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Selecting Thermoplastics for Engineering Applications

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Preface

It came as a surprise to be requested to prepare a procedure for selecting the proper engineering plastic for a given application. Since such decisions are made every day by someone, I assumed it was a fairly routine and repetitive exercise, and only needed to be reviewed, assembled in some logical sequence, and written.

The assumption was incorrect. It was a revelation to learn that, of nearly fifty experienced people interviewed who are close to the resin selection responsibility in all its aspects, no two of them could agree on a logical process for selection; and no one knew of a publication that could. It then occurred to me that the way to develop such a procedure would be to assemble a number of actual developments in engineering plastics from material suppliers, molders, and end users and arrange them logically; and, from these data, prepare a resin selection process based on practical case histories. This assumption, too, was incorrect, for such case histories are either not readily available, or records were never kept, or decisions were made based on pragmatic rather than logical considerations.

Therefore, to prepare this book, I was led to collecting as much pertinent data as practical and to writing a simple suggested route to resin selection. It has been prepared not for the plastic engineer expert in design, but for anyone with an appreciation for simple technical and mechanical considerations.

Charles P. MacDermott

Acknowledgments

Physical property data used in this book were taken from a number of sources, with a large share of them from promotional literature available from the major material suppliers. I am particularly indebted to the following companies for the information provided by the bulletins listed below:

Borg-Warner Chemicals

Injection Molding Polymers—Grade Selection Guide, Cycolac ABS

E. I. du Pont de Nemours & Co.

Zytel® Nylon Resin—Design Handbook
Delrin® Acetal Resin—Design Handbook
Zytel ST Super Tough Nylon Resin
Designing the Car of the Eighties
A Guide to Standard Physical Tests for Plastics, P. N. Richardson
Designing with Du Pont Engineering Plastics
Delrin Acetal Resins—Molding Manual
Rynite® Thermoplastic Polyester Resin—General Guide to Products and Properties
Minlon®—Design Handbook
Zytel Glass Reinforced Nylon Resins—Molding Manual
Plastics: An Overview, by David Stotz

Celanese Plastics and Specialties Company

Celanex® Thermoplastic Polyester—Properties and Processing
Celanese Engineering Resins
Celcon® Acetal Polymer
Celanese Nylon Selector
Celanese Nylon—Glass Reinforced Nylon, Bulletin N1B

General Electric Company

Lexan®, A Good Name to Stand On
Lexan Polycarbonate Resin
Designing with Lexan
Valox® Resin—Injection Molding
Noryl® Engineering Plastics

Hercules Company

Selection Guide to Mineral Filled Profax® Polypropylene

Union Carbide

Udel® Polysulfone Product Data
Designing for Polysulfone
Ardel® Polyarylate

Contents

1

Definition of Engineering Thermoplastic Resins

INTRODUCTION

The use of plastics expanded explosively over the past 40 years to the point that, today in the United States, there are more than 20,000,000 metric tons of plastics produced annually. A large part of this huge volume is extruded into film, sheet, pipe, wire and cable coatings, and tubing. Another significant share is injection or blow molded into toys or into throw-away articles such as bottles or food packages. Most of the plastics used for these purposes are considered general purpose materials and are not covered as part of the discussion in this book.

A smaller share of the total plastics production, although still measured in the billions of pounds annually, is reserved for "engineering plastics." This family of plastic resins include those that are capable of withstanding high loadings for long periods of time at elevated temperatures and in adverse environments, and that behave in a predictable manner when subjected to design techniques and formulas.

Thermoplastic engineering plastics are generally divided into two classes, crystalline and amorphous. It is not the intent here in making the distinction between crystalline and amorphous polymers to probe the depths of molecular structure. This information is available for those who want it in the vast literature devoted to the subject. Instead, only the practical differences will be covered.

Crystalline polymers have an ordered molecular arrangement, with a sharp, identifiable melting point. Due to the ordered structure of the molecules, crystalline polymers reflect most incident light and are thus opaque. In addition, these polymers undergo a significant reduction in volume when they solidify, resulting in high, although predictable, shrinkage. They are normally resistant to many organic solvents and have good fatigue and wear-resistant properties.

Amorphous polymers, on the other hand, have random molecular arrangements and melt over a broad temperature range compared to the crystalline polymers. A major physical difference is that light is transmitted easily through the polymer, making it transparent. Shrinkage is much lower with amorphous polymers. On the other hand, they are, in general, more sensitive to the effects of contacts with solvents and have poorer fatigue and wear characteristics.

The engineering plastics covered here will include examples of both crystalline and amorphous polymers. In some end uses, only one or the other can be used; but, in many applications, the properties of the two overlap sufficiently so that either one can be used.

Engineering thermoplastics, either crystalline or amorphous, are used in thousands of mechanical applications today in nearly every industry. As experience with them continues to grow, the mechanical uses of the engineering plastics continue to proliferate.

Some of the important reasons for this rapid growth, with particular emphasis on their use in place of metals, are the following.

Corrosion Resistance

This was early recognized as a significant advantage of plastics over metal. An outstanding single illustration of this advantage in action is the ball cock assembly used for controlling the water flow in toilets. The copper and brass ball cock assembly used in the past ultimately failed due to corrosion, the timing dependent upon the quality of the metal, and the properties of the water. Today, many of the ball cocks installed are made of an acetal resin and over 200 million of these have been used throughout the world with almost no failures due to corrosion.

Light Weight

At less than half the specific gravity of aluminum for most engineering plastics, the advantage of lighter weight is attractive for many applications in automotive, airplane, appliance, and sporting goods industries. The automotive industry in particular has increased its plastics use from 15 lbs./car to 200 lbs./car in the last 20 years, with lighter weight automobiles one of the major objectives, although this includes both general purpose and engineering plastics.

Low Cost

Over the years, as volumes have increased dramatically, engineering plastics costs have been reduced relative to the costs of such metals as magnesium, aluminum, and brass. Today, on a price per cubic inch basis, a number of the plastics actually cost less than those metals with which they are frequently in competition. Further, because of the degrees of freedom provided by the injection-molding process, complex parts in plastics can be made in a single operation in contrast to comparable metal parts that have to be assembled by joining a number of tediously formed metal parts. Of course, the reduction in labor costs obtained is significant.

High Strength to Stiffness Ratio

In the early days of engineering plastics, the replacement of metal parts to achieve lower costs and design flexibility was a viable objective, although the ratio of tensile strength to stiffness was not comparable to the die cast metals the plastics were replacing. The replacements were made, however, when design calculations indicated that the properties of metals were clearly more than the application required.

More recently, the successful reinforcement with fiber glass or minerals of the mature and the new engineering plastics have dramatically increased the strength to stiffness ratio to one approaching that of the die cast metals. Although the plastics still do not match the metals, their properties are much closer to metals than they used to be, resulting in a major increase in the range of applications in which the engineering plastics can supplant the metals.

Design Flexibility

The injection-molding process makes it possible to fabricate intricate shapes out of the plastics, a distinct improvement in the versatility provided by metal-forming operations.

Colorability

By incorporating dyes and pigments directly into the resin, it is possible to produce simply and economically items in an unlimited range of colors. This is another example of the versatility of plastics.

Other valuable attributes of engineering plastics and not related to metal replacement are the following.

Electrical Insulators

The dielectric properties of engineering plastics are outstanding and are responsible for the wide use of the plastics in the electrical/electronics industry.

Good Thermal Properties

Thermal conductivity of plastics is very low compared with metals. In appliances, for example, the thermal insulation provided for handles of cooking implements is an attractive, useful feature of a stiff, strong, high-heat, distortion-resistant, engineering plastic.

Transparency

This is a feature now provided by several of the amorphous engineering plastics that makes new end uses possible. An example of this is the line of instruments and vessels used in medical and other scientific laboratories.

THE NEED FOR A SELECTION PROCESS

Given the fact that engineering plastics are essential to the production of critical parts in many industries, how is the right plastic selected for a specific part?

Prior to the 1960s, the selection of a thermoplastic for an engineering application was simple since the number of appropriate engineering plastics was limited. Today, in the 1980s, there are literally hundreds of polymers and polymer modifications to choose from. While this proliferation makes it simpler to find a fit for almost all reasonable applications, it does require more effort to discriminate.

A perfect example of the proliferation of candidate materials is the nylon family. Within this family, there are 6, 6/6, 6/10, 6/12 nylons as well as numerous copolymers of these basic polyamides. Furthermore, most of them are available in glass-reinforced, flame-retarded, mineral-filled, etc., versions. To this must be added nylons blended or grafted with toughening agents, such as elastomers and polyesters, and again there are filled- and glass-reinforced versions of these nylons.

While the nylon polymers were one of the first of the engineering plastics to breed such a large family of available products, the newer ones have quickly followed suit. The polycarbonates, polyesters, acetals, and other families also include a wide variety of molecular weights, molecular weight distribution, fillers, additives, reinforcing compounds, antifriction agents, antioxidants, UV stabilizers, toughening agents, etc., to present a bewildering multiplicity of choices to those charged with the responsibility of selecting the "right stuff."

It seems obvious that there should be a reasonable procedure available that will make it possible for those responsible for selecting the appropriate plastic to follow a logical process of discrimination. Within certain limits, this book has been prepared to suggest a screening process that is based on logic as well as experience, but with the caveat that there are certain empirical considerations involved that do not always reflect strict scientific principles.

A review of a resin screening process should include an understanding of the diverse backgrounds of those who originate the need for the plastic part. Consider that included in the list of final end users of the parts are such heterogenous backgrounds as inventors, engineers, large corporations, entrepeneurs, scientists, toy manufacturers, mechanics, dress designers, boat designers, electronics specialists, and hospitals. The list of potential applications is nearly endless, and the degree of sophistication and the specific knowledge of the limitation of plastics vary widely. To begin with, the concept of a new object to be made of an engineering thermoplastic, or at least to have an engineering component, presents a challenge to some of the end users. Their approach to determining which plastic to use for their application will vary considerably, from trying to follow the entire selection process from beginning to end personally, to the hiring of plastics design engineers.

For those without any experience with plastics, it is advisable to seek out someone who can provide the kind of objective technical assistance that is required. One simple, and inexpensive, way to locate a reputable source of this kind of assistance is to contact any of the major resin manufacturers. These companies have access to the names of responsible plastic parts designers, and will usually be happy to provide their names and locations. At the same time, in some cases, they will be able to comment on the practicality of a proposed use themselves, although this might be only in general terms. For example, if the proposed use involves exposure to a continuous 1000°F environment, the material supplier could point out politely that the proposed application is simply not in the cards. On the other hand, if the application sounds reasonable, material suppliers can shed some light on what the next step should be and who should be contacted next to get the selection process moving, or they may volunteer to become further involved themselves.