tensile failure point. Rather they simply continue to deform, first elastically then plastically. In these cases, rupture is not the cause of component failure. Failure is due to loss of dimensional stability and tolerance control.

Since this degree of deformation is unacceptable in most applications, tensile failure is usually defined as elongation which exceeds a certain percentage of original length. An example is linear polyamide (nylon) fibers which can elongate elastically (stretch) up to 33% of their original length without damage to the product.

TENSILE ELASTIC MODULUS

ASTM D 638-72

This is simply the **modulus of elasticity** or **Young's Modulus**. It is an inherent property of every material, and is a measure of the stiffness of the material. Stiffness is the ability of a material to resist deformation or deflection under various modes of loading.

The elastic modulus is readily determined from values on the engineering (normalized) stress-strain curve, which are below the elastic limit. It is defined as unit stress divided by unit strain, and is measured in pounds per square inch (psi).

The numerical value and the name of the elastic modulus depend upon the type of loading applied. They are: elastic modulus in tensile loading, compressive or bulk modulus under compressive loading, modulus of rigidity under simple shear, and flexural modulus for bending loads.

COMPRESSIVE STRENGTH

ASTM D 695-69
ASTM D 621-64

This is the ability of a material to resist uniaxial compressive loading, and can be intuitively regarded as the reverse of tensile strength. For brittle plastics, maximum compressive strength is the point of actual material failure under load. For thermoplastics, compressive strength is defined as the strength at which transverse deformation exceeds design dimensions to an unacceptable degree.

Note that compressive strength is usually at least equal to, and is often higher than, the tensile strength of the same material.

When used on rigid plastics this test is an indicator of their ability to withstand continuous short-term compressive loading without yielding and loosening when fastened, as by bolts or rivets.

FLEXURAL YIELD STRENGTH

ASTM D 790-71

In this test, a beam of the material is subjected to bending stress. Bending places the inner fibers in compression, and the outer fibers in tension. Most thermoplastics do not break under this test, even after severe deformation. Thus the flexural strength cannot be directly calculated.

Instead, the flexural yield strength is simply defined as the loading (stress) in pounds per square inch that is necessary to stretch the outer fiber surface 5% of its original length.

The bending stress may be applied by loading that is either parallel to the longitudinal axis (column action), or perpendicular to it (true bending), with the latter being more usual.

IMPACT STRENGTH

ASTM D256-72a

This test is a measure the **toughness** of a material.

Toughness is usually associated with resilience or the ability of a material to withstand and recover from impact or shock loading which does not exceed the elastic limit.

Impact tests for toughness measure the energy required to break a notched specimen under standardized conditions. Test results are cited for a one inch specimen using **foot-pounds per inch of notch.**
Therefore, toughness or impact strength is an indicator of the amount of energy that a material can absorb. Since energy (or work) is the product of force times distance. the area beneath the load-elongation curve up to the elastic limit is equal to the energy required to elastically deform the specimen.

Since both load and elongation have been normalized, this area under the stress-strain curve can be regarded as the energy per unit volume which the material can absorb within the elastic range. This energy also defines the **modulus of resilience** of the material.

As might be expected, ductile materials have considerable area under their stress-strain curves, and so are more impact resistant than brittle materials whose stress-strain curves define much smaller areas.

Either the **Izod** or **Charpy** form of the impact test is used, with the Izod being more common. The Izod test mounts the material as a vertical cantilever, while the Charpy mounts it as a simply supported beam.

The technologist should be wary of comparing the overall toughness of two plastics on the basis of the impact test alone. Many plastics (e.g., the polyamides and aceteals) are quite tough in the molded condition, yet they also exhibit a high degree of notch-sensitivity.

A new test (ASTM D 1822-68) called the **tensile impact test** may be replacing the notch impact test. The advantage of this test is the elimination of the notch-sensitivity factor, and the conservation of the energy normally expended in pushing aside the broken portion of the specimen.

HARDNESS

ASTM D 785-65

In the case of plastics, hardness is NOT a measure of wear or abrasion resistance. It is an index of relative resistance to indentation, penetration, or dynamic rebound.

In penetrometer tests (Rockwell), most thermoplastics and some thermosets exhibit a degree of elastic recovery because both displacement of material and penetration are present. Penetrometer testing is useful in differentiating the relative hardness of different types of the same polymer. However, a valid comparison of the hardness of two different types of plastics cannot be made on this basis alone.

FLEXURAL ELASTIC MODULUS

ASTM D 747-70

This is simply the modulus of elasticity under simple bending stress.

This test does not allow for the plastic and elastic elements inherent in the measurement. Therefore, a true elastic modulus for flexure (bending) cannot be calculated.

Instead, an apparent value, **stiffness in flexure** is used to indicate resistance to bending stresses. Recall that stiffness varies directly as elastic modulus.

COMPRESSIVE MODULUS

ASTM D 695-59

This index gives relative stiffness under compressive loading. It is also called **bulk modulus** or **the coefficient**

of volume elasticity. It is analogous to Young's modulus in tension, and is calculated by dividing stress by strain.

The compressive or bulk modulus is typically equal to or slightly higher than the tensile modulus.

THERMAL PROPERTIES

THERMAL CONDUCTIVITY

This is the ability of the polymer to conduct or transfer heat. It is the rate of heat transfer per unit area of the material. Most plastics are typically poor conductors of thermal energy. Units are either $cal/sec/cm^2$ or $BTU/hr/ft^2$.

Tabular values are referenced to pure water which, by definition, has a thermal conductivity of unity (1).

SPECIFIC HEAT

By definition, specific heat is the ratio of the **heat capacity** of any substance to the heat capacity of an equal mass of water. Recall that heat capacity is the thermal energy required to produce unit temperature change in a substance.

We may also define specific heat as the quantity of thermal energy required to produce unit temperature change in unit mass of any substance.

Unlike crystalline materials, most polymers do not exhibit a definite melting point. Instead, they simply soften over a temperature range or decompose before or without melting.

In plastics, other measures of thermal characteristics are used such as the **heat distortion point** and the **softening point.**

THERMAL EXPANSION

Every material, including polymers, expands when heated and contracts when cooled. Changes in size occur in all dimensions of a solid body. However, the **coefficient of linear expansion** is defined as the increase in **length** per unit of length per degree rise in temperature. This property is indicative of the change in size which may be anticipated with the application of heat.

The coefficient of linear (thermal) expansion is temperature dependent, increasing at higher temperatures and decreasing at lower temperatures. It is also related to a material's specific heat and melting or softening point.

Generally, plastics have coefficients of thermal expansion several times higher than those of metals. Thermally induced dimensional changes are typically quite small - not more than 5%. However, even this small amount is sufficient to throw fits and tolerances off. This is especially pronounced in plastics, so the engineer must be aware of the effects of thermal expansion and design accordingly.

HEAT RESISTANCE

ASTM D 1525-70

This refers to the ability of a material's properties to remain stable with changes in temperature. It is usually indicated by making a determination of the softening point.

Softening point is determined by the **Vicat Needle Method.** As the plastic is slowly heated, a flat-ended needle having either square or circular cross-sectional area of 1 mm^2 is pressed into the material. The softening point (Vicat) is the temperature at which the needle penetrates the material to a depth of 1 mm.

DEFLECTION TEMPERATURE

ASTM D 648-72

This test is useful in comparing the relative behavior of various materials at elevated temperatures. Under a standard set of test conditions, the deflection temperature is that temperature at which the material exhibits a total deflection of not more than 0.10 inches. The material may be loaded to one of two standards, either 64 psi or 264 psi.

ELECTRICAL PROPERTIES

VOLUME RESISTIVITY

ASTM D 257-6

This property indicates the electrical resistance of a volume of the material which is 1 cm in length and which has a cross-sectional area of 1 cm^2. The unit of volume resistivity is the ohm-centimeter (Ω-cm).

Resistivity is an inherent characteristic of all materials, and is a constant for any given material. It is a very important property of polymers which are to be used as a dielectric in electrical applications.

Resistivity determinations are made under standardized conditions. They are a relative humidity of 50%, a temperature of 23° C., and pressure of 1 atmosphere.

DIELECTRIC STRENGTH

ASTM D 149-64

This is a measure of the insulating qualities of a polymer. It is the electric field intensity in megavolts per meter or volts per mil of thickness required to cause conduction of electric current across the dielectric material. Dielectric strength is inversely proportional to the thickness of the material.

This quality is extremely sensitive to many factors such as humidity, temperature, geometry and exposure time to the electric potential. Dielectric strength drops sharply if holes, bubbles or impurities are present in the specimen.

Typically, this test is conducted over a short period of time, thus the numerical data do not indicate the electrical stress the material can withstand for a prolonged period. Because of this, the test is useful only as a relative comparison among materials, not as an absolute specification.

DIELECTRIC CONSTANT

ASTM D 150-70

This is the ratio of the capacitance of a capacitor made with a particular dielectric material to the capacitance of a capacitor made with vacuum (or air) as the dielectric.

A dielectric tends to increase the capacitance (ability to store charge) of a capacitor by lowering the potential gradient of the electric field.

The dielectric constant is frequency dependent, and is usually measured at 60 Hz.

DISSIPATION FACTOR

ASTM D 150-70

The dissipation factor is a measure of the conversion of reactive power to real power in the form of heat generated within the dielectric material.

It may be calculated by finding the ratio of the real (in-phase) power to the reactive (90° out of phase) power. It may also be found by taking the cotangent of the phase angle.

ARC RESISTANCE

ASTM D 495-71

This test is used to simulate service conditions typically found in high voltage, high frequency alternating current circuits. The early stages of the test are mild, with later stages becoming progressively more severe. The test is measured by total elapsed time of test (in seconds) until failure occurs.

Two electrodes are placed into contact with the material. An alternating current is first applied for a specific amount of time, and then removed. As the early stages of the test progress, the interval between applications of the alternating current is gradually decreased to zero, or continuous arcing. Later in the test, the severity of arcing is gradually increased by increasing the current until failure occurs.

Four failure modes have been observed:

Inorganic dielectrics may become heated to incandescence, at which point they will conduct the current. Upon cooling, they regain their insulating properties.

Organic compounds may burst into flame without evidence of visible conduction paths (carbon tracking) on the surface of the dielectric.

Other organic compounds fail by carbon tracking between the electrodes.

Carbonization of the surface of the dielectric occurs until enough carbon is present to conduct the current.

OPTICAL PROPERTIES

REFRACTIVE INDEX

This parameter is used mainly with the optical plastics such as Plexiglass, Lexan and Zelux. It based on **Snell's Law of Refraction** which states that the ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant for any two given media.

The refractive index may be determined by passing a narrow beam of yellow light through the material and measuring the angles of incidence and refraction, and then applying Snell's Law. The standard yellow light used for determining refractive indices has a wavelength of 5893 Å.

Usually, air, with a refractive index of 1.000293 is used as the standard of reference for making relative comparisons.

CLARITY

This is no more than an adjective description or estimate of how well an object can be seen when viewed through the plastic.

Descriptors range from opaque (an object cannot be seen at all) to transparent (the object is clearly seen). More formally, a material is opaque if it passes no radiation at all. Conversely, a substance is transparent if it passes radiation with little or no absorption or refraction.

TRANSMITTANCE

ASTM D 1003-61

This is **luminous transmittance**, and is defined as the ratio of transmitted light to incident light expressed as a percent. Note that incident light will always be 100%.

HAZE

ASTM D 1003-61

The haze of a specimen is defined as the percentage of light transmitted through the specimen which is deviated more than 2.5° from the incident beam by forward scattering.

Haze and transmittance form a basis for the direct comparison of the optical properties of various grades and types of plastics.

DURABILITY

WATER ABSORPTION

ASTM D 570-63

All plastics absorb water to a varying degree. The presence of absorbed water may adversely affect the dimensional stability and electrical properties of many plastics.

As previously mentioned, the amount of **interstitial space** existing between the polymer chains determines the permeability of a plastic to both moisture and gasses. Hence, those plastics exhibiting a high degree of crystallinity, or having a high molecular weight (i.e., density) tend to absorb less moisture.

This property is determined by immersion of a 1/8 inch thick specimen in water for 24 hours at 23° C. and 1 atmosphere of pressure. Pre-immersion weight is subtracted from the post-immersion weight, and the change in weight is expressed as a percentage of the pre-immersion weight.

FLAMMABILITY

(ASTM D 635-72).

Flammability index is determined by attempting to burn a specimen of standard cross-sectional area having a length of 12 inches. If the specimen does not ignite, it is classified as "nonburning by this test".

If it ignites and continues to burn, it is timed until it stops, or until the 4 inch mark is reached. A specimen that burns all the way to the 4 inch mark is classified as "burning by this test". A specimen that stops burning before the 4 inch mark is classed as "self-extinguishing by this test". In both cases, the length of the burned portion of the specimen is given in addition to the citation.

ACTINIC RESISTANCE

This characteristic is an adjective description of the plastic's response to direct or simulated sunlight under varying conditions of temperature and relative humidity.

EFFECT OF WEAK ACIDS
EFFECT OF STRONG ACIDS
EFFECT OF WEAK BASES
EFFECT OF STRONG BASES
EFFECT OF ORGANIC SOLVENTS

These are adjective description of the effects which each of several classes of chemicals have on the polymer under various conditions of chemical concentration and temperature.

Typically, any effect which a chemical has is enhanced by elevated temperature.

INDUSTRIAL PLASTICS

Section E

Classification of Thermoplastics

INTRODUCTION

The number of monomeric and polymeric resins on the market is staggering. Each can be classified in a number of ways to suit the the needs of the user. Moreover, there are at least a dozen "standard" industrial classification systems in use. Most of these are based on chemical criteria, and are of no use to the technical student.

For our purposes, it is best to group the plastics into major categories **based on the structure of the monomer unit.** Each of these categories is then further subdivided to accommodate members with special characteristics.

Usually, the so-called "**engineering plastics**" are treated as a separate category. However, for continuity of presentation, these are not treated separately, but are included in their respective category. For the convenience of the user, the engineering plastics are denoted by a (*) in the outline that follows.

The classification scheme developed for use in this guide is my own composite of several other systems. I relied heavily upon the **Materials Handbook**, by Brady and Clauser, the **Plastics Engineering Handbook** edited by Pardos, and **Industrial and Engineering Materials** by Clauser. However, any errors are mine.

Those plastics which have an entry in the Table of Properties in the following sections are marked by a (#).

THERMOPLASTICS CLASSIFICATION

A. OLEFINS
   1. POLYETHYLENES
      a. Low Density Polyethylene
      b. Medium Density Polyethylene
      c. High Density Polyethylene
      d. Ultrahigh Molecular Weight Polyethylene (#)
   2. POLYPROPYLENE (#)
   3. OLEFIN COPOLYMERS
      a. Polyallomer
      b. Ionomer
      c. Ethylene Copolymers
         (1). Ethylene Vinyl Acetate (EVA)
         (2). Ethylene Ethyl Acetate (EEA)
         (3). Ethylene Hexene (EH)
         (4). Ethylene Butene (EB)

B. POLYSTYRENES
   1. General Purpose Grade (#)
   2. Impact Grades
   3. Styrene Acrylonitrile (SAN) (#)
   4. Acrylonitrile-Butadiene-Styrene Terpolymer (ABS)
      a. Extrusion Grades
      b. Molding Grades (#)

C. VINYLS
   1. Polyvinyl Chloride (PVC)
      a. Rigid PVC (#)
      b. Non-Rigid PVC (#)
   2. Chlorinated Polyvinyl Chloride Compound (CPVC) (#)
   3. Vinylidene Chloride (VDC)
   4. Polyvinyl Dichloride (PVD)
   5. Polyvinyl Formal (PVF)
   6. Polyvinyl Butyral (PVB)
   7. Polyvinyl Acetate (PVAc)
   8. Polyvinyl Alcohol (PVA)
   9. Polyvinyl Acetals
   10. Polyvinylidene

F. ARCRYLICS
   1. Polymethyl Methacrylate (PMMA)
      a. Cast Grade
      b. Molding Grade (#)

G. CELLULOSICS
   1. Cellulose Acetate
   2. Cellulose Acetate Butyrate
   3. Cellulose Propionate
   4. Ethyl Cellulose
   5. Cellulose Nitrate

H. POLYAMIDES (NYLON) (*)
  1. Type 66 (Mid Grade) (#)

I. ACETALS (*)
  1. Homopolymer (Delrin) (#)
  2. Copolymer (Celcon)

J. THERMOPLASTIC POLYESTERS (*)
  1. Linear Polyester
  2. Polyethylene Terephthalate (PET) (#)
  3. Poly Cyclohexylene Dimethylene Terephthalate (PCDT)

K. POLYCARBONATE (#)

L. POLYPHENYLENE OXIDE (PPO) (*) (#)

M. POLYPHENYLENE SULFIDES (PPS) (*) (#)

N. POLYSULFONES (*)
  1. Standard Polysulfone (#)
  2. Polyethersulfone
  3. Polyarylsulfone
  4. Polyphenylsulfone

O. POLYARYLATES

P. POLYETHERS (*)
  1. Polyaryl Ether (#)

Q. AROMATIC COPOLYESTER

R. FLUOROPLASTICS (*)
  1. Fluorocarbons
     a. Polytetrafluoroethylene (#)
     b. Fluoroinated Ethylene Propylene
  2. Chlorotrifluoroethylene
  3. Fluohydrocarbons
     a. Polyvinylidene Fluoride
     b. Polyvinyl Fluoride

INDUSTRIAL PLASTICS

Section F

THERMOPLASTICS

Description and Applications

INTRODUCTION

This section provides a general description of the important characteristics and typical industrial applications of representative members of the major groups of thermoplastic polymers, including the so-called "engineering plastics."

OLEFINS

ULTRAHIGH MOLECULAR WEIGHT POLYETHYLENE

In the polyethylenes, variation in properties is highly and directly density (molecular weight) dependent. The three major groups are:

Low density: 0.910 to 0.925

Medium density: 0.926 to 0.940

High density: 0.941 to 0.949

The molecular weight of UHMW polyethylene is 10 - 15 times that of the conventional polyethylenes.

The increased molecular weight imparts improved low temperature impact strength, increased energy absorption at high loading rates, higher elevated temperature tensile strength and improved stress cracking resistance.

It has good dielectric properties over a broad temperature range, and is resistant to most chemicals except strong oxidizing acids. Water absorption is notably low resulting in good dimensional stability. It exhibits slight swelling in the aromatic and halogenated hydrocarbons.

It is readily blended with other monomers, producing copolymers with more desirable characteristics. Exposure to high-energy radiation increases cross-linking resulting in greater stiffness and heat tolerance. It can be processed by all thermoplastic methods.

Unlike the lower density polyethylenes which tend to creep under load, UHMW polyethylene is useful in load-bearing applications such as machine components, gears, bearings, bushings, chute and conveyor linings, rollers, star wheels and vibration dampening pads.

Lower density grades are used for commercial and household containers, gaskets and film-packaging applications. As a rule, thicknesses under 10 mils are films, while thicknesses over 10 mils are considered sheet products.

Higher density grades are also used for electrical wire and power cable insulation, as chemically resistant liners for industrial containers, as pipe and pipe lining, labware and tubing.

POLYPROPYLENE

The properties of the homopolymer vary directly with molecular weight and degree of crystallinity. Resins of higher molecular weight tend to be softer and less rigid, but tougher. Resins of low molecular weight are stiffer and harder, but tend to be brittle and have less impact resistance.

The industrial usefulness of polypropylene depends upon polymeric structure. Atactic polypropylene is soft and rubbery and has little industrial value. Conversely, isotactic polypropylene exhibits dramatically improved properties which approach those of high-density polyethylene.

Polypropylenes have excellent electrical properties, even under moist and hot service conditions. Because polypropylene does not absorb water, it exhibits a high degree of dimensional stability. It is resistant to most inorganic chemicals, even at elevated temperatures. It is, however, vulnerable to oxidizing agents and some ketones. Polypropylene is chemically inert, and this property makes bonding it very difficult.

Thermal resistance is superior to polyethylene, and can be improved with the addition of reinforcing agents. The unreinforced resin creeps rapidly even under even moderate stress, so load bearing applications are not recommended. It does, however exhibit excellent low frequency fatigue strength. Fatigue resistance is improved with additional flexing because it increases molecular alignment in the material (this is analogous to work or strain hardening in metals). Impact strength is excellent, but is highly notch sensitive.

Polypropylene is easily machinable and injection molded. Moldings are typically quite hard and have a glossy surface finish. They are not easily thermoformed due to low melt strength.

Reinforced polypropylenes are used extensively in the appliance and automotive industries. Polypropylene fibers are replacing cotton, linen and silk in textile and fabric production. Polypropylene is also widely used in electrical and electronic manufacturing. Most recently, polypropylene structural foam and molded foam have been used in the prefabricated housing and furniture industries.

POLYSTYRENES

GENERAL PURPOSE POLYSTYRENE

This is a low density polymer having an amorphous atactic/syndiotactic structure with very little crystallinity. For most applications, it is used in unmodified form, except for the addition of pigments, dyes or lubricants.

Polystyrene exhibits relatively high tensile strength, however, it is quite brittle and shows little elongation or impact resistance. It is subject to cold-flow (creep), with a long-term (over two weeks) bearing strength which is only one-third that of the short-term bearing strength. With minimal loading creep is negligible, and the polymer exhibits good dimensional stability. Brittleness may be reduced and impact strength doubled if polystyrene is blended with a synthetic rubber or a polyolefin.

Thermal properties are generally poor to fair, with a maximum useful service temperature of 160° F. The heat deflection temperature is quite low, and applications are limited to room temperature environments.

Polystyrene has excellent electrical properties, especially at **radio frequencies**. Volume and surface resistivity are quite high, and the power factor is nearly zero. Electrical properties vary little with temperature or moisture.

Except for negligible water absorption, environmental resistance is poor. Natural and synthetic hydrocarbon lubricants cause softening and crazing. It is soluble in aromatic and chlorinated hydrocarbons, esters and ketones.

Polystyrene films are permeable to water vapor. Prolonged exposure to ultraviolet radiation (sunlight) causes age degradation.

Optical characteristics are excellent, and polystyrene has exceptional clarity. Before the development of polycarbonates, it was used as a replacement for glass in many applications that did not require impact resistance.

The major industrial applications for polystyrene is in the manufacture of foams. Foams are used for water resistant insulation, and in making disposable patterns for the metal casting industry. The pattern is constructed of foamed polystyrene and placed into a sand mold or ceramic investment. The molten metal is poured into the mold, and the pattern is destroyed and removed via the slag.

Other uses include large vacuum formed parts such as business machine housings, axially oriented filaments, sheets and films, containers and packaging materials.

STYRENE ACRYLONITRILE ALLOY (SAN)

This styrene copolymer is the chemically resistant grade of polystyrene. Its properties are shown on page 4 of the tables.

ACRYLONITRILE-BUTADIENE-STYRENE ALLOY (ABS)

This is a terpolymer (a polymer consisting of three or more monomers) which was originally described as a "gum plastic" because it contains nitrile rubber. This styrene alloy provides a blend of properties similar to the heat and impact resistant grades of polystyrene. See page 5 of the tables.

VINYLS

POLYVINYL CHLORIDE, RIGID AND FLEXIBLE

The vinyls are, after the polyethylenes and styrenes, the most used commercial and industrial plastic. They are competitive in cost, and with the addition of plasticizers and/or fillers, can assume a wide range of properties.

Unmodified (commercial) PVC is approximately 5 percent crystalline and is very hard and brittle at room temperature. Up to 50 percent crystallinity can be obtained through appropriate treatment. PVC has a comparatively high tensile strength, however, its low creep strength limits load bearing applications. The chlorine in the polymer makes it flame retarding.

PVC has generally poor thermal characteristics and service temperatures are low. Resistivity, dielectric constant and dissipation factor are very satisfactory. It is attacked by strong acids and is soluble in some organic solvents. PVC can be both injection and compression molded with good results, and has excellent machinability.

To overcome the limitations of the pure PVC homopolymer, **plasticizers** are often added. These are high boiling point solvents which tend to soften the polymer by weakening interchain forces. This makes the polymer more plastic in behavior.

The term "solvent" is misleading since the polymer is not actually dissolved in the plasticizer, rather it is blended with the polymer to produce the desired characteristics in a mixture which is stable at room temperature.

The addition of more than 15 percent plasticizer produces a decrease in tensile strength, increases elongation and toughness, and decreases hardness and abrasion resistance. These are changes which would be expected with increased softening of the polymer.

However, at a levels of 10 to 15 percent of plasticizer, the so called **"antiplasticizer effect"** occurs. This is a marked increase in crystallinity which causes an increase in the cohesive forces between the chains. This imparts more rigidity to the polymer with attendant changes in properties. Rigid PVC is typically plasticized below the level of 15 percent, while flexible PVC is plasticized above the 15 percent level.

The addition of plasticizers reduces processing temperatures and pressures, improves flowability under pressure and increases the wettability of chemically inert fillers. The increased wettability produced by the the plasticizer assists in the formation of the interface between the polymeric chain matrix (**dispersion phase**) and the filler **(dispersed phase)**.

The rigid PVC's are used for chemical tanks, pipes, ducts, hoods and various architectural shapes. Flexible PVC's are used for electrical wire and cable insulation, gaskets, seals, weather stripping and pipe wrapping.

CHLORINATED POLYVINYLCHLORIDE (CPVC)

Typical PVC is about 57 percent chlorine. In contrast, CPVC contains 66 to 67 percent chlorine. This increases both **melt viscosity** and the glass transition temperature which tends to make them somewhat brittle and less tough (impact resistant) at normal service temperatures.

The additional chlorine raises the service temperature limit from 170° F. to a maximum of 230° F. The polymer is highly flame retarding, and retains the general mechanical and electrical properties of PVC.

CPVC is widely used as semi-rigid tubing and pipe, and is especially useful for economically carrying hot **aqueous** (water-based) liquids.

ACRYLICS

POLYMETHYL METHACRYLATE (PMMA)

Acrylics are noted for their excellent mechanical and optical properties. Their tensile strength is high, approaching that of the unreinforced engineering resins. However, this strength is only short-term. Long term stress in excess of 1500 psi will cause **crazing** or surface cracking.

Acrylics exhibit a high degree of stiffness and hardness, with very little elongation. They are somewhat brittle, have low impact resistance, and are highly notch sensitive. High impact grades are obtained by blending with rubber. As a class, they exhibit excellent abrasion resistance.

Service temperatures are low, with a maximum of 200° F. Linear expansion is high (about 8 - 10 times that of glass), resulting in poor dimensional stability as maximum service temperatures are approached. Their electrical properties are unremarkable, being somewhat less than those of polyethylene.

Optical properties are superb, with a transmittance of 92 percent, and very little hazing. PMMA has the property of **piping light**, i.e., light will follow an acrylic (PPMA) path, even through 180° bends. The index of refraction is 1.49, so a high degree of optical accuracy is maintained, even in curved sections.

As a class, the acrylics weather quite well. Of the transparent plastics, the acrylics are the most resistant to atmospheric weathering and ultraviolet light, and are well suited to outdoor applications. The acrylics are unmatched in maintaining color integrity under continuous outdoor exposure.

Acrylics cast well, and can be injection and compression molded or extruded with excellent results. Moldings are hard, have a glossy surface and reproduce detail nicely. All acrylics machine very well at high speeds and low feeds with aqueous based coolants.

Uses include windows, aircraft canopies, lenses of all types, protective machine enclosures, lighting diffusers, instrument panels and as dental fillings. In practice, an acrylic can be used in almost any application that calls for a glass. The notable exceptions are high temperature and impact applications.

POLYAMIDES

NYLON (TYPE 6/6)

Nylon is an important engineering plastic, and was the first plastic to be used in load-bearing applications. As a class, the nylons are expensive, and so are not general-purpose industrial materials.

The main difference between the various types of nylons is the length of the polymer chains. Mechanical properties tend to improve with increasing chain length. Nylons are essentially linear in structure, and exhibit a high degree of crystallinity which accounts for their excellent mechanical properties.

The glass transition temperature of nylons is below room temperature, so they exhibit some flexibility despite their high level of crystallinity. Nylon can be cast, molded, extruded and machined with good results.

Nylon has excellent tensile and compressive strength, high impact resistance and superior fatigue strength. It has extremely good abrasion resistance which is improved with the addition of surface lubricants, or by surface impregnation with PTFE or molybdenum disulfide particles.

Nylons are not noted for their electrical properties which are mediocre when dry, and deteriorate rapidly with increasing temperature and humidity. Nylon melts in flame, but is self-extinguishing when the source of flame is removed.

The nylons are opaque and have no optical uses. They are resistant to most organic solvents, but are attacked by strong acids. They weather poorly and ultraviolet light causes deterioration. Extended environmental exposure causes discoloration and embrittlement.

They are quite hygroscopic, that is, they absorb moisture, so dimensional stability in wet environments is a problem. Absorbed water has a plasticizing effect, causing loss of tensile strength, but an increase in impact resistance. The amount of moisture absorbed is a function of polymer chain length. As the chain lengthens, water absorption decreases.

Nylons are used as machine parts such as cams, gears, pulleys, sleeves, bearings, bushings and valve seats. They are cast and molded into non-corroding hardware such as nuts, bolts, washers, spacers, cable ties and the like.

Nylon fibers are woven into such diverse products as parachute cloth, projectile proof protective gear, surgical suture, rope and tire cords.

ACETALS

POLYACETAL HOMOPOLYMER

These plastics were developed to compete with aluminum and zinc die castings. They are the first plastics which have approached the non-ferrous metals in mechanical properties. Due to a high degree of crystallinity, they are denser than most other plastics, but some 80 percent lighter than any of the die-casting alloys.

Crystallinity ranges from 77 to 80 percent, depending upon the temperature at which they are quenched. An anneal at 300° F. will further increase crystallinity. This marked crystallinity accounts for the polymer's excellent stiffness, and high tensile, flexural and fatigue strengths. The polymer exhibits very low but definite creep under moderate loads. The acetals exhibit no brittleness, high impact strength, slight notch sensitivity,and excellent resilience. Abrasion resistance is superior to that of most plastics except the nylons. Due to low moisture absorption, dimensional stability is excellent.

The least friction and wear is obtained with acetal to steel contact, and the most with acetal to aluminum contact. Acetal to acetal contact (as in bearings) results in high heat build-up and excessive wear.

Electrical properties are good. This combined with toughness, temperature resistance and insulating qualities allows for use in some electrical applications.

Thermal characteristics are excellent, and are retained under adverse conditions of temperature and humidity. Maximum prolonged service temperature is 220° F. in air.

Acetals have no optical uses. They burn slowly, are susceptible to attack by strong acids, alkalis and oxidizing agents, but are highly resistant to organic solvents. Exposure to ultraviolet light causes chalking and embrittlement.

Typical engineering uses are pump impellers, fan blades, oil-field pipe, hardware, plumbing components, conveyor belt links, sprockets, drive chain, check valves, machine housings, bearings, gears, pulleys, sleeves, pushrods, belcranks, linkages and other machine parts. Over 80 percent of all applications involve the replacement of metals, usually zinc, aluminum or brass.

THERMOPLASTIC POLYESTERS

POLYETHYLENE TEREPHTHALATE (PET)

This is the oldest of the "engineering" thermoplastic polyesters, and it illustrates the dramatic improvement in qualities that can be obtained through mechanical working of the resin.

Mechanical working and appropriate heat treatment cause the molecules to lock together, imparting a high degree of crystallinity and concomitant density. PET is most often used as sheet or film. As such, it exhibits a good balance of mechanical properties. It has a high modulus of rigidity making possible the use of thin sections. Its plasticity and toughness permit conformance to complex surfaces without tearing. Sheets and molded shapes have such good impact resistance that they are termed "shatterproof".

Electrical properties are unremarkable, however, because the polymer demonstrates very low moisture absorption, its electrical properties are very stable, even when wet.

PET and has no optical uses. However, it does have excellent clarity and gloss, making it ideal as a container. Ultraviolet light causes slight discoloration. It is attacked by oxidizing acids and strong bases, but is resistant to organic solvents.

Uses are as a carrier for pigment in hot-stamping or embossing operations, photographic film base, recording (audio) tape, drafting or printing film, as a fiber in synthetic or blended cloths, dielectric or insulation in transformers, motors and generators, and shatterproof containers.

POLYCARBONATES

POLYCARBONATE POLYMER

This is an engineering resin of linear polymeric structure. Unlike other thermoplastic resins, the crystallinity of the polymer decreases with increasing molecular weight.

It exhibits a very high melt viscosity, so high temperatures and pressures are necessary for injection and compression molding, extrusion and vacuum forming. This increases processing costs since special equipment is required. It machines quite well at high speeds and low feeds.

Polycarbonate is the toughest of all the plastics, and has excellent impact strength. As a comparison, polycarbonate has 30 times the impact resistance of safety glass. It is, however, somewhat notch sensitive. Interestingly, impact strength is section- thickness dependent, and the relationship is not linear. A 1/8 inch thick specimen has 5 to 6 times the impact resistance of a 1/4 inch thick specimen. There is for all grades a **critical thickness** above which Izod impact strength decreases markedly.

Polycarbonate is also one of the hardest plastics. It exhibits good strength and rigidity, and a high elastic modulus, which makes it creep resistant. Its rigidity (strength to weight ratio) is twice that of metals. It tends to craze under strain. Due to low water absorption, dimensional stability of products is high.

The polymer has a continuous service temperature of 257° F., without impact. If a part is subject to impact, the service temperature limit drops to 234° F. It has very good low temperature resistance, and the heat distortion temperature under load is high.

Electrical properties are outstanding, and remain so over a wide temperature range. This coupled with low water absorption makes polycarbonate an excellent insulator and dielectric material. It will flame, but it is self-extinguishing.

Optical properties are superb, with a maximum transmittance of 92 percent, and hazing of less than 2 percent. Only PMMA and polystyrene are more transparent. The chemical and environmental resistance of polycarbonate is only fair. Exposure to sunlight causes embrittlement and color change or loss of transparency. It is resistant to weak acids, but is susceptible to the action of other inorganic chemicals, and is soluble in hydrocarbons.

Polycarbonate sees the most use in the electrical/electronic industries. Examples are appliance and power tool housings, cabinets and other enclosures for computing equipment and the manufacture of electronic and electrical parts such as capacitors, transformers, motors and generators. Optical applications includes lamp lenses of all kinds, especially where impact resistance is desirable. It has replaced PMMA and the acrylics as tail-light lenses, streetlight covers and aircraft landing light lenses. It is also coated with melamine or a fluorocarbon for use as windows in busses and rail cars.

PHENYLENE OXIDE RESINS

POLYPHENYLENE OXIDE

Currently, most commercial PPO resins are actually blends of PPO and polystyrene, called Noryl. This mixture lowers their considerable cost, and improves processability. Pure PPO polymers are available, but are quite expensive. Tensile and compressive strengths are excellent, as are notched impact strength and hardness. The elastic modulus is high which imparts good creep resistance and excellent dimensional stability.

Electrical properties are good with high dielectric strength and low dissipation factor. These qualities are maintained throughout a broad range of temperature and humidity.

PPO flames, but is self-extinguishing. Among the plastics, PPO has one of the lowest coefficients of thermal expansion. This also contributes to its high degree of dimensional stability. It is resistant to all inorganic chemicals, but is soluble in aromatic and aliphatic hydrocarbons.

Major uses are business and computing machine cabinets, electrical and electronic components, aircraft and automotive components, and plumbing and piping parts.

PHENYLENE SULFIDES

POLYPHENYLENE SULFIDES (PPS)

This polymer is available in three basic types: as a branched polymer processed by sintering, a linear polymer which is compression molded at high temperature (650° F. or more) to promote cross-linking of polymer chains, and as moderate molecular weight grades for injection molding.

These engineering resins have excellent mechanical properties, which are retained over a broad temperature range, from cryogenic to 500° F. They do not stress crack, but they are notch sensitive.

PPS has a low coefficient of linear expansion, especially in the direction flow, hence, their molding qualities are good, although mold shrinkage can be high depending upon grade. Cross-linkable grades have the highest heat deflection temperature of all the plastics, and are heat resistant up to 500° F.

Electrical properties are outstanding over a wide range of temperature, frequency and humidity. PPS is inherently non-flammable, hence no flame retardants are needed.

All members of this family have excellent chemical and environmental resistance. At temperatures below 400° F., there is no known solvent for any of these resins. The polymers are extremely resistant to neutron and gamma radiation, and exposure to ultraviolet light has no effect.

They are used for components in fluid transport systems such as pump housings, vanes and impellers, fittings and connections and piping and tubing. At this time, the largest use of PPS is in the electrical and electronic industries for molded interconnection devices.

POLYSULFONES

STANDARD POLYSULFONE (UNFILLED)

The chemical structure of these polymers is such that the bonds between the chain elements are quite strong, resulting in a structure which is spatially grouped into a planar configuration. This provides considerable rigidity to the chain which is retained at high temperatures.

The polymer has excellent tensile, compressive and flexural strength. The rigidity of its molecular structure makes it very creep resistant. However, the rigidity also reduces its impact resistance.

The polysulfones exhibit excellent thermal properties, with a continuous heat resistance temperature of 345° F., and a loaded deflection temperature of 345° F.

Electrical properties are quite good, with high volume resistivity and dielectric strength, and low dissipation factor over a wide frequency range. However, they tend to carbon-track.

Water absorption is moderate to high, resulting in some instability of electrical and dimensional properties. They are resistant to all inorganic chemicals, but are partly soluble in aromatic hydrocarbons. Ultraviolet radiation causes a loss of strength and yellowing.

Typical uses are in commercial and home appliances which are subject to temperature extremes. They are useful in making electrical/electronic components such as terminal blocks, printed circuit boards, IC carriers and battery cases.

Other uses include instrument and equipment housings and cases. They are typically used to replace parts made of metal, thermosets and ceramics rather than those made of other thermoplastics.

POLYETHERS

POLYARYL ETHER

This is an engineering plastic whose chemistry and polymerization have not been disclosed. It is believed to be a polymer of ABS and a polyethersulfone.

Although many of its properties are unremarkable, three are outstanding as combined in this single material: its heat deflection temperature of 300° F. is exceeded only by PPS and polysulfone; it has the highest impact strength of all the engineering plastics; and it exhibits excellent flowability which allows filling of intricate sections and thin walls.

Linear shrinkage is low, permitting precision injection molding of void-free parts. Thermal expansion is also low which results in only small dimensional changes. In fact, it can withstand prolonged immersion in boiling water with only negligible weight gain.

Volume resistivity and dielectric strength are quite good, and the dissipation factor is low. Continuous arc resistance is in excess of 180 seconds.

Exposure to sunlight causes slight embrittlement, however, this is overcome by blending pigments into the polymer. In addition, it readily takes most industrial coatings and finishes without pretreatment or priming. It is resistant to all inorganic chemicals except some strong acids. It is soluble in aromatic hydrocarbons, esters and ketones.

Polyaryl ether is used for molded and extruded automotive and aircraft parts, appliance components and housings, electrical and electronic components, business machine and computing equipment cabinetry, power tool housings, instrument cases and clusters, plumbing valves, fixtures and piping, and fluidic controls.

FLUOROPOLYMERS

POLYTETRAFLUOROETHYLENE (PTFE or TEFLON)

Fluoropolymers are formed when the hydrogen atoms of a linear polymer are replaced by fluorine atoms. Hence the name, fluorocarbons or fluoroplastics. PTFE is the most widely used fluoroplastic.

The material does not fuse, even at temperatures above 900° F. At 620° F. the molecular segments are discrete and the particles cohere, forming an amorphous gel rather than a true liquid. Decomposition and evaporation of the gel begin at 750° F.

Since PTFE has no true fusion point, none of the common methods of forming thermoplastics are applicable. Instead, in a process similar to powder metallurgy, the resin in powder form is compacted in a mold and sintered. Costs for production of molded forms is typically very high, since extrusion speeds must be slow enough to allow for sintering.

PTFE has the best chemical resistance of all the plastics. It is immune to the effects of all organic compounds, acids and bases. Only molten alkalis attack PTFE. Useful service temperatures range from a low of -100° F. to a high limit of 500° F. Electrical properties remain excellent throughout this temperature range.

Physical and mechanical properties are very similar to those of polyethylene. It has notably poor cold-flow (creep) properties. The addition of appropriate fillers will improve density, stiffness, compressive strength and thermal conductivity. Addition of fillers lowers tensile strength, elongation and impact strength because no bonding takes place between filler and polymer. PTFE also exhibits poor wear resistance, and moderately good abrasion resistance.

PTFE has a very slippery surface and virtually nothing will adhere to it. It also exhibits extremely low coefficients of friction which change little, regardless of temperature or load. The static and dynamic coefficients are almost identical so start-up forces are not increased when PTFE bearing surfaces are employed.

PTFE is used as a non-stick, low-friction coating on mating surfaces where lubrication is undesirable, or in corrosive environments where synthetic or natural lubricants cannot be used. When surfaces are coated, they must be allowed to dry, and then be sintered to bond the coating to the substrate material. Single coat thickness is limited to 1.5 mils, with sintering between multiple coats.

Its chemical inertness makes it ideal for use as gaskets, seals, expansion joints, packings, tubing, pump and valve parts and diaphragms in highly corrosive environments.

PTFE is used as an electrical/electronic insulator and dielectric in motors, generators, capacitors and transformers.

PTFE is also used to provide a non-stick surface in many applications other than industrial or commercial. For example, home cookware is coated with PTFE to prevent sticking and make clean-up easy, and PTFE tape is available for sealing threaded joints of all kinds.

INDUSTRIAL PLASTICS

Section G

THERMOPLASTICS

Property Data Tables

INTRODUCTION

The tables in this section follow the general pattern of those found in Plastic Materials and Processes, by Seymour S. Schwartz and Sidney H. Goodman, copyright 1982, by the Van Nostrand Reinhold Company, New York, New York.

Due to the space limitations in this paper, some of the more esoteric entries in the tables were eliminated, and others were abbreviated.

For continuity of presentation and to facilitate preparation using a PC word processor, the format of the tables has been altered.

Most notably, units have been placed in a separate column, major property headings are horizontal rather than vertical, ASTM test methods have been placed in a separate section, and common commercial names have been added to the tables.

For more detailed tabular, descriptive and chemical data, the student is urged to consult Plastics Materials and Processes.

Type: Olefinic Name: UHMW Polyethylene

Property	Unit	Range
PROCESSING PROPERTIES:		
Molding Qualities		Fair
Compression Molding Temp.	°F.	400 - 500
Compression Molding Pres.	psi	800 - 1200
Injection Molding Temp.	°F.	
Injection Molding Pres.	psi	
Compression Ratio		
Linear Shrinkage	in/in	
Specific Gravity (Density)		0.94
Specific Volume	in^3/lb	29.4
Machining Qualities		Excellent
MECHANICAL PROPERTIES:		
Tensile Strength	psi	2500 - 3500
Elongation	%	300 - 500
Tensile Elastic Modulus	10^5 psi	0.20 - 1.10
Compressive Strength	psi	
Flexural Yield Strength	psi	
Impact Strength, notch	ft-lb/in	No Break
Hardness	Shore	D 60 - 70
Flexural Elastic Modulus	10^5 psi	1.30 - 1.40
Compressive Modulus	10^5 psi	
THERMAL PROPERTIES:		
Thermal Conductivity	10^{-4} cal/sec/cm^2	
Specific Heat	cal/°C/Gm	
Thermal Expansion	10^{-5} in/in/°C	7.2
Heat Resistance	°F	
Deflection Temperature @ 264psi	°F	155 - 180
ELECTRICAL PROPERTIES:		
Volume Resistivity (50% RH)	ohm-cm at 23°C	$> 10^{16}$
Dielectric Strength	Volts/Mil	710
Dielectric Constant, 60Hz		2.34
Dissipation Factor, 60Hz		0.0003
Arc Resistance	sec	
OPTICAL PROPERTIES:		
Refractive Index		
Clarity		Transl - Opaque
Transmittance	%	
Haze	%	
DURABILITY:		
Water Absorption, 1/8" sect	% in 24 hr	< 0.01
Flammability		Very Slow
Actinic Resistance		Good
Weak Acids		Resistant
Strong Acids		Attacked by Oxidizing Acids
Strong Bases		Resistant
Weak Bases		Resistant
Organic Solvents		Resistant below 80°C.

TRADE NAMES: AC, Ceram P, Impax, Jaytrex, Polyceram, Ultrex

Type: Olefinic Name: Polypropylene

Property	Unit	Range
PROCESSING PROPERTIES:		
Molding Qualities		Excellent
Compression Molding Temp.	°F.	340 - 450
Compression Molding Pres.	psi	500 - 1000
Injection Molding Temp.	°F.	400 - 550
Injection Molding Pres.	psi	1000 - 20000
Compression Ratio		2.0 - 2.4
Linear Shrinkage	in/in	0.010 - 0.025
Specific Gravity (Density)		0.902 - 0.910
Specific Volume	in^3/lb	30.8 - 30.4
Machining Qualities		Good
MECHANICAL PROPERTIES:		
Tensile Strength	psi	4300 - 5500
Elongation	%	200.0 - 700.0
Tensile Elastic Modulus	10^5 psi	1.60 - 2.25
Compressive Strength	psi	5500 - 8000
Flexural Yield Strength	psi	6000 - 8000
Impact Strength, notch	ft-lb/in	0.5 - 2.2
Hardness	Rockwell R	50 - 96
Flexural Elastic Modulus	10^5 psi	1.7 - 2.5
Compressive Modulus	10^5 psi	1.5 - 3.0
THERMAL PROPERTIES:		
Thermal Conductivity	10^{-4} cal/sec/cm^2	2.8
Specific Heat	cal/°C/Gm	0.46
Thermal Expansion	10^{-5} in/in/°C	5.8 - 10.2
Heat Resistance	°F	225 - 260
Deflection Temperature @ 264 psi	°F	125 - 140
ELECTRICAL PROPERTIES:		
Volume Resistivity (50% RH)	ohm-cm at 23°C	$> 10^{16}$
Dielectric Strength	Volts/Mil	500 - 660
Dielectric Constant, 60Hz		2.2 - 2.6
Dissipation Factor, 60Hz		< 0.0005
Arc Resistance	sec	136 - 185
OPTICAL PROPERTIES:		
Refractive Index		1.49
Clarity		Transp - Opaque
Transmittance	%	55 - 90
Haze	%	1.0 - 3.5
DURABILITY:		
Water Absorption, 1/8" sect	% in 24 hr	< 0.01 - 0.03
Flammability		0.75 - 0.83
Actinic Resistance		Crazing
Weak Acids		Resistant
Strong Acids		Attacked by oxidizing acids
Strong Bases		Resistant
Weak Bases		Resistant
Organic Solvents		Resistant below 80°C.

TRADE NAMES: Aerotuf, Delflex, Formid, Microfoam, Plaskon

Type: Styrene Name: Polystyrene, General Purpose

Property	Unit	Range
PROCESSING PROPERTIES:		
Molding Qualities		Excellent
Compression Molding Temp.	°F.	265 - 400
Compression Molding Pres.	psi	1000 - 10000
Injection Molding Temp.	°F.	325 - 500
Injection Molding Pres.	psi	10000 - 30000
Compression Ratio		1.6 - 4.0
Linear Shrinkage	in/in	0.001 - 0.006
Specific Gravity (Density)		1.04 - 1.09
Specific Volume	in^3/lb	26.0 - 25.6
Machining Qualities		Fair - Good
MECHANICAL PROPERTIES:		
Tensile Strength	psi	5000 - 12000
Elongation	%	1.0 - 2.5
Tensile Elastic Modulus	10^5 psi	4.0 - 5.0
Compressive Strength	psi	11500 - 16000
Flexural Yield Strength	psi	8000 - 14000
Impact Strength (Notch)	ft-lb/in	0.25 - 0.40
Hardness	Rockwell	M65 - M80
Flexural Elastic Modulus	10^5 psi	4.0 - 4.7
Compressive Modulus	10^5 psi	
THERMAL PROPERTIES:		
Thermal Conductivity	10^{-4} cal/sec/cm^2	2.4 - 3.3
Specific Heat	cal/°C/Gm	0.32
Thermal Expansion	10^{-5} in/in/°C	6.0 - 8.0
Heat Resistance	°F	150 - 170
Deflection Temperature @ 264 psi	°F	220 max.
ELECTRICAL PROPERTIES:		
Volume Resistivity (50% RH)	ohm-cm at 23°C	> 10^{16}
Dielectric Strength	Volts/Mil	500 - 700
Dielectric Constant, 60Hz		2.45 - 3.1
Dissipation Factor, 60Hz		0.0001 - 0.0006
Arc Resistance	sec	60 - 140
OPTICAL PROPERTIES:		
Refractive Index		1.59 - 1.60
Clarity		Transp
Transmittance	%	87 - 92
Haze	%	< 0.1 - 3.0
DURABILITY:		
Water Absorption, 1/8" sect	% in 24 hr	0.03 - 0.10
Flammability		< 1.5
Actinic Resistance		Yellows slightly
Weak Acids		Resistant
Strong Acids		Attacked by oxidizing acids
Strong Bases		Resistant
Weak Bases		Resistant
Organic Solvents		Soluble in arom & chlor HC

TRADE NAMES: Amoco, Cerex, Dow, E-Z Flow, Gulf, Monsanto, Shell

Type: Styrene Alloy Name: Styrene Acrylonitrile (SAN)

Property	Unit	Range
PROCESSING PROPERTIES:		
Molding Qualities		Good
Compression Molding Temp.	°F.	300 - 400
Compression Molding Pres.	psi	1000 - 10000
Injection Molding Temp.	°F.	375 - 575
Injection Molding Pres.	psi	10000 - 33000
Compression Ratio		1.6 - 4.0
Linear Shrinkage	in/in	0.002 - 0.007
Specific Gravity (Density)		1.075 - 1.100
Specific Volume	in^3/lb	25.8 - 25.2
Machining Qualities		Good
MECHANICAL PROPERTIES:		
Tensile Strength	psi	9000 - 12000
Elongation	%	1.5 - 3.7
Tensile Elastic Modulus	10^5 psi	4.0 - 5.6
Compressive Strength	psi	14000 - 17000
Flexural Yield Strength	psi	14000 - 19000
Impact Strength (Notch)	ft-lb/in	0.35 - 0.50
Hardness	Rockwell	M80 - M90
Flexural Elastic Modulus	10^5 psi	to 5.5
Compressive Modulus	10^5 psi	5.3
THERMAL PROPERTIES:		
Thermal Conductivity	10^{-4} cal/sec/cm^2	2.9
Specific Heat	cal/°C/Gm	0.32 - 0.34
Thermal Expansion	10^{-5} in/in/°C	3.6 - 3.8
Heat Resistance	°F	140 - 205
Deflection Temperature @ 264 psi	°F	190 - 220
ELECTRICAL PROPERTIES:		
Volume Resistivity (50% RH)	ohm-cm at 23°C	$> 10^{16}$
Dielectric Strength	Volts/Mil	400 - 500
Dielectric Constant, 60Hz		2.6 - 3.4
Dissipation Factor, 60Hz		0.006 - 0.008
Arc Resistance	sec	100 - 150
OPTICAL PROPERTIES:		
Refractive Index		1.56 - 1.57
Clarity		Transp
Transmittance	%	78 - 88
Haze	%	0.4 - 0.1
DURABILITY:		
Water Absorption, 1/8" sect	% in 24 hr	0.20 - 0.30
Flammability		
Actinic Resistance		Yellows slightly
Weak Acids		Resistant
Strong Acids		Attacked by oxidizing acids
Strong Bases		Resistant
Weak Bases		Resistant
Organic Solvents		Soluble in esters and ketones

TRADE NAMES: Bexan, Kostil, Lacqsan, Restil, Styrex, Trylon

Type: Styrene Name: Acrylonitrile-Butadiene-Styrene

Property	Unit	Range
PROCESSING PROPERTIES:		
Molding Qualities		Good - Excellent
Compression Molding Temp.	°F.	325 - 450
Compression Molding Pres.	psi	1000 - 8000
Injection Molding Temp.	°F.	380 - 525
Injection Molding Pres.	psi	8000 - 25000
Compression Ratio		1.1 - 2.0
Linear Shrinkage	in/in	0.004 - 0.009
Specific Gravity (Density)		1.01 - 1.04
Specific Volume	in^3/lb	27.0 - 26.0
Machining Qualities		Good - Excellent
MECHANICAL PROPERTIES:		
Tensile Strength	psi	4800 - 6300
Elongation	%	5.0 - 70.0
Tensile Elastic Modulus	10^5 psi	2.3 - 3.3
Compressive Strength	psi	4500 - 8000
Flexural Yield Strength	psi	8000 - 11000
Impact Strength (Notch)	ft-lb/in	6.5 - 7.5
Hardness	Rockwell	R-85 - R105
Flexural Elastic Modulus	10^5 psi	2.5 - 3.5
Compressive Modulus	10^5 psi	1.4 - 3.0
THERMAL PROPERTIES:		
Thermal Conductivity	10^{-4} cal/sec/cm^2	4.5 - 8.0
Specific Heat	cal/°C/Gm	0.3 - 0.4
Thermal Expansion	10^{-5} in/in/°C	9.5 - 11.0
Heat Resistance	°F	140 - 180
Deflection Temperature @ 264 psi	°F	205 - 215
ELECTRICAL PROPERTIES:		
Volume Resistivity (50% RH)	ohm-cm at 23°C	1.0 - 4.8 x 10^{16}
Dielectric Strength	Volts/Mil	400 - 450
Dielectric Constant, 60Hz		2.4 - 5.0
Dissipation Factor, 60Hz		0.003 - 0.008
Arc Resistance	sec	50 - 85
OPTICAL PROPERTIES:		
Refractive Index		
Clarity		Tranl - Opaque
Transmittance	%	28
Haze	%	100
DURABILITY:		
Water Absorption, 1/8" sect	% in 24 hr	0.20 - 0.25
Flammability		0.6 - 1.0
Actinic Resistance		Some embrittlement, yellowing
Weak Acids		Resistant
Strong Acids		Attacked by oxidizing acids
Strong Bases		Resistant
Weak Bases		Resistant
Organic Solvents		Soluble in ketones, esters

TRADE NAMES: Blendex, Cycolac, Formid, Royalite, Vulkide, Urtal

Type: Vinyl Name: Polyvinylchloride, Rigid

Property	Unit	Range
PROCESSING PROPERTIES:		
Molding Qualities		Fair to good
Compression Molding Temp.	°F.	285 - 400
Compression Molding Pres.	psi	750 - 2000
Injection Molding Temp.	°F.	300 -415
Injection Molding Pres.	psi	10000 - 40000
Compression Ratio		2.0 - 2.3
Linear Shrinkage	in/in	0.001 - 0.005
Specific Gravity (Density)		1.16 - 1.35
Specific Volume	in^3/lb	20.5 - 19.1
Machining Qualities		Excellent
MECHANICAL PROPERTIES:		
Tensile Strength	psi	6000 -7500
Elongation	%	40 - 80
Tensile Elastic Modulus	10^5 psi	3.5 - 6.0
Compressive Strength	psi	8000 -13000
Flexural Yield Strength	psi	10000 - 16000
Impact Strength (Notch)	ft-lb/in	0.4 - 20.0
Hardness	Shore	D65 - D85
Flexural Elastic Modulus	10^5 psi	3 - 5
Compressive Modulus	10^5 psi	
THERMAL PROPERTIES:		
Thermal Conductivity	10^{-4} cal/sec/cm^2	3.5 - 5.0
Specific Heat	cal/°C/Gm	0.25 - 0.35
Thermal Expansion	10^{-5} in/in/°C	5.0 - 10.0
Heat Resistance	°F	130 - 175
Deflection Temperature @ 264 psi	°F	140 - 170
ELECTRICAL PROPERTIES:		
Volume Resistivity (50% RH)	ohm-cm at 23°C	> 10^{16}
Dielectric Strength	Volts/Mil	350 - 500
Dielectric Constant, 60Hz		3.2 - 4.0
Dissipation Factor, 60Hz		0.007 - 0.020
Arc Resistance	sec	60 - 80
OPTICAL PROPERTIES:		
Refractive Index		1.52 - 1.55
Clarity		Transl - Opaque
Transmittance	%	76 - 82
Haze	%	8 - 18
DURABILITY:		
Water Absorption, 1/8" sect	% in 24 hr	0.04 - 0.4
Flammability		< 0.16
Actinic Resistance		Varies
Weak Acids		Resistant
Strong Acids		Slightly Attacked
Strong Bases		Resistant
Weak Bases		Resistant
Organic Solvents		Soluble in ketones, esters

TRADE NAMES: Armodur, Cyclon, Duranyl, Nalgon, Regalite, Vylon

Type: Vinyl Name: Polyvinylchloride, Flexible

Property	Unit	Range
PROCESSING PROPERTIES:		
Molding Qualities		Good
Compression Molding Temp.	°F.	285 - 350
Compression Molding Pres.	psi	500 - 2000
Injection Molding Temp.	°F.	320 - 385
Injection Molding Pres.	psi	8000 - 25000
Compression Ratio		2.0 - 2.3
Linear Shrinkage	in/in	0.010 - 0.050
Specific Gravity (Density)		1.16 - 1.35
Specific Volume	in^3/lb	23.8 - 20.5
Machining Qualities		
MECHANICAL PROPERTIES:		
Tensile Strength	psi	1500 - 3500
Elongation	%	200 - 450
Tensile Elastic Modulus	10^5 psi	
Compressive Strength	psi	900 - 1700
Flexural Yield Strength	psi	
Impact Strength (Notch)	ft-lb/in	Varies
Hardness	Shore	A50 - A100
Flexural Elastic Modulus	10^5 psi	
Compressive Modulus	10^5 psi	
THERMAL PROPERTIES:		
Thermal Conductivity	10^{-4} cal/sec/cm^2	3.0 - 4.0
Specific Heat	cal/°C/Gm	0.3 - 0.5
Thermal Expansion	10^{-5} in/in/°C	7.0 - 25.0
Heat Resistance	°F	150 - 175
Deflection Temperature @ 264 psi	°F	
ELECTRICAL PROPERTIES:		
Volume Resistivity (50% RH)	ohm-cm at 23°C	10^{11} - 10^{15}
Dielectric Strength	Volts/Mil	300 - 400
Dielectric Constant, 60Hz		5.0 - 9.0
Dissipation Factor, 60Hz		0.08 - 0.15
Arc Resistance	sec	
OPTICAL PROPERTIES:		
Refractive Index		
Clarity		Transp - Opaque
Transmittance	%	
Haze	%	
DURABILITY:		
Water Absorption, 1/8" sect	% in 24 hr	0.15 - 0.75
Flammability		
Actinic Resistance		Stabilizer Dependent
Weak Acids		Resistant
Strong Acids		Slight Attack
Strong Bases		Resistant
Weak Bases		Resistant
Organic Solvents		Soluble in ketones, esters

TRADE NAMES: Chemclad, Clearflo, Duflex, Elaston, Krystaltite

Type: Vinyl **Name:** Chlorinated Polyvinlychloride Compound

Property	Unit	Range
PROCESSING PROPERTIES:		
Molding Qualities		Good
Compression Molding Temp.	°F.	350 - 400
Compression Molding Pres.	psi	1500 - 2000
Injection Molding Temp.	°F.	425 - 440
Injection Molding Pres.	psi	15000 - 40000
Compression Ratio		2.0 - 2.5
Linear Shrinkage	in/in	0.003 - 0.007
Specific Gravity (Density)		1.49 - 1.58
Specific Volume	in^3/lb	18.4 - 17.8
Machining Qualities		Excellent
MECHANICAL PROPERTIES:		
Tensile Strength	psi	7500 - 9000
Elongation	%	4.5 - 65.0
Tensile Elastic Modulus	10^5 psi	3.60 - 4.75
Compressive Strength	psi	9000 - 22000
Flexural Yield Strength	psi	14500 - 17000
Impact Strength (Notch)	ft-lb/in	1.0 - 5.6
Hardness	Rockwell	R117 - R122
Flexural Elastic Modulus	10^5 psi	3.8 - 4.5
Compressive Modulus	10^5 psi	3.35 - 6.0
THERMAL PROPERTIES:		
Thermal Conductivity	10^{-4} cal/sec/cm^2	3.3
Specific Heat	cal/°C/Gm	0.33
Thermal Expansion	10^{-5} in/in/°C	6.8 - 7.6
Heat Resistance	°F	230
Deflection Temperature @ 264psi	°F	202 - 234
ELECTRICAL PROPERTIES:		
Volume Resistivity (50% RH)	ohm-cm at 23°C	10^{15}
Dielectric Strength	Volts/Mil	1220 - 1500
Dielectric Constant, 60Hz		3.08
Dissipation Factor, 60Hz		0.01887 - 0.02080
Arc Resistance	sec	
OPTICAL PROPERTIES:		
Refractive Index		
Clarity		
Transmittance	%	
Haze	%	
DURABILITY:		
Water Absorption, 1/8" sect	% in 24 hr	0.02 - 0.15
Flammability		
Actinic Resistance		Excellent
Weak Acids		Resistant
Strong Acids		Resistant
Strong Bases		Resistant
Weak Bases		Resistant
Organic Solvents		Soluble in ketones, esters

TRADE NAMES: Geon, Hi-Temp Geon, Khlorin, Lucalor, Solvitherm

Type: Acrylic Name: Methyl Methacrylate

Property	Unit	Range
PROCESSING PROPERTIES:		
Molding Qualities		Excellent
Compression Molding Temp.	°F.	300 - 425
Compression Molding Pres.	psi	2000 -10000
Injection Molding Temp.	°F.	325 - 500
Injection Molding Pres.	psi	10000 - 20000
Compression Ratio		1.6 - 2.0
Linear Shrinkage	in/in	0.002 - 0.008
Specific Gravity (Density)		1.17 - 1.20
Specific Volume	in^3/lb	23.7 - 23.1
Machining Qualities		Good to excellent
MECHANICAL PROPERTIES:		
Tensile Strength	psi	7000 - 11000
Elongation	%	2.0 - 10.0
Tensile Elastic Modulus	10^5 psi	3.8 - 4.5
Compressive Strength	psi	12000 - 18000
Flexural Yield Strength	psi	13000 - 19000
Impact Strength (Notch)	ft-lb/in	0.3 - 0.5
Hardness	Rockwell	M85 - M105
Flexural Elastic Modulus	10^5 psi	4.2 - 4.6
Compressive Modulus	10^5 psi	3.7 - 4.6
THERMAL PROPERTIES:		
Thermal Conductivity	10^{-4} cal/sec/cm^2	4.0 - 6.0
Specific Heat	cal/°C/Gm	0.35
Thermal Expansion	10^{-5} in/in/°C	5.0 - 9.0
Heat Resistance	°F	140 - 200
Deflection Temperature @ 264 psi	°F	175 - 225
ELECTRICAL PROPERTIES:		
Volume Resistivity (50% RH)	ohm-cm at 23°C	$> 10^{14}$
Dielectric Strength	Volts/Mil	400 - 500
Dielectric Constant, 60Hz		3.3 - 3.9
Dissipation Factor, 60Hz		0.04 - 0.06
Arc Resistance	sec	No track
OPTICAL PROPERTIES:		
Refractive Index		1.49
Clarity		Transp - Opaque
Transmittance	%	92
Haze	%	< 3
DURABILITY:		
Water Absorption, 1/8" sect	% in 24 hr	0.1 - 0.4
Flammability		0.6 - 1.2
Actinic Resistance		Excellent
Weak Acids		Resistant
Strong Acids		Attacked by oxidizing acids
Strong Bases		Attacked
Weak Bases		Resistant
Organic Solvents		Soluble in ketones, esters AHC, CHC

TRADE NAMES: AcryGlass, Paraglas, Degalon, Dakril, Vedril

Type: Polyamide Name: Nylon 6/6

Property	Unit	Range
PROCESSING PROPERTIES:		
Molding Qualities		Excellent
Compression Molding Temp.	°F.	
Compression Molding Pres.	psi	
Injection Molding Temp.	°F.	530 - 580
Injection Molding Pres.	psi	
Compression Ratio		
Linear Shrinkage	in/in	0.016
Specific Gravity (Density)		1.13 - 1.15
Specific Volume	in^3/lb	
Machining Qualities		Excellent
MECHANICAL PROPERTIES:		
Tensile Strength	psi	12000
Elongation	%	60
Tensile Elastic Modulus	10^5 psi	4.1
Compressive Strength	psi	
Flexural Yield Strength	psi	13800
Impact Strength (Notch)	ft-lb/in	1.0
Hardness	Rockwell	R118
Flexural Elastic Modulus	10^5 psi	4.1
Compressive Modulus	10^5 psi	4.1
THERMAL PROPERTIES:		
Thermal Conductivity	10^{-4} cal/sec/cm^2	2.9
Specific Heat	cal/°C/Gm	0.3
Thermal Expansion	10^{-5} in/in/°C	5.5
Heat Resistance	°F	250
Deflection Temperature @264 psi	°F	150 - 220
ELECTRICAL PROPERTIES:		
Volume Resistivity (50% RH)	ohm-cm at 23°C	10^{13}
Dielectric Strength	Volts/Mil	
Dielectric Constant, 60Hz		4.0
Dissipation Factor, 60Hz		0.02
Arc Resistance	sec	
OPTICAL PROPERTIES:		
Refractive Index		
Clarity		Opaque
Transmittance	%	
Haze	%	
DURABILITY:		
Water Absorption, 1/8" sect	% in 24 hr	1.10
Flammability		Self-extinguishing
Actinic Resistance		Good - Excellent
Weak Acids		Slightly attacked
Strong Acids		Strongly attacked
Strong Bases		Slightly attacked
Weak Bases		Resistant
Organic Solvents		Resistant

TRADE NAMES: Antron, BASF, Celanese, Plaslube, Xylon, Zytel

Type: [Poly(Oxymethylene)] **Name: Polyacetal Homopolymer**

Property	Unit	Range
PROCESSING PROPERTIES:		
Molding Qualities		
Compression Molding Temp.	°F.	Excellent
Compression Molding Pres.	psi	
Injection Molding Temp.	°F.	380 - 470
Injection Molding Pres.	psi	10000 - 20000
Compression Ratio		
Linear Shrinkage	in/in	0020 - 0.025
Specific Gravity (Density)		1.42
Specific Volume	in^3/lb	19.46
Machining Qualities		Excellent
MECHANICAL PROPERTIES:		
Tensile Strength	psi	10000
Elongation	%	25.0 - 75.0
Tensile Elastic Modulus	10^5 psi	5.2
Compressive Strength	psi	18000 (10%defl)
Flexural Yield Strength	psi	14100
Impact Strength (Notch)	ft-lb/in	1.85
Hardness	Rockwell	M94, R120
Flexural Elastic Modulus	10^5 psi	4.1
Compressive Modulus	10^5 psi	6.7
THERMAL PROPERTIES:		
Thermal Conductivity	10^{-4} cal/sec/cm^2	5.5
Specific Heat	cal/°C/Gm	0.35
Thermal Expansion	10^{-5} in/in/°C	8.1
Heat Resistance	°F	195
Deflection Temperature @264 psi	°F	255
ELECTRICAL PROPERTIES:		
Volume Resistivity (50% RH)	ohm-cm at 23°C	10^{15}
Dielectric Strength	Volts/Mil	380
Dielectric Constant, 60Hz		3.7
Dissipation Factor, 60Hz		0.0048
Arc Resistance (15 mil spec)	sec	129
OPTICAL PROPERTIES:		
Refractive Index		1.48
Clarity		Transl - Opaque
Transmittance	%	
Haze	%	
DURABILITY:		
Water Absorption, 1/8" sect	% in 24 hr	0.25
Flammability		1.0 - 1.1
Actinic Resistance		Slight chalking
Weak Acids		Resists some
Strong Acids		Attacked
Strong Bases		Not recommended
Weak Bases		Resists some
Organic Solvents		Excellent resistance

TRADE NAMES: Delrin, Celcon, Drelux, Plaslube, Ultraform

Type: Thermoplastic Polyester Name: Polyethylene Terephthalate

Property	Unit	Range
PROCESSING PROPERTIES:		
Molding Qualities		Excellent
Compression Molding Temp.	°F.	
Compression Molding Pres.	psi	
Injection Molding Temp.	°F.	437 - 540
Injection Molding Pres.	psi	8000 - 23000
Compression Ratio		
Linear Shrinkage	in/in	0.015 - 0.020
Specific Gravity (Density)		1.31 - 1.38
Specific Volume	in^3/lb	20.2 - 21.1
Machining Qualities		Excellent
MECHANICAL PROPERTIES:		
Tensile Strength	psi	8200
Elongation	%	50 - 300
Tensile Elastic Modulus	10^5 psi	2.8
Compressive Strength	psi	8600 - 14500
Flexural Yield Strength	psi	12000 - 16700
Impact Strength (Notch)	ft-lb/in	0.8 - 1.0
Hardness	Rockwell	M68,78,85,98
Flexural Elastic Modulus	10^5 psi	3.3 - 4.01
Compressive Modulus	10^5 psi	
THERMAL PROPERTIES:		
Thermal Conductivity	10^{-4} cal/sec/cm^2	4.2 - 6.9
Specific Heat	cal/°C/Gm	0.28 - 0.55
Thermal Expansion	10^{-5} in/in/°C	6.0 - 9.5
Heat Resistance	°F	122 - 250
Deflection Temperature @ 263 psi	°F	240 - 374
ELECTRICAL PROPERTIES:		
Volume Resistivity (50% RH)	ohm-cm at 23°C	10^{15} - 2 x 10^{16}
Dielectric Strength	Volts/Mil	420 -556
Dielectric Constant, 60Hz		3.290 - 3.30
Dissipation Factor, 60Hz		0.0014 - 0.005
Arc Resistance	sec	75 - 192
OPTICAL PROPERTIES:		
Refractive Index		
Clarity		Opaque
Transmittance	%	
Haze	%	
DURABILITY:		
Water Absorption, 1/8" sect	% in 24 hr	0.08 - 0.09
Flammability		0.4
Actinic Resistance		Discolors slightly
Weak Acids		Resistant
Strong Acids		Attacked by oxidizing acids
Strong Bases		Attacked
Weak Bases		Resistant
Organic Solvents		Resistant

TRADE NAMES: Celanex, Dacron, Fortrel, Codel, Mylar, Webril

Type: Thermoplastic Name: Polycarbonate

Property	Unit	Range
PROCESSING PROPERTIES:		
Molding Qualities		Good - Excellent
Compression Molding Temp.	°F.	480 - 620
Compression Molding Pres.	psi	1000 - 2000
Injection Molding Temp.	°F.	480 - 650
Injection Molding Pres.	psi	10000 - 20000
Compression Ratio		1.74 - 5.5
Linear Shrinkage	in/in	0.005 - 0.007
Specific Gravity (Density)		1.2
Specific Volume	in^3/lb	23.0
Machining Qualities		Excellent
MECHANICAL PROPERTIES:		
Tensile Strength	psi	8000 - 9500
Elongation	%	100.0 - 130.0
Tensile Elastic Modulus	10^5 psi	3.0 - 3.5
Compressive Strength	psi	12500
Flexural Yield Strength	psi	13500
Impact Strength (Notch)	ft-lb/in	12.0 - 18.0
Hardness	Rockwell	R115 - R125
Flexural Elastic Modulus	10^5 psi	3.2 - 3.5
Compressive Modulus	10^5 psi	3.45
THERMAL PROPERTIES:		
Thermal Conductivity	10^{-4} cal/sec/cm^2	4.6
Specific Heat	cal/°C/Gm	0.28 - 0.30
Thermal Expansion	10^{-5} in/in/°C	6.6
Heat Resistance	°F	250
Deflection Temperature @ 264 psi	°F	265 - 285
ELECTRICAL PROPERTIES:		
Volume Resistivity (50% RH)	ohm-cm at 23°C	2.1×10^{16}
Dielectric Strength	Volts/Mil	380
Dielectric Constant, 60Hz		2.97 - 3.17
Dissipation Factor, 60Hz		0.009
Arc Resistance	sec	10 - 20
OPTICAL PROPERTIES:		
Refractive Index		1.586
Clarity		Transp - opaque
Transmittance	%	85 - 91
Haze	%	0.5 - 2
DURABILITY:		
Water Absorption, 1/8" sect	% in 24 hr	0.15 - 0.18
Flammability		
Actinic Resistance	Slight embrittlement & color change	
Weak Acids		Resistant
Strong Acids		Slowly Attacked
Strong Bases		Attacked
Weak Bases		Limited resistance
Organic Solvents		Soluble in hydrocarbons

TRADE NAMES: Carbaglas, Celanex, Lexan, Mertex, Panlite, Zelux

Type: Phenylene Oxide Resin Name: Polyphenylene Oxide (PPO)

Property	Unit	Range
PROCESSING PROPERTIES:		
Molding Qualities		Excellent
Compression Molding Temp.	°F.	400 - 460
Compression Molding Pres.	psi	500 - 1000
Injection Molding Temp.	°F.	425 - 600
Injection Molding Pres.	psi	14000 - 20000
Compression Ratio		1.3 - 2.2
Linear Shrinkage	in/in	0.005 - 0.007
Specific Gravity (Density)		1.06 - 1.10
Specific Volume	in^3/lb	26.1 - 25.2
Machining Qualities		Excellent
MECHANICAL PROPERTIES:		
Tensile Strength	psi	7800 - 9600
Elongation	%	50.0 - 60.0
Tensile Elastic Modulus	10^5 psi	3.55 - 3.80
Compressive Strength	psi	16000 - 16400
Flexural Yield Strength	psi	12800 -13500
Impact Strength (Notch)	ft-lb/in	5.0
Hardness	Rockwell	R115 - R119
Flexural Elastic Modulus	10^5 psi	3.6 - 4.0
Compressive Modulus	10^5 psi	3.7
THERMAL PROPERTIES:		
Thermal Conductivity	10^{-4} cal/sec/cm^2	5.16
Specific Heat	cal/°C/Gm	0.32
Thermal Expansion	10^{-5} in/in/°C	5.2
Heat Resistance	°F	175 - 220
Deflection Temperature @ 264 psi	°F	212 - 265
ELECTRICAL PROPERTIES:		
Volume Resistivity (50% RH)	ohm-cm at 23°C	$> 10^{17}$
Dielectric Strength	Volts/Mil	400 - 550
Dielectric Constant, 60Hz		2.64
Dissipation Factor, 60Hz		0.004
Arc Resistance	sec	75
OPTICAL PROPERTIES:		
Refractive Index		
Clarity		Opaque
Transmittance	%	
Haze	%	
DURABILITY:		
Water Absorption, 1/8" sect	% in 24 hr	0.066
Flammability		< 0.16
Actinic Resistance		Colors fade
Weak Acids		Resistant
Strong Acids		Resistant
Strong Bases		Resistant
Weak Bases		Resistant
Organic Solvents	Soluble in aromatics and aliphatics	

TRADE NAMES: Alphalux, Doryl, Fiberlene, Noryl, PPO, Ztron

Type: Phenylene Sulfide Name: Polyphenylene Sulfide

Property	Unit	Range
PROCESSING PROPERTIES:		
Molding Qualities		Excellent
Compression Molding Temp.	°F.	650
Compression Molding Pres.	psi	
Injection Molding Temp.	°F.	600
Injection Molding Pres.	psi	
Compression Ratio		
Linear Shrinkage	in/in	0.002 - 0.10
Specific Gravity (Density)		1.34 - 1.80
Specific Volume		
Machining Qualities		Good
MECHANICAL PROPERTIES:		
Tensile Strength	psi	10800 - 14000
Elongation	%	0.7 - 3.0
Tensile Elastic Modulus	10^5 psi	4.8
Compressive Strength	psi	16000
Flexural Yield Strength	psi	20000
Impact Strength (Notch)	ft-lb/in	0.3 - 1.0
Hardness	Rockwell	R121 - R124
Flexural Elastic Modulus	10^5 psi	6.0 - 18.07
Compressive Modulus	10^5 psi	
THERMAL PROPERTIES:		
Thermal Conductivity	10^{-4} cal/sec/cm^2	6.84
Specific Heat	cal/°C/Gm	
Thermal Expansion	10^{-5} in/in/°F	2.8 - 3.0
Heat Resistance	°F	500
Deflection Temperature @ 264 psi	°F	278 - > 500
ELECTRICAL PROPERTIES:		
Volume Resistivity (50% RH)	ohm-cm at 23°C	$1.5 - 3.0 \times 10^{16}$
Dielectric Strength	Volts/Mil	
Dielectric Constant, 60Hz		3.11
Dissipation Factor, 60Hz		0.0004
Arc Resistance	sec	185
OPTICAL PROPERTIES:		
Refractive Index		
Clarity		Opaque
Transmittance	%	
Haze	%	
DURABILITY:		
Water Absorption, 1/8" sect	% in 24 hr	0.020 - 0.030
Flammability		Non-burning
Actinic Resistance		Excellent
Weak Acids		Resistant
Strong Acids		Resistant
Strong Bases		Resistant
Weak Bases		Resistant
Organic Solvents		Resistant

TRADE NAMES: Ryton

Type: Polysulfone **Name:** Standard Polysulfone

Property	Unit	Range
PROCESSING PROPERTIES:		
Molding Qualities		Excellent
Compression Molding Temp.	°F.	550 - 600
Compression Molding Pres.	psi	1000
Injection Molding Temp.	°F.	650 - 750
Injection Molding Pres.	psi	15000 - 20000
Compression Ratio		1.8 - 2.2
Linear Shrinkage	in/in	0.007
Specific Gravity (Density)		1.24
Specific Volume		22.3
Machining Qualities		Excellent
MECHANICAL PROPERTIES:		
Tensile Strength	psi	10200
Elongation	%	50 - 100 at break
Tensile Elastic Modulus	10^5 psi	3.6
Compressive Strength	psi	13900 at yield
Flexural Yield Strength	psi	15400 at yield
Impact Strength (Notch)	ft-lb/in	1.3
Hardness	Rockwell	M69, R120
Flexural Elastic Modulus	10^5 psi	3.9
Compressive Modulus	10^5 psi	3.7
THERMAL PROPERTIES:		
Thermal Conductivity	10^{-4} cal/sec/cm^2	2.8
Specific Heat	cal/°C/Gm	0.31
Thermal Expansion	10^{-5} in/in/°C	5.2 - 5.6
Heat Resistance	°F	300 - 345
Deflection Temperature @ 264 psi	°F	345
ELECTRICAL PROPERTIES:		
Volume Resistivity (50% RH)	ohm-cm at 23°C	5.0×10^{16}
Dielectric Strength	Volts/Mil	425
Dielectric Constant, 60Hz		3.07 - 3.14
Dissipation Factor, 60Hz		0.0008
Arc Resistance	sec	75 - 122
OPTICAL PROPERTIES:		
Refractive Index		1.633
Clarity		Transp - opaque
Transmittance	%	
Haze	%	
DURABILITY:		
Water Absorption, 1/8" sect	% in 24 hr	0.22
Flammability		
Actinic Resistance		Strength loss, yellowing
Weak Acids		Resistant
Strong Acids		Resistant
Strong Bases		Resistant
Weak Bases		Resistant
Organic Solvents		Soluble in aromatic hydrocarbons

TRADE NAMES: Arylon T, Thermalux, Ucardel, Udel

Type: Polyether Copolymer Name: Polyarylether

Property	Unit	Range
PROCESSING PROPERTIES:		
Molding Qualities		Excellent
Compression Molding Temp.	°F.	
Compression Molding Pres.	psi	
Injection Molding Temp.	°F.	540 - 590
Injection Molding Pres.	psi	10000 - 20000
Compression Ratio		2.6 - 1.8
Linear Shrinkage	in/in	0.007
Specific Gravity (Density)		1.14
Specific Volume		25.2
Machining Qualities		Excellent
MECHANICAL PROPERTIES:		
Tensile Strength	psi	7500
Elongation	%	25.0 - 90.0
Tensile Elastic Modulus	10^5 psi	3.2
Compressive Strength	psi	
Flexural Yield Strength	psi	11000
Impact Strength (Notch)	ft-lb/in	8.0
Hardness	Rockwell	R117
Flexural Elastic Modulus	10^5 psi	3.0
Compressive Modulus	10^5 psi	
THERMAL PROPERTIES:		
Thermal Conductivity	10^{-4} cal/sec/cm^2	7.13
Specific Heat	cal/°C/Gm	0.35
Thermal Expansion	10^{-5} in/in/°C	3.6
Heat Resistance	°F	250
Deflection Temperature @ 264 psi	°F	300
ELECTRICAL PROPERTIES:		
Volume Resistivity (50% RH)	ohm-cm at 23°C	1.5×10^{16}
Dielectric Strength	Volts/Mil	430
Dielectric Constant, 60Hz		3.14
Dissipation Factor, 60Hz		0.006
Arc Resistance	sec	180+
OPTICAL PROPERTIES:		
Refractive Index		
Clarity		Transl - opaque
Transmittance	%	
Haze	%	
DURABILITY:		
Water Absorption, 1/8" sect	% in 24 hr	0.25
Flammability		
Actinic Resistance	Slight embrittlement, yellowing	
Weak Acids		Resistant
Strong Acids		Resistant
Strong Bases		Resistant
Weak Bases		Resistant
Organic Solvents	Soluble in aromatics, esters, ketones	

TRADE NAMES: Arylon

Type: Fluoroplastic Homopolymer Name: Polytetrafluoroethylene

Property	Unit	Range
PROCESSING PROPERTIES:		
Molding Qualities		Good
Compression Molding Temp.	°F.	
Compression Molding Pres.	psi	
Injection Molding Temp.	°F.	
Injection Molding Pres.	psi	
Compression Ratio		
Linear Shrinkage	in/in	
Specific Gravity (Density)		2.1 - 2.2
Specific Volume	in^3/lb	
Machining Qualities		Poor
MECHANICAL PROPERTIES:		
Tensile Strength	psi	2800 -3000
Elongation	%	250 - 400
Tensile Elastic Modulus	10^5 psi	0.4 - 0.9
Compressive Strength	psi	0.7 - 1.8
Flexural Yield Strength	psi	
Impact Strength (Notch)	ft-lb/in	2.5 - 4.0
Hardness	Durometer	D50 - D65
Flexural Elastic Modulus	10^5 psi	0.9
Compressive Modulus	10^5 psi	0.7 - 0.9
THERMAL PROPERTIES:		
Thermal Conductivity	10^{-4} cal/sec/cm^2	
Specific Heat	cal/°C/Gm	
Thermal Expansion	10^{-5} in/in/°C	5 - 10
Heat Resistance	°F	550 max. No Load
Deflection Temperature	°F	130 @ 264 psi
ELECTRICAL PROPERTIES:		
Volume Resistivity (50% RH)	ohm-cm at 23°C	$> 10^{18}$
Dielectric Strength	Volts/Mil	500 -550
Dielectric Constant, 60Hz		2.1
Dissipation Factor, 60Hz		0.0002
Arc Resistance	sec	360
OPTICAL PROPERTIES:		
Refractive Index		
Clarity		
Transmittance	%	
Haze	%	
DURABILITY:		
Water Absorption, 1/8" sect	% in 24 hr	
Flammability		> 95
Actinic Resistance		Excellent
Weak Acids		Resistant
Strong Acids		Resistant
Strong Bases		Resistant
Weak Bases		Resistant
Organic Solvents		Resistant

TRADE NAMES: Chemlon, Fluorolene, Polyflon, Teflon, Tefzel,

INDUSTRIAL PLASTICS

Section H

Classification of Thermosets

INTRODUCTION

The number of monomeric and polymeric resins on the market is staggering. Each can be classified in a number of ways to suit the the needs of the user. Moreover, there are at least a dozen "standard" industrial classification systems in use. Most of these are based on chemical criteria, and are of no use to the technical student.

For our purposes, it is best to group the plastics into major categories **based on the structure of the monomer unit.** Each of these categories is then further subdivided to accommodate members with special characteristics.

Usually, the so-called **"engineering plastics"** are treated as a separate category. However, for continuity of presentation, these are not treated separately, but are included in their respective category. For the convenience of the user, the engineering plastics are denoted by a (*) in the outline that follows.

The classification scheme developed for use in this guide is my own composite of several other systems. I relied heavily upon the **Materials Handbook**, by Brady and Clauser, the **Plastics Engineering Handbook** edited by Pardos, and **Industrial and Engineering Materials** by Clauser. However, any errors are mine.

Those plastics which have an entry in the Table of Properties in the following sections are marked by a (#).

THERMOSETS CLASSIFICATION

A. ALDEHYDE BASED RESINS
   1. PHENOLICS (#)
   2. AMINO RESINS
      a. Urea-Formaldehydes
      b. Melamine-Formaldehydes (#)
   3. FURAN RESINS

B. THERMOSETTING POLYESTERS
   1. ALKYDS (*)
   2. VINYL ESTERS
   3. ALLYL RESINS

C. EPOXIDES
   1. EPOXY RESINS (*)
      a. Phenol-Novolac Resin
      b. Cycloaliphatic Resin
      c. Ortho-Cresol Resin
      d. Molding and Casting Grades (#)

D. POLYURETHANES (#)

E. SILICONES (#) (*)

INDUSTRIAL PLASTICS

Section 1

THERMOSETS

Description and Applications

INTRODUCTION

This section provides a general description of the important characteristics and typical industrial applications of representative members of the major groups of thermosetting plastics, including the so-called "engineering plastics."

As a group, the thermosets have the following general characteristics: they are seldom used as pure polymers, and all require some type of filler to be useful as moldings; they are hard and brittle; they exhibit good thermal stability; processing is somewhat more difficult as compared to the thermoplastics, with longer molding cycles being the norm; thermal, mechanical and electrical properties are strongly influenced by type of filler; and once polymerized by heat and pressure, they are **infusible** (will not soften or flow on reheating) and chemically **insoluble** (will not soften or decompose in a solvent).

The term **resin system** as applied to thermosets means the polymer proper, curing agents, hardeners, inhibitors and plasticizers. Added to these is some type of filler or reinforcement to impart the desired characteristics.

The processing of a thermosetting resin system has several phases:

Mixing - polymer and filler in the appropriate concentrations are blended to obtain a uniform distribution of the filler throughout the matrix.

Preforming - the mixture is compressed at room temperature into a shape which will fit into the mold.

Preheating - the preformed shape is heated to shorten molding time and promote flowability.

Molding - heat and pressure are applied to the mold to polymerize the mixture into final shape. In this context, the polymerization process is termed **curing**.

PHENOL-FORMALDEHYDE RESINS

PHENOLICS

These polymers are the oldest and least expensive of the thermosetting plastics. Six standard grades have been developed, with their properties and end applications determined by the type of filler added. These grades are:

General Purpose - wood flour or flock filler

Impact Grade - paper, fabric or glass fiber filler

Electrical Grade - mineral fillers

Heat Resistant Grade - mineral or glass filler

Special Purpose Grades - filler is application dependent

Nonbleed Grade - for contact with food, cosmetics or drugs

It is difficult to characterize the phenolics as a group since their properties are filler dependent. However, we can generalize and say that phenolics are relatively dense and have a high stiffness-to-weight ratio.

Strength is moderately good relative to other plastics and they are creep resistant. Toughness and impact resistance are not exceptional unless the resin is filled. Addition of fillers results in decreased flowability and moldability.

Mold shrinkage and dimensional stability are very good. Organic fillers provide the least dimensional stability, while glass-fiber fillers provide the most stability.

Electrical and thermal properties are generally very good depending upon the filler used. These properties are retained at elevated temperatures and in high moisture environments.

Exposure to ultraviolet radiation causes darkening, loss of gloss in moldings, crazing, stress cracking and loss of mechanical and electrical properties. Phenolics are attacked by strong oxidizing acids and alkalis, but are resistant to the action of organic solvents.

Most phenolic parts are produced by injection, compression and transfer molding. They can also be extruded, however, cycle times are high due to the curing required.

Applications are numerous in the automotive, aerospace, appliance and electrical/electronic industries. Typical applications are:

Molded Parts - rotors, fuse blocks, coil towers, ash trays, instrument clusters, distributor caps, handles, knobs, motor housings, appliance handles, lamp and tube housings and sockets, electrical cookware, circuit breakers, relay housings, receptacles, terminal blocks, various housings and enclosures, and brake and transmission parts.

Industrial Laminates - propellers, pulleys and gears, aviation antenna masts, telephone switchgear and electrical power transmission equipment.

Decorative Laminates - wall tiles, automobile interior panels, table and desk tops, and facings for wood by-products.

Adhesives - bonding of asbestos fibers in friction materials such as brake linings, clutch pressure plate facings, and automatic transmission disks; bonding of abrasive particles to wheels, abrasive cloth belts and abrasive papers; as an adhesive matrix to bond wood dust, particles and shavings into particle board and exterior (moisture resistant) grades of plywood.

Metal casting - for making molds from metal patterns using refractory sand fused with a phenolic resin.

Coatings - as dip coatings for electrical and electronic components, and as an **ablative** coating on rocket and spacecraft reentry shields. An **ablative coating** is one which is burned away due to the friction generated by the passage of a spacecraft through the atmosphere.

AMINO RESINS

MELAMINE-FORMALDEHYDE AND UREA MOLDING COMPOUNDS

This family consists of two groups, the melamines and the ureas. As a family, the aminos are the hardest of all the plastics. Their impact strength is notably poor. They have good molding qualities and are low in cost. Aminos are processed almost exclusively by compression molding.

They are rigid, abrasion resistant and do not become brittle, even at temperatures approaching -70° F. Their dimensional stability is only fair, and post-molding shrinkage can be as much as 2 percent over time.

Their thermal qualities are only fair, and the maximum service temperature is 210° F. They are flame resistant.

Their electrical insulating properties are excellent, with high resistance to arcing and no carbon tracking.

Their colorability is unlimited, however, colors fade with prolonged exposure to ultraviolet light. They are resistant to most inorganic chemicals except strong acids and bases. Resistance to organic solvents is notably excellent. For industrial and engineering uses, they are filled with asbestos or glass fiber.

Major commercial uses are molded institutional tableware, decorative and durable laminated covering for wood by-product composites and as a water and crease resistant coating for textiles.

Industrial uses are primarily in the automotive, aerospace, electrical/electronic and appliance areas. Typical products are molded knobs and handles, instrument, machine and appliance housings, ignition parts, circuit breakers, fuse blocks, terminal strips connectors and switch gear. Dip coatings and brush-on or spray-on varnishes are used extensively in the manufacture, service and repair of electrical/electronic components and systems.

EPOXIDES

MOLDING AND CASTING EPOXY RESINS

These are very high cost engineering grade thermosets which are employed in high-performance applications where their cost can be justified. Most engineering applications required the use of a filler in one form or another.

In the uncured form the resins are thermoplastic, and in the cured form they are thermosetting. Curing is the process of transforming the thermoplastic resin into a thermoset, and is accomplished by a catalyst or with hardners or activators (chemicals which contain active hydrogens).

This ability to be transformed from thermoplastic to thermoset is the single most valuable property of the epoxies. Heat is necessary to accomplish the cure and may be generated by either an exothermic reaction (the heat is generated by the chemical reaction itself) or an endothermic reaction (the heat is applied externally). The temperature range for curing is from 40° F. to 300° F., depending upon the curing agent used.

When curing, the epoxides evolve no volatile (easily evaporated) by-products, and very little water. In addition, hence they cure with only slight molecular reorientation. These factors contribute to their remarkably low shrinkage during cure. Low shrinkage tends to minimize stresses that would otherwise weaken the mechanical structure of the set resin.

Epoxides are readily injection, transfer or compression molded. Due to being thermoplastic in the pre-mold state, melt viscosity is low and flowability is excellent, allowing the molding of intricate parts of varying section thickness. Mold shrinkage is quite low, and the cured parts will machine satisfactorily.

In the unfilled state, their mechanical properties are fair to good. However, when filled with filament wound glass fiber, they can achieve strengths in excess of 250,00 psi, the highest of all plastics. Similarly, impact strength is low when the resin is unfilled, but improves dramatically with the addition of reinforcing filler.

Thermal properties are excellent with a maximum service temperature of 525° F. Epoxies are outstanding electrical insulators, especially when mineral filled. Volume resistivity and dielectric strength are high, and the dissipation factor low. Continuous arc resistance is also very good, being in excess of 150 seconds, with only slight tracking.

The epoxies exhibit varying degrees of chemical resistance depending upon the curing agent used. In general, resistance ranges from resins that are attacked only by strong acids to those which are resistant to all inorganic chemicals and organic solvents. In all cases, a slight darkening is the only effect of ultraviolet radiation.

Of all the plastics, the epoxies have the broadest range of commercial and industrial applications.

In the aerospace industries, epoxies are used as adhesives for aircraft structural honeycombing, laminating resins for airframe members in missiles, planes and spacecraft, and as whole parts such as wing tips, leading edges, nose radomes and fairings.

In manufacturing, epoxies are used for fixtures, as a casting compound for the fabrication of molds, stamping dies, and patterns, and as tooling for mold and die work.

In the electrical and electronic industries, they are used for potting, impregnating and encapsulating components, and for the molding of various parts.

Epoxy coatings are used in exterior steel construction, marine finishes, as cement, asphalt,tank and container coatings, aircraft finishes, appliance and automotive primers, and as a chemically resistant pipe lining in the processing industries.

Cost aside, the single disadvantage of the epoxies is their potential for skin irritation. However, serious cases of chemical contact dermatitis have seldom developed where good industrial housekeeping and safety are standard practices.

POLYURETHANES

The polyurethanes are a broad group of polymers and copolymers whose properties are determined by their specific end use. Included are flexible foams, rigid foams, fibers, and elastomers. Each of these is discussed below.

FLEXIBLE FOAMS

These are urethane foams having a high (15 - 70:1) tensile-to-compressive strength ratio, high elongation, fast stress **recovery rate** (ability to assume original shape and dimensions after removal of compressive stress) and a high elastic limit.

The density and crystallinity of a foam is dependent upon the degree of cross-linking present in the polymer, hence stiffness is also cross-linking dependent. In terms of structure, the presence of water or **auxiliary blowing agents** cause the polymer to expand into a **cellular foam**. All cellular foams tend to exhibit **compression fatigue**; that is to loose height and load bearing capacity with continued use.

The flexible foams tend to stiffen at low temperatures, are quite solvent resistant, have low burning rates, are durable and resistant to fungus growth, are light in weight and are easily fabricated.

The most common fabrication method is **integral skin molding.** In this method, a single foaming composition is charged into a heated mold and immediately evolves a tough outer skin, while the remainder of the charge is expanded into a supporting cellular structure.

Flexible urethane foam is used as cushioning in cars, boats, furniture, rail cars, and aircraft.

RIGID FOAMS

Rigid foams have a low tensile-to-compressive strength ratio (1:0.5), very low elongation (less than 10 percent), low elastic limit and a greatly reduced stress recovery rate.

Their noteworthy properties include excellent thermal insulating properties, high strength-to-weight ratio, good heat resistance and excellent energy absorbing properties.

Typical applications are as refrigeration insulation, pipe and tank insulation, pour in place wall insulation, slab insulation for roofing, aircraft fuselage insulation, spacecraft compartment insulation, ship and boat insulation and buoyancy enhancement, packing of delicate and/or precision products and parts, general void filling applications and as sound and vibration dampening agents.

ELASTOMERS

Urethane **elastomers** (compounds having rubber-like qualities) are prepared by three methods.

Casting - The reactants are mixed in the liquid state, poured into a mold and cured into a rubbery solid. Additional curing time is needed after demolding.

Millable Gum - A soluble polymer is mixed with an activator, placed into the mold and cured by a combination of heat and chemical action.

Thermoplastic - A soluble polymer is injected into the mold and cured by external heat.

The urethane rubbers can be formulated and processed to have a wide range of properties. As a group, they possess excellent tensile, compressive and impact strength, and have a high load bearing capacity. Their resistance to fatigue in flexion is poor in large masses due to the heat generated by mechanical hysteresis.

Resilience is excellent. Elongation is usually high, although it is reduced as hardness is increased. They also have high tear strength, abrasion resistance and coefficients of friction. Additives can be used to make them essentially self-lubricating.

Electrical properties are excellent, being comparable to the phenolics. The harder grades usually have better electrical properties than the softer grades. They are resistant to ozone, oxidizing agents and hydrocarbons. They decompose hydrolytically with exposure to water, steam, acids and alkalis.

Urethane elastomers are used extensively in friction drives, as small wheels and tires, drive belts and as shock absorbing or vibration dampening pads. They can be injection molded into gears, bushings, shock mounts and "O" rings. They are frequently used as potting compounds or as cast encapsulements for electrical and electronic components. They are extruded to form wire and cable insulation and tubing.

Other uses include solid propellant binder, caulking and sealing compounds.

URETHANE COATINGS

Coatings of urethane are flexible, tough, and very abrasion resistant. They possess excellent chemical resistance and electrical properties. They tend to yellow upon prolonged exposure to ultraviolet radiation.

They are typically used as a clear varnish or in a pigmented varnish base. They can be formulated for dipping, brushing or spraying.

URETHANE FIBERS

The single fiber in this category is Spandex, which is used extensively in the medical, sports-medical and athletic equipment industries.

They exhibit high tensile strength, extensive elongation and very good resilience. Stress decay (excessive flow of the polymer fiber under tension) is greatly reduced by the primary cross-bonding occurring between adjacent polymer chains.

SILICONES

CAST FLEXIBLE SILICONE RESINS

The silicones are a family of engineering polymers and copolymers whose long chain backbone is based upon silicon and oxygen atoms, rather than carbon atoms.

They cure without the need of heat, and several one and two component RTV (room temperature vulcanizing) systems are available. Acetic acid or methyl alcohol is evolved during curing.

These polymers are extremely expensive, and unless filled, they have poor physical and mechanical properties (filled tensile strength never exceeds 2000 psi). They tend to decompose when exposed to specific combinations of relative humidity and elevated temperature.

Their primary usefulness is a consequence of the following properties:

Thermal - extremely stable and heat resistant at temperatures above 1200° F.

Surface - silicone films on surfaces provide water repellency and protection from chemical activity.

Inertness - except for strong acids and alkalis, they are resistant to all inorganic chemicals and organic solvents.

Electrical - the silicones exhibit high volume resistivity, high dielectric constant, low dissipation factor and excellent are resistance.

The range of uses for this family is extensive, and is best seen in outline form (after Schwartz and Goodman, 1982). Note that the final application or end-use depends upon the form in which the basic material is first supplied.

I. ORGANOCHLOROSILANES

A. LIQUIDS

1. EMULSIONS
   a. Mold Release Agents
   b. Defoamers
   c. Waterproofing Materials
2. GREASES
   a. Extreme Temperature Lubricants
   b. Dielectric Greases
3. OILS
   a. Damping Fluids
   b. Defoamers
   c. Polishes
   d. Cosmetic Additives
   e. Waterproofing Materials
   f. Extreme Temperature Lubricants

B. RESINS

1. VARNISHES
   a. Impregnating Varnish
   b. Mica Bonding Varnish
   c. Glass Cloth Coatings
   d. Wire Coating
   e. Laminates
   f. Adhesive Coatings
   g. Paints
2. ADHESIVES
   a. Fabricating Aids
3. MOLDING POWDERS
   a. Electrical Components
   b. Mechanical Parts

C. ELASTOMERS

1. MOLDING COMPOUNDS
   a. Mechanical Goods
2. EXTRUDING COMPOUNDS
   a. Tubing
   b. Gaskets
   c. Wire and Cable Insulation
3. COATINGS
   a. Electrical Tapes
   b. Aircraft Heater Ducts
   c. Seals
4. GUM
   a. For Combining With Other Polymers

Representative uses include: silicone rubber glazing and caulking compounds, joint sealants, foundation waterproofing compounds, auto ignition system wiring and spark plug boots; extruded and molded seals and gaskets, elastomers for space suits, aircraft and spacecraft cabin seals, oxygen hoses and masks, compositions for ablation seals, matrices for solid fuels and fuel binders, weatherproof coatings for electrical and electronic components and connections, encapsulating material for semi-conductors and IC's, synthetic human parts, binders for high temperature paints, mechanical parts, "O" rings, and many other uses.

INDUSTRIAL PLASTICS

Section J

THERMOSETS

Property Data Tables

INTRODUCTION

The tables in this section follow the general pattern of those found in Plastic Materials and Processes, by Seymour S. Schwartz and Sidney H. Goodman, copyright 1982, by the Van Nostrand Reinhold Company, New York, New York.

Due to the space limitations in this paper, some of the more esoteric entries in the tables were eliminated, and others were abbreviated.

For continuity of presentation and to facilitate preparation using a PC word processor, the format of the tables has been altered.

Most notably, units have been placed in a separate column, major property headings are horizontal rather than vertical, ASTM test methods have been placed in a separate section, and common commercial names have been added to the tables.

For more detailed tabular, descriptive and chemical data, the student is urged to consult Plastics Materials and Processes.

Type: Phenol-Formaldehyde Resin Name: General Purpose Phenolic

Property	Unit	Range
PROCESSING PROPERTIES:		
Molding Qualities		Excellent
Compression Molding Temp.	°F.	
Compression Molding Pres.	psi	
Injection Molding Temp.	°F.	340 - 390
Injection Molding Pres.	psi	
Compression Ratio		
Linear Shrinkage	in/in	0.005 - 0.012
Specific Gravity (Density)		1.37 - 1.42
Specific Volume		
Machining Qualities		Good
MECHANICAL PROPERTIES:		
Tensile Strength	psi	6000 - 7400
Elongation	%	
Tensile Elastic Modulus	10^5 psi	
Compressive Strength	psi	27000 - 33400
Flexural Yield Strength	psi	9000 - 14000
Impact Strength (notch)	ft-lb/in	0.29 - 0.30
Hardness	Rockwell	M110
Flexural Elastic Modulus	10^5 psi	10.0
Compressive Modulus	10^5 psi	
THERMAL PROPERTIES:		
Thermal Conductivity	10^{-4} cal/sec/cm^2	
Specific Heat	cal/°C/Gm	
Thermal Expansion	10^{-5} in/in/°C	1.5 - 1.6
Heat Resistance	°F	300 - 375
Deflection Temperature	°F	330 - 375
ELECTRICAL PROPERTIES:		
Volume Resistivity (50% RH)	ohm-cm at 23°C	10^{11}
Dielectric Strength	Volts/Mil	234 - 340
Dielectric Constant, 60Hz		7.8 - 18.8
Dissipation Factor, 60Hz		0.13 - 0.81
Arc Resistance	sec	35
OPTICAL PROPERTIES:		
Refractive Index		
Clarity		Opaque
Transmittance	%	
Haze	%	
DURABILITY:		
Water Absorption, 1/8" sect	% in 24 hr	0.28 - 0.50
Flammability		Flammable
Actinic Resistance		Exposure to UV causes property loss
Weak Acids		Resistant
Strong Acids		Attacked by oxidizing acids
Strong Bases		Attacked
Weak Bases		Resistant
Organic Solvents		Resistant

TRADE NAMES: Bakelite, Catalac, Durez, Micarta, Pyroloy, Unirez

Type: Amino Resin **Name:** Melamine-Formaldehyde Molding Cpd.

Property	Unit	Range
PROCESSING PROPERTIES:		
Molding Qualities		Good
Compression Molding Temp.	°F.	300 - 330
Compression Molding Pres.	psi	2000 - 5000
Injection Molding Temp.	°F.	
Injection Molding Pres.	psi	
Compression Ratio		2.0
Linear Shrinkage	in/in	0.011 - 0.012
Specific Gravity (Density)		1.48
Specific Volume		18.7
Machining Qualities		
MECHANICAL PROPERTIES:		
Tensile Strength	psi	
Elongation	%	
Tensile Elastic Modulus	10^5 psi	
Compressive Strength	psi	40000 - 45000
Flexural Yield Strength	psi	11000 - 14000
Impact Strength (notch)	ft-lb/in	0.3
Hardness	Rockwell	M120
Flexural Elastic Modulus	10^5 psi	15
Compressive Modulus	10^5 psi	
THERMAL PROPERTIES:		
Thermal Conductivity	10^{-4} cal/sec/cm^2	
Specific Heat	cal/°C/Gm	
Thermal Expansion	10^{-5} in/in/°C	
Heat Resistance	°F	210
Deflection Temperature @ 264 psi	°F	298
ELECTRICAL PROPERTIES:		
Volume Resistivity (50% RH)	ohm-cm at 23°C	10^{13}
Dielectric Strength	Volts/Mil	320
Dielectric Constant, 60Hz		5.7
Dissipation Factor, 60Hz		0.03
Arc Resistance	sec	120
OPTICAL PROPERTIES:		
Refractive Index		
Clarity		Opaque
Transmittance	%	
Haze	%	
DURABILITY:		
Water Absorption, 1/8" sect	% in 24 hr	0.3 - 0.5
Flammability		Self-extinguishing
Actinic Resistance		Color fades
Weak Acids		Resistant
Strong Acids		Decomposition
Strong Bases		Attacked
Weak Bases		Resistant
Organic Solvents		Resistant

TRADE NAMES: Aminolac, Cymel, Decola, Formica, Melamine, Stello

Type: Molding Compound Name: Low Density Epoxy

Property	Unit	Range
PROCESSING PROPERTIES:		
Molding Qualities		Good
Compression Molding Temp.	°F.	250 - 320
Compression Molding Pres.	psi	100 - 2000
Injection Molding Temp.	°F.	250 - 300
Injection Molding Pres.	psi	100 - 1500
Compression Ratio		3.0 - 7.0
Linear Shrinkage	in/in	0.006 - 0.010
Specific Gravity (Density)		0.75 - 1.00
Specific Volume		
Machining Qualities		Good
MECHANICAL PROPERTIES:		
Tensile Strength	psi	2500 - 4000
Elongation	%	
Tensile Elastic Modulus	10^5 psi	
Compressive Strength	psi	10000 - 15000
Flexural Yield Strength	psi	5000 - 7000
Impact Strength (notch)	ft-lb/in	0.15 - 0.25
Hardness		
Flexural Elastic Modulus	10^5 psi	5.0 - 7.5
Compressive Modulus	10^5 psi	4.0 - 6.0
THERMAL PROPERTIES:		
Thermal Conductivity	10^{-4} cal/sec/cm^2	4.0 - 6.0
Specific Heat	cal/°C/Gm	
Thermal Expansion	10^{-5} in/in/°C	
Heat Resistance	°F	
Deflection Temperature @ 264 psi	°F	200 - 250
ELECTRICAL PROPERTIES:		
Volume Resistivity (50% RH)	ohm-cm at 23°C	10^{13} - 10^{14}
Dielectric Strength	Volts/Mil	380 - 420
Dielectric Constant, 60Hz		2.0 - 3.0
Dissipation Factor, 60Hz		0.005 - 0.012
Arc Resistance	sec	120 - 150
OPTICAL PROPERTIES:		
Refractive Index		
Clarity		Opaque
Transmittance	%	
Haze	%	
DURABILITY:		
Water Absorption, 1/8" sect	% in 24 hr	0.2 - 1.0
Flammability		
Actinic Resistance		Excellent
Weak Acids		Slight attack
Strong Acids		Slight attack
Strong Bases		Attacked
Weak Bases		Slight attack
Organic Solvents		Slight attack

TRADE NAMES: CopyCast, Hyflo, Polychem, Plenco, Randac, Polyset

Type: Polyurethane Name: Cast Urethane Liquid & Unsaturated

Property	Unit	Range
PROCESSING PROPERTIES:		
Molding Qualities		Good to excellent
Compression Molding Temp.	°F.	185 - 250
Compression Molding Pres.	psi	100 - 5000
Injection Molding Temp.	°F.	
Injection Molding Pres.	psi	
Compression Ratio		
Linear Shrinkage	in/in	0.0 - 0.020
Specific Gravity (Density)		1.10 - 1.50
Specific Volume		27.0 - 22.0
Machining Qualities		Fair to excellent
MECHANICAL PROPERTIES:		
Tensile Strength	psi	175 - 10000
Elongation	%	100 - 1000
Tensile Elastic Modulus	10^5 psi	1.0 - 10.0
Compressive Strength	psi	20000
Flexural Yield Strength	psi	700 - 4500
Impact Strength (notch)	ft-lb/in	25.0 - flexible
Hardness	Shore	10A - 90D
Flexural Elastic Modulus	10^5 psi	0.10 - 1.0
Compressive Modulus	10^5 psi	0.10 - 1.0
THERMAL PROPERTIES:		
Thermal Conductivity	10^{-4} cal/sec/cm^2	5.0
Specific Heat	cal/°C/Gm	0.42 - 0.44
Thermal Expansion	10^{-5} in/in/°C	10.0 - 20.0
Heat Resistance	°F	190 - 225
Deflection Temperature	°F	Varies widely
ELECTRICAL PROPERTIES:		
Volume Resistivity (50% RH)	ohm-cm at 23°C	2 x 10^{11} - 10_{15}
Dielectric Strength	Volts/Mil	300 - 500
Dielectric Constant, 60Hz		4.0 - 7.5
Dissipation Factor, 60Hz		0.015 - 0.017
Arc Resistance	sec	0.1 - 0.6
OPTICAL PROPERTIES:		
Refractive Index		1.50 - 1.60
Clarity		Clear to opaque
Transmittance	%	
Haze	%	
DURABILITY:		
Water Absorption, 1/8" sect	% in 24 hr	0.02 - 1.50
Flammability		
Actinic Resistance		Slight yellowing
Weak Acids		Slight attack
Strong Acids		Moderate attack
Strong Bases		Slight attack
Weak Bases		Slight attack
Organic Solvents		None - Moderate attack

TRADE NAMES: Casthane, Daltoflex, Extone, Polytool, Royalar

Type: Cast Resin Name: Flexible Silicone

Property	Unit	Range
PROCESSING PROPERTIES:		
Molding Qualities		Excellent
Compression Molding Temp.	°F.	
Compression Molding Pres.	psi	
Injection Molding Temp.	°F.	
Injection Molding Pres.	psi	
Compression Ratio		
Linear Shrinkage	in/in	0 - 0.006
Specific Gravity (Density)		0.99 - 1.50
Specific Volume		
Machining Qualities		
MECHANICAL PROPERTIES:		
Tensile Strength	psi	350 - 1000
Elongation	%	100 - 10000
Tensile Elastic Modulus	10^5 psi	900.0
Compressive Strength	psi	100
Flexural Yield Strength	psi	
Impact Strength (notch)	ft-lb/in	
Hardness	Shore	A15 - A65
Flexural Elastic Modulus	10^5 psi	
Compressive Modulus	10^5 psi	
THERMAL PROPERTIES:		
Thermal Conductivity	10^{-4} cal/sec/cm^2	3.5 - 7.5
Specific Heat	cal/°C/Gm	
Thermal Expansion	10^{-5} in/in/°C	8.0 - 30.0
Heat Resistance	°F	500
Deflection Temperature	°F	
ELECTRICAL PROPERTIES:		
Volume Resistivity (50% RH)	ohm-cm at 23°C	10^{14} - 10^{15}
Dielectric Strength	Volts/Mil	550
Dielectric Constant, 60Hz		2.75 - 4.20
Dissipation Factor, 60Hz		0.001 - 0.025
Arc Resistance	sec	115 - 130
OPTICAL PROPERTIES:		
Refractive Index		1.43
Clarity		Clear to opaque
Transmittance	%	
Haze	%	
DURABILITY:		
Water Absorption, 1/8" sect	% in 24 hr	0.017
Flammability		
Actinic Resistance		Good
Weak Acids		Resistant
Strong Acids		Attacked
Strong Bases		Attacked
Weak Bases		Resistant
Organic Solvents		Resistant

TRADE NAMES: Blu-Sil, Calrite, RTV, Lubricone, Releaso

INDUSTRIAL PLASTICS

Section H

A Glossary of Plastics Terminology

ablative coating - a heat resistant coating designed to withstand the thermal stress generated by atmospheric friction.

abrasion resistance - resistance to the removal of surface material by cutting action. Contrast with **wear resistance**.

actinic resistance - resistance to the effects of of sunlight.

activator - component added to a resin which initiates the conversion of the resin from a thermoplastic condition to a thermoset condition.

addition polymerization - polymer formed through the application of heat, pressure or catalysis, and which has the same repeating units as the starting monomer.

amorphous structure - a random spatial arrangement of structural units which does not exhibit long range order.

anneal - a treatment in which the plastic is heated to just below the glass transition temperature, and held there for a time. The effect of annealing is to increase crystallinity and improve mechanical properties.

antiplasticizer effect - effect seen in vinyl plastics when plasticizer concentration is between 10 and 15 percent. It is a marked increase in crystallinity which imparts more rigidity to the polymeric structure.

aqueous - containing water, as in a solution which is water based.

arc resistance - a polymer's resistance to electrical arcing when placed in a high potential electric field.

ASTM - American Society for Testing and Materials. Prescribes standards and procedures for testing materials.

atactic - polymeric structure in which side chains are not coplanar, and are randomly attached to the main chain.

auxiliary blowing agent - substance added to a polymer which expands to cause the formation of bubbles or voids. Used to produce cellular foams.

average molecular weight - the sum of the molecular weights of each constituent of a polymer calculated on the basis of the percentage of that constituent present in the polymer. This the "weighted average molecular weight."

axial - on or along an axis or straight line.

branched polymer - polymer chain which continues concurrent growth as two or more chains.

bulk modulus - compressive modulus or coefficient of volume elasticity. A measure of stiffness under compressive loading.

carbonization - deposition of a carbon coating on a surface due to exposure to a high tension electric field.

carbon tracking - the formation of visible conduction paths on the surface of a dielectric.

catalysis - the facilitation of a chemical reaction by the addition of a chemical, or the application of heat and/or pressure.

catalyst - substance that initiates or facilitates a chemical reaction, but is not consumed or changed by the reaction.

Charpy Impact Test - test for toughness or impact resistance in which the specimen is mounted as a simply supported beam.

coefficient of linear expansion - the change in length per unit of original (gage) length per degree change in temperature.

coefficient of dynamic friction - measure of the force necessary to maintain relative motion between two surfaces in contact. Always less than the coefficient of static friction.

coefficient of linear expansion - the increase in length per unit of length per degree rise in temperature. A measure of a material's dimensional stability under thermal stress.

coefficient of static friction - limiting friction; a measure of the force necessary to start relative motion between two surfaces. Always greater than dynamic friction.

coefficient of volume elasticity - compressive modulus or bulk modulus. A measure of stiffness under compression.

cold flow - plastic flow of a polymer subjected to continuous loading over a period of time. Synonymous with creep.

colorability - ability of a plastic to be colored by the addition of pigments, and to retain the color during processing.

column action - failure of a slender member by buckling due to axial compressive loading.

compressibility - the ability of a given mass of polymer to undergo reduction in volume.

compression fatigue - plastic failure due to cyclic compressive loading.

condensation polymerization - reaction in which two distinct monomers combine into a third new monomer, with the evolution of water as a by-product.

coplanar - in a single plane.

copolymer - polymer formed from two different monomers.

covalent bond - primary chemical bond in which two atoms complete their valence shells using the same pair of electrons. Also called shared electron pair.

crazing - formation of a network of numerous shallow cracks on a surface.

creep - time dependent plastic flow (strain) under stress.

critical thickness - a composition dependent property of the polycarbonates. Above the critical thickness, Izod impact strength decreases sharply.

cross-linking - the formation of primary covalent bonds between the side chains of a polymer. Increased cross-bonding enhances rigidity, strength and temperature stability.

crystallinity - areas of long range structural order within an amorphous matrix of the same material.

curing - the process of polymerization in a thermosetting resin initiated by activators or hardeners.

damping - the ability of the structure of a polymer to reduce ("absorb") mechanical vibration. The mechanical energy of vibration is converted into heat within the molecular structure of the polymer.

deflection temperature - the temperature at which a material exhibits a deflection of not more than 0.10 inch when loaded at either 64 psi or 264 psi.

defoamers - substance added to solutions to enhance surface tension and reduce the formation of bubbles.

demolding - process of ejecting a molded part from the mold.

density - mass (or weight) per unit volume of a material.

dermatitis - irritation of the skin produced by contact with a a particular substance. Seen frequently in those who work with epoxides.

differentiating factors - material selection factors which permit relative comparisons of the properties of different materials.

diffraction (radiographic) - determination of crystalline or molecular structure using X-rays.

dimensional stability - ability to retain design dimensions when loaded or exposed to thermal stress.

discoloration - change in or loss of color or clarity.

dispersed phase - a substance which is **mixed with** or **mechanically blended** into another.

dispersion phase - a substance which has another substance **mixed with** or **mechanically blended** into it. By definition, the substance having the larger volume is the dispersion phase. When both substances are liquids, the system is termed an emulsion.

disposability - a measure of the reducibility of a substance to its simpler constituents, usually for recycling.

dissipation factor - a measure of the conversion of reactive power to real power in the form of heat within a dielectric material.

ductility - ability to withstand plastic deformation without rupture. Typically a property of metals.

dynamic rebound test - testing based on the resilience of a material which uses the height of rebound (bounce) as a relative indicator of hardness, e.g. the Shore Scleroscope.

elastic behavior - a material behaves elastically if it returns to its original shape and dimensions when a load is removed. Implies that the elastic limit of the material has not been exceeded.

elastic limit - a level of stress below which a material behaves elastically. Above this limit, the material behaves plastically. Below this limit, Hooke's Law applies.

elastomer - a plastic polymer mixed with a natural or synthetic rubber.

embrittle - to cause a material to become brittle. Brittleness implies a decrease in plasticity and toughness, and an increase in hardness.

emulsion - a mixture of two liquids in which one liquid is suspended in the other.

encapsulate - the formation of a protective capsule or barrier around a part.

endothermic reaction - a chemical reaction which requires the application of external heat to proceed

engineering plastic - high performance and high cost polymers developed to replace metals in load bearing applications.

engineering strain - strain which has been normalized by dividing the deformation by the gauge length; measured in **inches per inch.**

engineering stress - stress which has been normalized by dividing the load by the cross-sectional area; measured in pounds per square inch, or psi.

exothermic reaction - a chemical reaction whose progress generates heat.

fabricability - general term describing the relative ease with which parts can be formed from a material.

FAHMY - Usually preceeded by "Dr.". An Egyptian professor generally regarded as exceptionally knowledgable in many technical areas, and whom many students regard as a the guru of Industrial Technology at UNI. Affectionately known among graduate students as "The Fahm".

filament - continuous single or multiple strand polymeric fiber.

filled - a polymer is said to be filled if any solid substance (a **filler**) has been added to it to enhance its properties.

flammability index - a relative numerical measure of a polymer's ability to support combustion.

fatigue strength - the ability of a material to resist repetitive cyclic loading.

flexural strength - the ability of a material to resist the combined tensile and compressive stresses developed under bending loads.

flowability - property of a material which enables it to readily flow to take the shape of the mold, and completely fill sections of intricate shape and varying thickness.

fluoroplastic - a linear polymer which has had some, or all, of its hydrogen atoms replaced with fluorine atoms.

fusion - melting; conversion from the solid to the liquid state. Some polymers do not become liquid per se, rather they become a gel which is capable of being molded under pressure.

glass transition temperature - temperature at which a polymer changes from a brittle rigid state to a softer more flexible condition.

go no-go factors - in the selection process, these are minimum screening criteria which every material must meet if it is to be further further consideration.

gum plastic - a plastic to which a natural rubber has been added to enhance elastic properties.

hardener - an agent which initiates the polymerization of a thermosetting resin.

hardness - resistance to penetration or indentation.

haze - percentage of light transmitted through a specimen which is deviated more than 2.5 degrees from the incident beam by forward scattering.

heat distortion point - temperature at which a plastic no longer retains dimensional stability.

high energy radiation - generally, X and gamma radiation.

homopolymer - a polymer composed only of one type of monomer.

Hooke's Law - states that below the elastic limit, stress is always proportional to strain. The ratio of unit stress to unit strain is the elastic modulus for the material.

hydrocarbon - a large chain molecule whose monomers are composed of carbon and hydrogen atoms, and which is formed by the covalent bonding of its carbon atoms. All plastics are hydrocarbons except the silicones.

hydrogen bond - weaker secondary bond (attraction) between a hydrogen atom in one molecule and a net negative polar group in another molecule.

hydrolytic - a chemical reaction in which a compound is split into other compounds by the addition of water. The hydrogen and oxygen are incorporated into the new compounds.

hygroscopic - a substance which absorbs moisture directly from the atmosphere.

hysteresis (mechanical) - the energy per unit volume that is converted to heat within a material as it is cyclically loaded.

impregnate - to completely fill one substance with another, as in a glass fiber impregnated resin.

incandescence - occurs when a body is sufficiently heated to cause it to emit visible light.

incandescent failure - electrical failure caused by a high voltage overload. Heats an inorganic dielectric to incandescence, at which point it will conduct current. Upon cooling, the dielectric properties are regained.

inert - not chemically reactive.

infusible - not capable of being melted in the sense of becoming liquid.

insoluble - a substance which is incapable of being dissolved or destroyed by another substance.

integral skin molding - molding process in which a melt is injected into a heated mold which causes the formation of a denser outer layer supported by an inner cellular structure.

interstitial space - in a polymer, all the space not occupied by the polymer chains. The area between and around polymer chains.

isotactic - polymer whose side chains branch out on only one side of the main chain, AND all side chains lie in a single plane.

Izod Impact Test - test for toughness or impact resistance in which the specimen is loaded as a vertical cantilever.

linear polymer - the simplest type of polymeric organization consisting of many long macromolecule chains with few side chains and minimal attraction or bonding between the chains.

long range order - crystallinity; in polymers, this is areas of denser ordered structure within a amorphous matrix.

luminous transmittance - the ratio of transmitted light to incident light expressed as a percent.

machinability - general adjective term describing how well a plastic can be shaped by machine tool operations.

macromolecule - a large molecule composed of atoms covalently bonded together.

melt - a mass of polymeric material in the mold ready condition.

melt viscosity - the viscosity of a mass of a polymeric compound in the mold ready condition. Low melt viscosity means greater flowability of the melt.

mer - basic structural unit of a polymer. Mers are always molecules whose atoms are covalently bonded together.

modulus of elasticity - Young's Modulus; the ratio of engineering stress to strain below the elastic limit. Stiffness under simple tensile stress.

modulus of resilience - a measure of the energy necessary to deform unit volume of a material within its elastic range.

modulus of rigidity - stiffness under a simple shearing load.

moldability - general adjective description of how well a plastic can be molded by various molding processes. A plastic will mold well if it exhibits low melt viscosity, has good compressibility, and has a low rate of linear shrinkage.

mold shrinkage - the difference between design dimensions and the dimensions of the finished molded product.

molecular weight - the sum of the atomic weights of the atoms making up a molecule.

monomer - one mer. A single molecular structural unit.

nonbleeding - said of a plastic whose constituents are not to other substances placed in contact with them.

nonburning - a plastic which will not ignite in the presence of open flame.

normalized strain - unit or engineering strain; inches of deformation divided by inches of gauge length.

normalized stress - unit or engineering stress; pounds of load divided by square inches of area.

notch sensitive - a plastic is said to be notch-sensitive if its impact resistance is lowered when notched for testing.

packing - in polymers with considerable interstitial space, the polymer chains may be brought closer together through the application of heat and pressure. Increases density without increasing molecular weight.

penetrometer - any type of testing in which the material is physically penetrated or indented, e.g., Vicat Softening Point or Rockwell Hardness.

permeability - ability of a substance to take up liquids or vapors into its interstitial spaces.

pigmented - colored by the addition of pigments.

piping (of light) - light is piped when a light source at one end of an acrylic tube is transmitted to the other end.

plastic deformation - strain occurring above the elastic limit. Elastic recovery is not possible, and the deformation is permanent.

plastic flow - permanent deformation due to the application of stress which is above the elastic limit. May be unintentional such as minute plastic flow to redistribute stresses, or intentional such as heat and pressure used to form an object.

plastic set - plastic deformation; a permanent change in shape.

plasticizer - a solvent added to a plastic (e.g., PVC's) which weakens interchain forces and promotes plastic behavior.

polar bond - a weak secondary bond caused by the unsymmetrical distribution of electrical charge on a molecule.

polymer - general term for any group of monomers (mers) covalently bonded together to form a long-chain macromolecule.

polymerization - chemical reaction in which polymers are formed from monomers.

primary bond - extremely strong bonds formed between atoms due to their tendency to maintain or regain a stable state in the valence shell. Primary bonds are ionic, covalent and metallic.

processability - general term describing the ability of a plastic to be shaped.

quench - the cooling of a material from the heated state.

radio frequencies - electromagnetic radiation with a wavelength in the range of 10^6 to 10^{-5} meters. These are the frequencies most typically found in electronic communications equipment.

radiographic - related to or utilizing X-rays.

recyclability - the ability of a substance to be reduced to its pre-product state, and then reused.

reduction in area - the difference between the pretest area of the specimen, and its posttest area expressed as a percent. It is a measure of ductility.

refractive index - ratio of the sine of the angle of incident light to the sine of the angle of refracted light as it passes through a material. An indicator of the degree of optical distortion of an image as seen through the material.

resilience - ability to recover from distortion due to impact energy. It is the amount of energy that unit volume of the material can absorb within its elastic range.

resin - general term for any plastic compound. Usually means a thermosetting polymer in the uncured form.

resin system - a complete thermosetting polymer. In addition to the polymer proper, a resin system includes a hardner, curing agents, inhibitors, plasticizers and fillers.

resistivity - inherent property of a material which offers opposition to the flow of electric current. It is numerically equal to the resistance in ohms of 1 circular mil per foot of the material.

retardant - substance added to a plastic which reduces its tendency to burn.

rigidity - the stiffness if a material under shearing stress.

RTV - acronym for [R]oom [T]emperature [V]ulcanizing. A thermoplastic resin which cures to a thermoset at room temperature.

secondary bond - weak bonds based on the electrostatic properties of atoms and molecules. The two types are polar bonds and van der Waals' bonds.

self-extinguishing - a specimen which will ignite and support flame, however, the flame is self-extinguished before 4 inches of the specimen are consumed.

self-lubricating - polymeric material which is impregnated with a lubricant, and which is intended to be used without further lubrication.

sinter - process in which discrete particles of a resin are compressed into a denser solid mass while being held at an elevated temperature and pressure.

Snell's Law - optical principle stating that ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant for any given material.

softening point (Vicat) - the temperature at which a needle 1 mm^2 in area will penetrate a plastic to a depth of 1 mm. The shape of the needle can be either square or circular.

soluble - a material is soluble if it can be decomposed and incorporated into another substance.

solvent - substance which will decompose (dissolve) another substance.

stiffness - a material's resistance to deformation (strain) under different types of loading. In tension, stiffness is the resistance to reduction in area. In compression, stiffness is the resistance to the expansion in area. Under simple shear, it is the resistance offered to the shearing stress. In bending, stiffness is the resistance to deflection.

strain - the deformation in a material in response to the application of stress.

stress crack - cracks resulting from excessive or prolonged loading of a part.

stress decay - excessive plastic flow of polymer fibers under tensile stress.

substituent group - a molecular structure (e.g., a benzene ring) which is incorporated onto the monomers of a polymer chain. These groups are large and unsymmetrical, and tend to prevent the free movement of the chains.

substrate - the base material to which a polymeric coating may be applied.

syndiotactic - a polymer chain is syndiotactic in structure if its side chains are coplanar, and alternate from one side of the chain to the other.

tensile impact test - newer impact test designed to overcome the disadvantages of the Izod and Charpy impact tests. This test eliminates both notch sensitivity and the kinetic energy expended in moving the broken pieces of the specimen aside.

terpolymer - a polymer which is composed of three or more distinct types of monomers.

thermoform - forming of a part by heating it and then working it to shape.

thermoplastic - a polymer which can be repeatedly softened by heating, and hardened (polymerized) by cooling.

thermoset - a plastic whose shape is permanently set into it, by the application of heat and pressure or catalysts, and which cannot be remelted and formed into another shape.

toughness - impact resistance. It is the work per unit volume that is required to fracture (rupture) a material.

ultraviolet radiation - electromagnetic radiation whose wavelength is shorter than 4000 Angstrom Units. It is the component of sunlight which damages plastics.

unfilled - a polymer which has had no mechanical filler added to it to enhance its properties.

unreinforced - unfilled; having no substance added to increase or enhance properties.

van der Waal's force - weak attractive atomic force arising as a result of the electrostatic imbalances occurring in molecules which are covalently bonded.

Vicat Needle Method - a procedure for determining the softening point of a plastic.

viscoelastic behavior - continued deformation over time after an applied load has been removed.

volatile - easily evaporated.

vulcanize - the polymerization of a natural rubber, usually under heat and pressure.

wear resistance - resistance to material removal by continuous dynamic contact with the same or another material. Used as a relative gauge of useful service life.

wettability - the ability of a surface to hold a film, or to form an interface between dissimilar phases.

Young's Modulus - modulus of elasticity in tension.

INDUSTRIAL PLASTICS

Section L

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