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Model Dichotomous Key for Plastics Identification

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MODEL DICHOTOMOUS KEY FOR PLASTICS IDENTIFICATION

by
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This Thesis submitted by Diane L. Burnham in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota is hereby approved by the Faculty Advisory Committee under whom the work has been done.

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This Thesis meets the standards for appearance and conforms to the style and format requirements of the Graduate School of the University of North Dakota, and is hereby approved.

A. William Johnson 5/2/84
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Signature Diane L. Burnham

Date April 24, 1984

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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ABSTRACT

The purpose of this study was to investigate selected plastics when treated by means of heat, fire, solvents, and specific gravity tests for the development of a model dichotomous key.

The study included: (1) a review of literature that contained a brief historical overview of plastics, an examination of their uses, advantages, and chemical make up, and the selection of four tests to be conducted that would reveal characteristics of the plastics, (2) an explanation of the equipment, materials, and procedures for each of the tests, (3) an analysis of the data obtained from the tests, and (4) a recommendation on how to use the plastics dichotomous key.

Methods

Specified plastics were donated for testing purposes by several plastics manufacturing companies. The plastics were cut to size and used as samples in four tests. These tests included the effects of heat, the fire test, the effects of solvents, and specific gravity. The test data was analyzed and arranged into a basic dichotomous key format.

Conclusions

The conclusions for this study are as follows: (1) A form of media is needed to help individuals identify common plastics; (2) a propane torch is too powerful of a flame source to use in the fire test; (3) discrepancies in the colors of the flames between the writer's findings and reports from other sources were caused by an incomplete observation of the total flame on the writer's part in the fire test; (4) contaminated solvents may have caused difficulties in determining effects on some of the plastics; and (5) specific gravity results may have been affected by inaccurate balance scale and graduated cylinder readings.

Recommendations

The following recommendations have been suggested for this study: (1) A gentler flame source, such as the Bunsen burner flame, should be used in the fire test; (2) all parts of the flame should be noted and recorded in the fire test; (3) fresh chemicals should be used for each test conducted in determining the effects of solvents; (4) because of its tendency to curl and stick to the sides of the graduated cylinder, cellulose acetate should be tested in a form other than photographic film in the specific gravity test; (5) to determine the identity of the plastics samples, testing and comparison of characteristics should follow the same order as that of the dichotomous key; and (6) a pilot study should be conducted using the dichotomous key as a testing instrument to determine the key's validity. A questionnaire would be used to provide supplementary information.

CHAPTER I

INTRODUCTION

The plastics industry has grown rapidly. "In about one hundred years, the plastics industry has gone from its discovery to production of nearly 22 billion pounds per year" (Curriculum Guide for Plastics Education 1977, p. 5). This pace continues as new materials with new applications are created. The public is often left ignorant as to the potentials of these new plastics because of the difficulties in keeping up with current developments.

It has been estimated that by the year 2000, annual consumption of plastics for each individual will total 212 liters. In addition, the forecast for plastics is that they "will eventually become the basis of the American economy" (Milby 1973, p. 5).

Because plastics have been integrated into virtually every facet of life, their few known characteristics have been learned from day-to-day contact with them. This limited knowledge of plastics has caused problems. For example, the public's unfavorable view of some plastics products has resulted from improper application of the materials. Katz (1978, p. 168) explains that:

> Whenever a plastics design fails, the material itself is denigrated. The possibility of misjudgment in other areas of the design process is rarely contemplated. A crazed mug, a cracked toy, a melted bowl are invariably considered material failures and not design failures. The ultimate form a moulding assumes is the result of a combination of many factors: The properties of the material itself, the limitations of the moulding process, the skill of the mould designer, the function of the article and definition of consumer needs, and finally the "desire to make beautiful things."
>
> For economic reasons, manufacturers usually employ plastics very close to their ultimate performance capability, and hence very close to failure-point. The more frequent the failures, the more the concept of plastics as cheap and inferior materials becomes reinforced.

Not only the public, but even those in industry have much to learn about plastics says DeYoung (1983, p. 63):

> At first glance, plastic composites seem too good to be true. As strong or stronger than most metals, composites--combinations of plastic resins and organic or inorganic reinforcements--are far lighter in weight, virtually noncorrosive, and can be formed into complex shapes with little or no machining or wasted material. After more than 30 years of R & D, however, composites are still struggling for acceptance by U.S. auto producers and other big-ticket industries.
>
> There are several reasons for industry's reluctance, and work is underway to counter each of them. One is that there is still much less hard data on composite properties, durability, and failure mechanisms than on metals. The bond between the plastic resin and the reinforcing fiber is known to be crucially important, for example, but researchers have only recently begun to learn about these bonds and determine when they are about to fail.

Harry B. Hollander, in Plastics for Artists and Craftsmen (1972), reported of the frustration as well as the intrigue that the artist-craftsman has experienced from having such an abundance of these new materials at his disposal.

> Along with his experiments and successful creative efforts with resins and plastics, has come puzzlement

> regarding new combinations of materials which he does not fully understand. He finds that if he wishes to use polyesters, epoxies, silicones, or polyurethanes, he needs to know more about their very nature, what they are capable of doing, and why a catastrophe occurs! . . . Rarely is the artist-craftsman a trained chemist and for this reason he often finds that he is over his head in materials he does not understand (p. 11).

Future applications also call for increased knowledge of plastics with special emphasis directed at students. Richardson (1974, p. 8) stated:

> Because plastics could potentially become the basis of the American economy in the near future, and because there is a dire shortage of trained plastics personnel, educators should increase the availability of plastics educational facilities and courses at the high-school and post-high-school levels.

Because the majority of the people are still unfamiliar with even the most common plastics used today, a form of media is needed to help them identify these plastics. After examining the characteristics of the plastics, the individual would be better equipped to select the material best suited for his or her needs.

Problem Statement

The purpose of this study was to investigate selected plastics when treated by means of heat, fire, solvents, and specific gravity tests for the development of a model dichotomous key.

Objectives

The objectives of this study were to:

1. Research and identify appropriate tests that reveal characteristics of selected plastics.
2. Administer tests using standardized plastics.
3. Gather and analyze test data (characteristics of the plastics).
4. Arrange test data (characteristics of the plastics) in dichotomous key format.

Limitations

Limitations for this study included the following:

1. Information researched for this study was limited to that found in the Chester Fritz Library and in the Department of Industrial Technology at the University of North Dakota.
2. The plastics tested included the following in their intermediate form:

Acetal polymers	
Acrylics	
Amides	Nylon
Amino resin	Melmac
Cellulosics	Cellulose Acetate
Epoxy resins	
Ethylene polymers	Polyethylene
Phenolics	
Polyester resins	
Propylene polymers	Polypropylene
Silicones	

Styrene polymers	Polystyrene
Synthetic rubbers	Neoprene
Vinyl polymers	
Urethane polymers	Polyurethane

3. Tests conducted included:
    a) effects of heat,
    b) fire test,
    c) effects of solvents, and
    d) specific gravity.

Definition of Terms

Coefficient of Friction. The name given to the quotient obtained when the force just necessary to move two solid bodies past each other, or the force necessary to keep them moving at a steady rate, is divided by the force pressing the solids together (Tver 1974).

Dichotomous Key. A key to classification based on a choice between two alternative characteristics (Webster's Third New International Dictionary 1981).

Elastomer. A material which at room temperature stretches under low stress to at least twice its length and snaps back to the original length upon release of stress (Glossary of Plastics Terms, Phillips Petroleum Company n.d.).

Inorganic. Materials which are based on mineral (Katz 1978).

Monomer. Individual units. Monomers are the raw materials from which plastics are built (Katz 1978).

Olefin. "Oil forming." All hydrocarbons with carbon-to-carbon double bonds (Richardson 1974). Polyethylene and polypropylene are examples of polyolefins.

Organic. Materials in which carbon is the chief element (Katz 1978).

Plastics. Any one of the large and varied group of materials consisting wholly or in part of combinations of carbon with oxygen, hydrogen, nitrogen and other organic and inorganic elements which, while solid in the finished state, at some stage in its manufacture is made liquid, and is thus capable of being formed into various shapes, most usually through the application, either singly or together, of heat and pressure (Administrator's Manual for Plastics Education 1978).

Polymer. A very long molecular chain constructed from many repeated identical units (monomers) (Katz 1978).

Polymerization. The process of building up continuous molecular chains from individual identical monomer units.

Solvents. A material used to produce a liquid state in a solid material (Patton 1976).

Thermoplastics. A material that will repeatedly soften when heated and harden when cooled (Glossary of Plastics Terms, Phillips Petroleum Company n.d.).

Thermoset. A material that will undergo or has undergone a chemical reaction by the action of heat, catalysts, ultra-violet light, etc., leading to a relatively infusible state (Glossary of Plastics Terms, Phillips Petroleum Company n.d.).

Valence (valency). A positive number that characterizes the combining power of an element for other elements, as measured by the number of bonds to other atoms which one atom of the given element forms upon chemical combination; hydrogen is assigned valence 1, and the valence is the number of hydrogen atoms, or their equivalent, with which an atom of the given element combines (McGraw-Hill Dictionary of Scientific and Technical Terms 1978).

CHAPTER II

REVIEW OF LITERATURE

Introduction

This chapter focuses on four major areas: The first deals with the history of plastics; second, their uses and advantages; third, how plastics are made; and finally, a look at each of the plastics to be tested.

Plastics--A Brief Historical Overview

In 1843, natives on the Malay peninsula used a gum from the trees to make knife handles and whips. Dr. George IV William Montgomerie, a Malayan surgeon, found this gum to be a natural polymer material: gutta percha. This marked the first commercial use of a polymeric material.

There is discrepancy as to the date and name of the first synthetic plastics discovered in the United States. Richardson (1974) claims that it was John W. Hyatt's efforts, in 1868, to find a substitute material for billiard balls that marked their beginning. Gutta percha had replaced ivory, but its supply was limited. Hyatt's experimentations with cellulose nitrate and camphor led him to his discovery of Celluloid. This material was characterized as a tough, easily fabricated, and colorful thermoplastic (DuBois 1972).

A second account was done by DuBois (1972) who reported findings of Dr. Leo H. Baekeland. Dr. Baekeland's quest was to create a phenolic resin that would not soften again once the chemical reaction had been completed.

> After several years of work, he discovered the value of hexamethylenetetramine as a catalyst and the need for pressure to stop the foaming; after endless experiments, he wound up with a clear amber phenolic resin. Here was the first truly synthetic resin and the start of the synthetic plastics. [This material was given the trademark name "Bakelite" after Dr. Baekeland].
>
> The materials before Hyatt were the natural plastics; Celluloid was a semisynthetic plastic material. Dr. Baekeland's invention opened the door to the entire field of synthetics and sparked the greater growth and expansion of plastics from the novelty into the industrial fields (DuBois 1972, p. 78).

World War II was an incentive for new developments in the plastics industry because materials typically used in wartime were in short supply. After the war, use of plastics decreased but rose sharply again in 1950. Since then the industry has grown consistently in its developments of new materials, applications, and processes.

Plastics--Uses and Advantages

Plastics are used today because of their many appealing properties. These include:

1. light weight,
2. electrical insulation,
3. pleasant to the touch,
4. color,
5. ability to be metallized,
6. transparency,

7. water resistance,
8. chemical resistance,
9. hygienic and nonallergenic,
10. mildew and fungus resistance,
11. can be mass produced,
12. provide design freedom,
13. adaptability, and
14. good flow characteristics.

DuBois (1967, p. 5) also recognizes another major advantage to using plastics--their cost.

> A widely recognized formula states that a sale is made by the material that offers the most "plus" properties for the price asked. The plastics are used in many applications because there are no other materials that will do the job at a reasonable price. In other cases, they are selected merely because they are as good as other materials, yet cost less. The savings in price may be the result of a low-cost material, but in most cases, the savings result from reduced processing and fabricating costs. As direct labor becomes more expensive, the automated processes become an essential in overcoming the high cost of handwork, thus enabling a manufacturer to meet his competition. Use of plastics frequently eliminates the cost of finishing and painting. Plastics require no buffing after plating. Molded and extruded products come finished to dimension, ready for the assembly line, so that the final product is merely a mechanized assemblage of mass-produced parts--and the molded plastics offer a very low-cost means of producing just such pieces. All of the mass-produced products of industry use plastics as basic materials, as well as finishes and adhesives.

Plastics are being used in the construction of buildings as well as the construction of human bodies. In structural and semistructural applications, plastics offer the building designer formability, strength, toughness, and light transmission. They are used as handrails, siding, cabinet work, furniture, tile, paneling, vents, plumbing fixutres, sound breakers, insulation, and conduits. Plastics lend themselves to auxiliary applications as well in the forms of coatings, adhesives, and sealants (Deitz 1969).

Medical technology's use of plastics has enabled them to come up with a portable liquid oxygen system. "The device makes it possible for people with severe respiratory problems to enjoy a far more active and fulfilling life than they might otherwise lead" ("Formed to Perform," Rohm and Haas Reporter 1983, p. 20).

Internal body parts, as well, have been designed through medicine's research and development with plastics. Breasts, once formed by silicone injections, are now created by silicone implants with a piece of Dacron cloth on the back that allows "natural tissue to interweave with it so that the implant becomes one with the body" (Katz 1978, p. 28).

> Other implants made of silicone rubber include ears, skull plates and jaw bones. Silicone rubber joints straighten arthritic fingers and remobilize wrists, arms and big toes, bile and tear ducts can be made to refunction; . . . . How far are we from the reality of plastics muscles or kidneys--the Plastics Man (Katz 1978, p. 19)?

Plastics--How They Are Made

Plastics are divided into two main classes: Thermosets and Thermoplastics. It was reported in "Section 3--Plastics" of Machine Design (April 14, 1983, p. 139) that:

> the main distinguishing factor between the two classes

> is whether the polymer chains remain linear and separate after molding or whether they undergo three-dimensional chain combination by crosslinking. Linear plastics are chemically unchanged during molding (except for possible degradation) and can be remolded again and again. Crosslinked plastics start with linear chains that are joined irreversibly during molding into an interconnected, molecular network. They cannot be remolded.

Other differences include the forms in which plastics are produced and the fabrication processes used on each. The thermosets are most often found as powders, preforms, and resins and are compression molded, transfer molded, or cast. Thermoplastics come in powders, granular, and pellet forms and are extruded, calendared, vacuum molded, blow molded, and injection formed (Richardson 1974).

Another category to consider is the elastomers, or rubbers. "Section 4--Rubber" of Machine Design (1983, p. 239) refers to rubber as "any material capable of extreme deformability, with more or less complete recovery upon removal of the deforming force."

Plastics are oftentimes referred to as synthetics; in other words, elements are "synthesized" (or combined) to form the various plastics. These elements include carbon, oxygen, nitrogen, hydrogen, and sulphur and are taken from raw materials like water, air, coal, petroleum, and natural gas.

> Complex chemical reactions are used to produce a great variety of plastics by slightly modifying the processes and ingregients.
>
> The chemist literally takes the natural materials apart by separating their basic molecules and atoms. He then recombines them in different ways with the aid of heat, pressure, and chemical action (Swanson 1965, p. 18).

This process of recombining molecules is called polymerization. Addition, or linear addition polymerization, is one process used to create plastics. Polymer units are added together to make a chain "by opening out a double bond to free a valency." Below is an example of addition polymerization. The basic ethylene monomer is repeated to form the polythene chain (Katz 1978, p. 15).

$$CH_2 = CH_2 \text{ or } \underset{\displaystyle H}{\overset{\displaystyle H}{\overset{|}{\underset{|}{C}}}} = \underset{\displaystyle H}{\overset{\displaystyle H}{\overset{|}{\underset{|}{C}}}} \text{ becomes } -\underset{\displaystyle H}{\overset{\displaystyle H}{\overset{|}{\underset{|}{C}}}}-\underset{\displaystyle H}{\overset{\displaystyle H}{\overset{|}{\underset{|}{C}}}}-\underset{\displaystyle H}{\overset{\displaystyle H}{\overset{|}{\underset{|}{C}}}}-\underset{\displaystyle H}{\overset{\displaystyle H}{\overset{|}{\underset{|}{C}}}}- \ . \ . \ .$$

Plastics--Brief Descriptions

This section is a compilation of the plastics to be tested. Information pertaining to "Characteristics and Properties" of plastics has been taken from "Section 3--Plastics" from the Materials Reference Issue of Machine Design (April 14, 1983, p. 143), and the Modern Plastics Encyclopedia was reviewed for "Applications." (All information for the synthetic rubbers was taken from "Section 4--Rubber" of Machine Design [p. 244]).

Acetal (Thermoplastic)

Characteristics and Properties

> Very strong, stiff engineering plastic with exceptional dimensional stability and resistance to creep and vibration fatigue; low coefficient of friction; high resistance to abrasion and chemicals; retains most properties when immersed in hot water; low tendency to stress-crack.

Applications

Metal castings, self-threading screws, seat belts, steering columns, shower heads, faucet cartridges, butane lighter bodies, garden sprayers, zippers, mechanical couplings, and agricultural machinery components.

Acrylics (Thermoplastic)

Characteristics and Properties

High optical clarity; excellent resistance to outdoor weathering; hard, glossy surface; excellent electrical properties, fair chemical resistance; available in brilliant, transparent colors.

Applications

Furniture, lighting fixture diffusers, glazing in skylights, pool enclosures and greenhouses, reflective devices, medical trays, video discs, computer data storage.

Amides--Nylon (Thermoplastic)

Characteristics and Properties

Family of engineering resins having outstanding toughness and wear resistance; low coefficient of friction, and excellent electrical properties and chemical resistance. Resins are hygroscopic; dimensional stability is poorer than that of most other engineering plastics.

Applications

Gears and bearings, fish line, fender extensions, mechanical components of computer hardware, antenna mounts, boil-in-bags, sausage casing, bottles, bicycle wheels, mallet heads.

Amino Resins--Urea, Melamine (Thermoset)

Characteristics and Properties

Abrasion and chip resistant; good solvent resistance; urea molds faster and costs less than melamine; melamine has harder surface and higher heat and chemical resistance.

Applications

Electric blanket control housings, buttons, utensil handles, decorative laminates for counter and table tops, orthopedic casts (with glass or mineral fiber mats), school desk tops and seats (with wood chips or wood flour), appliances.

Cellulosics (Thermoplastic)

Characteristics and Properties

Family of tough, hard materials: cellulose acetate, propionate, butyrate, and ethyl cellulose. Property ranges are broad because of compounding; available with various degrees of weather, moisture, and chemical resistance; fair to poor dimensional stability; brilliant color.

Applications

Tool handles, eyeglass frames, blister packages, electrical insulation, metallized flash cubes, tape, safety goggles, microfilm, skylights, and pen and pencil barrels.

Epoxy (Thermoset)

Characteristics and Properties

Exceptional mechanical strength, electrical properties, and adhesion to most materials; low mold shrinkage; some formulations can be cured without heat or pressure.

Applications

Protective and decorative surface coatings, floor finishes, tank and pipe coatings, aircraft primers, bonds new concrete to old, high-voltage insulators, tools, sporting goods, drive shafts, rocket motors, helicopter rotor blades.

Ethylene Polymers--Polyethylene (Thermoplastic)

Characteristics and Properties

Wide variety of grades: low, medium, and high density formulations. LD types are flexible and tough. MD and HD types are stronger, harder, and more rigid; all are lightweight, easy to process, low-cost materials; poor dimensional stability and heat resistance; excellent chemical resistance and electrical properties. Also available in ultrahigh-molecular weight grades.

Applications

Trash bags, stretch wrap film, lids and closures, toys, wire and cable coating, pails and tubs, tumblers, pipe extrusion, grocery carryout sacks.

Phenolics (Thermoset)

Characteristics and Properties

Low-cost material with good balance of mechanical, electrical, and thermal properties; limited in color to black and brown.

Applications

Telephone relay systems, pulleys, handles, brush holders, steam irons, vaporizers, laminating exterior or marine-grade plywood, and in the processing of paper.

Polyester Resins (Thermoplastic/ Thermoset)

Characteristics and Properties (Thermoplastic)

Excellent dimensional stability, electrical properties, toughness, and chemical resistance, except to strong acids or bases; notch sensitive; not suitable for outdoor use or for service in hot water; also available in thermosetting formulations.

Characteristics and Properties (Thermoset)

Excellent balance of properties; unlimited colors, transparent or opaque; gives off no volatiles during curing, but mold shrinkage is high; can use low-cost molds without heat or pressure; widely used with glass reinforcement to produce "fiberglass" components; also available in thermoplastic formulations.

Applications

Transformer housings, cookware applications, solar energy collectors, fasteners, springs, bearings, distributor caps, power tool housings, sewing thread, carbonated beverage bottles, film, cosmetic containers, tub and shower stalls.

Propylene Polymers--Polypropylene (Thermoplastic)

Characteristics and Properties

Outstanding resistance to flex and stress cracking; excellent chemical resistance and electrical properties; good impact strength above 15°F; good thermal stability; light weight, low cost, can be electroplated.

Applications

Textiles and flat yarns, interior trim parts for automobiles and trucks, food packages, laundry agitators, parts or dishwashers and refrigerators, syringes, luggage, tote boxes, and seating.

Silicones (Thermoset)

Characteristics and Properties

Outstanding heat resistance (from -100° to +500°F), electrical properties, and compatibility with body tissue; cures by a variety of mechanisms; high cost; available in many forms: laminating resins, molding resins, coatings, casting or potting resins, and sealants.

Applications

Mold release agents, lubricants, sealants, formed-in-place gaskets, wire insulation, contact lenses, circuit board coatings, and for mold-making in the furniture industry.

Styrene Polymers--Polystyrene (Thermoplastic)

Characteristics and Properties

Low cost, easy to process, rigid, crystal-clear, brittle material; low moisture absorption, low heat resistance, poor outdoor stability; often modified to improve heat or impact resistance.

Applications

Audio visual equipment, smoke detectors, data processing machines, cutlery, air conditioner and fan grills, culture dishes, test tubes, egg cartons, meat and poultry trays, blister packs, panels for lighting home decorative use.

Vinyl Polymers--Polyvinyl chloride (Thermoplastic)

Characteristics and Properties

Many formulations available; rigid grades are hard, tough, and have excellent electrical properties, outdoor stability, and resistance to moisture and chemicals; flexible grades are easier to process but have lower properties; heat resistance is low to moderate for most types of PVC; low cost.

Applications

Pipline systems, siding, gutters, shower curtains, wall coverings, auto tops and upholstery, floor mats, meat wrap, footwear, phonograph records, and sporting goods.

Urethane Polymers--Polyurethane (Thermoplastic/Thermoset)

Characteristics and Properties (Thermoplastic)

Tough, extremely abrasion and impact resistant material; good electrical properties and chemical resistance; can be made into films, solid moldings, or flexible foams; UV exposure produces brittleness, lower properties, and yellowing; also made in thermoset formulations.

Characteristics and Properties (Thermoset)

Can be flexible or rigid, depending on formulation, outstanding toughness and resistance to abrasion and impact; particularly suitable for large foamed parts, in either rigid or flexible types; also produced in thermoplastic formulations.

Applications

Foam insulation, cushioning in furniture and automobiles (dashboards, seats, and door panels), mattresses and beddings, coating; and in elastomer form they are used as automobile sight shields, ski boots, roller skate wheels, and health care applications.

Synthetic Rubbers--Neoprene

Characteristics and Properties

> Resistant to oils, ozone, oxidation, and flame; exposure to heat will not cause them to soften; "do not have the low-temperature flexibility of natural rubber, which detracts from their use in shock or impact applications" (p. 244).

Applications

Hose, footwear, tires, bearing pads, seals for window and curtain-wall panels.

Table 1 highlights additional information pertaining to the sample's flame, odor, and physical-visual characteristics as well as their reactions to solvents. This information was taken from Modern Industrial Plastics (Richardson 1974, pp. 86-88).

Summary of Literature

Even though descrepancies have arisen as to their actual beginning, plastics have been around for over 100 years. World War II's need for new materials boosted production in the plastics industry. Since that time, new discoveries have flooded the market. As a result, plastics have achieved greater levels of versatility and are used in applications that range from buildings to bodies.

All plastics began as a combination of various common

TABLE 1

ADDITIONAL CHARACTERISTICS OF PLASTICS

Plastics	Physical/Visual	Flame	Odor
ACETAL	tough, hard, metal-like ring when struck, translucent, low coefficient of friction, waxy feel	blue flame, no smoke, drippings may burn	formaldehyde
ACRYLIC	brittle, hard, transparent	blue flame, yellow top	fruit, floral-like
POLYAMIDES (Nylon)	tough, waxy feel, low coefficient of friction, translucent	blue flame, yellow tip, melts and drips, self-extinguishing	burned wool or hair
AMINOS (melmac)	hard, brittle, opaque but some translucent		
CELLULSICS (Cellulose Acetate)	(varies) tough, transparent	yellow flame, sparks, drippings may burn	acetic acid
EPOXIES	hard, mostly filled, reinforced, transparent	yellow flame, some soot	phenolic-phenol
POLYOLEFINS (Polyethylene)	waxy feel, tough, soft, translucent	blue flame, yellow top, drippings may burn, transparent hot area	paraffin

TABLE 1--(Continued)

Plastics	Physical/Visual	Flame	Odor
PHENOLICS	hard, brittle, reinforced, transparent	cracks, deforms, difficult to burn, yellow flame	phenolic-phenol
POLYESTERS	hard, brittle, filled, reinforced, transparent		
POLYOLEFINS (Polypropylene)	waxy feel, tough, soft, translucent	blue flame, drips, transparent hot area	heavy, sweet
SILICONES	tough, hard, filled, reinforced, some flexible, opaque	bright yellow-white	none
POLYSTYRENE	brittle, white bend marks, metal-like ring when struck, transparent	yellow flame, dense smoke, clumps of carbon in air	illuminating gas, sweet,
VINYLS	tough, some flexible, transparent	(vinyl chloride) yellow flame, green at edges, white smoke, self-extinguishing	hydrochloric acid
URETHANES (Polyurethane)	tough castings, mostly foams, flexible opaque	yellow with blue base	acrid

TABLE 1--(Continued)

Plastics	Acetone	Benzene	Ethylene Dichloride	Toluene
ACRYLIC	soluble	soluble	soluble	soluble
POLYAMIDES (Nylon)	insoluble	insoluble		insoluble
CELLULOSICS (Cellulose Acetate)	soluble	partially soluble		partially soluble
POLYOLEFIN (Polyethylene)	insoluble	insoluble		insoluble
POLYOLEFIN (Polypropylene)	insoluble	insoluble		insoluble
POLYSTYRENE	soluble	soluble		soluble
VINYLS (Vinyl Chloride)		insoluble		

elements. They differ because the amounts of the elements and the processes used to form each plastic were different.

Plastics are either thermoplastic or thermosetting materials; meaning that if heat is applied, their molecular structure allows the thermoplastics to soften while the thermosets remain rigid.

> In general, thermosets have better dimensional stability, heat resistance, chemical resistance and electrical properties than do the thermoplastics. Most thermosets are used principally in filled and/or reinforced form to increase dimensional stability or other properties, or for economy. Most formulations require heat and/or pressure for curing.
>
> Thermoplastics generally offer higher impact strength, easier processing, and better adaptability to complex designs than do thermosets ("Section 3--Plastics," Machine Design 1983, p. 143).

CHAPTER III

METHODOLOGY

This chapter discusses the methods and procedures followed to develop the plastics model dichotomous key. Again, the purpose of the study was to investigate selected plastics when treated by means of heat, fire, solvents, and specific gravity tests for the development of a model dichotomous key. The procedures followed for the study were to: 1) review the literature, 2) send out a form letter to plastics manufacturers requesting scrap plastics samples for testing purposes, 3) conduct the tests, 4) analyze the data, and 5) arrange the data into a dichotomous key format.

It should be noted that the purpose of these tests was not only to investigate the characteristics of the plastics, but also to compare test data with previous findings from various published sources and to check the ease in carrying out testing procedures.

Procedures for the Study

The first course of action for the study was to review the literature. As a result of the review of literature a list of 15 of "the most familiar groups of plastics" was taken from the Plastics Engineering Manual (p. 14) Lionel

Engineering Series. This list represented the plastics to be used as test samples for this study. In addition, appropriate tests were identified that would reveal characteristics of the selected plastics.

Procedures for the first three tests were taken from Harry L. Hess' Plastics Laboratory Procedures. These included the effects of heat, the fire test, and the effects of solvents. Two additional tests discussed by Hess, tensile strength and impact strength, were not feasible for this study because many of the samples were sent to the writer of this study in odd shapes and forms and could not be cut to any standard measurements.

The testing procedures for the fourth test, specific gravity, were derived from a formula found in the Textbook of Wood Technology, Vol. I. The step-by-step procedures for each of the tests are found in Appendix A.

To acquire the plastics needed for the tests, a form letter was sent out to thirty-five plastics manufacturers requesting scrap samples. These companies were chosen because the 1983 Thomas' Register of American Manufacturers revealed that they manufactured or had access to the plastics needed for testing purposes. Appendix B and Appendix C, respectively, contain a sample of the form letter sent and a list of the manufacturing companies.

After acquiring the plastics, the samples were cut to size and the four tests were conducted. The approximate size of samples used in the effects of heat, solvents, and specific gravity tests was one-quarter inch thick by one-half inch wide by one inch long; the fire test samples were roughly one-quarter inch thick by one-half inch wide by five inches long.

The effects of heat test was done simply to determine if the plastics were of a thermoplastic or thermosetting nature. A heated pencil soldering gun was placed against each sample for 3-4 seconds. Thermoplastic samples melted, whereas the thermosetting samples were unaffected.

The purpose of the fire test was not only to examine those plastics that did burn, but also to note the differences in the colors of the flames and the smoke, the amount of smoke given off, any odors, sputtering or crackling noises, burning drips that fell from the lit plastic pieces, and those plastics that did not burn at all or that were self-extinguishing.

The samples were positioned in a welding clamp approximately 18 inches above the counter top and were held in a small propane torch flame for 8-10 seconds. If they did not ignite on the first try, the procedure was repeated. Information was recorded after observing the burning tendencies for each sample. A metal plate was placed below the burning samples to catch any falling pieces.

To determine which plastics were affected by solvents, the samples were individually placed in jars of acetone, benzene, ethylene dichloride, and toluene for 5 minutes. The samples were then removed from the jar and examined for any softening or break-down effect. The plastics were considered soluble if a reaction had occurred. When no reaction occurred or when it was difficult to determine if a sample had actually been affected, the sample was recorded as being non-soluble.

Specific gravity is defined as "the ratio of the density of a material to the density of some standard material, such as water at a specified temperature . . . " (McGraw-Hill Dictionary of Scientific and Technical Terms 1978). To calculate the specific gravity, the samples were weighed on a balance beam scale. Next, the amount of water displaced in a graduated cylinder by each sample was recorded. (The water was at room temperature, approximately 68° F). These figures were placed in the following equation and divided out to determine the specific gravity of each sample.

$$\text{Sp. Gr.} = \frac{W_1}{W_2} = \frac{\text{weight of sample (grams)}}{\text{weight of water displaced (ml)}}$$

* (Note: 1 gram = 1 ml)

It should be noted that:

> Specific gravity calculations do not always match the standard results. This is caused by fillers and other additives in the plastic. This makes exact thermoplastic identification hard to do (Plastics Laboratory Procedures 1980, p. 14).

The vinyl, urethane, and polyester plastics were received in their pellet form. Because of the difficulties encountered in working with plastic pellets, the flame test was repeated on these samples. Different forms of the vinyl and urethane were acquired to determine any difference in the outcomes as compared to the original pellet samples that were tested. The new samples were a transparent vinyl film and a polyurethane foam. The polyester was done twice because it was thought that the flame of the propane torch may have been too powerful to allow the polyester to ignite properly. Therefore, a match was used in the second test.

The vinyl film and polyurethane foam were also tested for solvent reactions and specific gravity. The specific gravity test for the foam was not feasible, however, because the foam would soak up the water in the graduated cylinder, making an accurate reading impossible.

After administering the tests, the data was condensed onto a Comprehensive Data Form (Appendix D). The data was analyzed primarily as to the common characteristics of the plastics. These characteristics were designated as the basic steps to form a model dichotomous key for plastics.

CHAPTER IV

ANALYSIS OF DATA

Introduction

The purpose of this chapter is to present and analyze the test data. The tests conducted on the plastics for this study included the effects of heat, the fire test, the effects of solvents, and a specific gravity test. The plastics used and the companies that supplied the samples are compiled in Table 2.

In addition to the plastics noted in Table 2, the University of North Dakota Industrial Technology Department donated a roll of cellulose acetate photographic film. Also, a melmac plate, GE Brand RTV Silicone Rubber Adhesive Sealant and E-Pox-E Glue by Duro were purchased at local hardware stores. Because the latter two were sold in a tube, the plastics were squeezed out of their containers and allowed to cure in long strips and disk shapes, respectively, for testing purposes.

Effects of Heat

In the effects of heat test, the plastics were examined for any softening or melting tendencies while heat from a pencil soldering gun was applied to them. Those plastics affected by the heat source were considered thermoplastic materials; those not affected were labeled thermosets. Table 3 reveals the outcomes for each sample.

TABLE 2

PLASTICS AND SUPPLIERS

Polypropylene (Propylux Sheet)	Westlake Plastics Company
General Purpose Styrene (Styrolux Sheet)	Westlake Plastics Company
Nylon 6/6	Plastic Materials Co., Inc.
Type 10100 Natural Virgin Ultra High Molecular Weight Polyethylene	Solidur Plastics
B. F. Goodrich clear polyvinyl chloride 86155	3M
DuPont "Hytrel" polyester elastomer	3M
Polyurethane, polyester type high tensile strength extension grade ("Quinn" urethane type II--polyester urethane)	3M
Neoprene	3M
Polypenco® Acetal	Total Plastics
Acrylic	Total Plastics
Phenolic	Total Plastics

Fire Test

After identifying the samples as thermoplastics or thermosets, the plastics were categorically divided a second time for the fire test. These three main divisions were: a) plastics that burned; b) plastics that did not burn; and

c) self-extinguishing plastics. The plastics that readily caught fire were put under the "burn" heading. "Didn't burn" referred to the samples that would not catch at all; and those that caught but later went out were "self-extinguishing" plastics. Supplementary characteristics included smoke, odor, and drips. (Appendix E illustrates these burning drips.) These characteristics were provided as further helps to pinpoint the plastics being identified. Table 4 is a breakdown of the fire test results.

TABLE 3

EFFECTS OF HEAT

Thermoplastics--Melt	Thermosets--No Response
Acetal	Aminos/Melmac
Acrylic	Epoxy
Amides/Nylon	Phenolic
Cellulose Acetate	Silicones
Polyethylene	
Polyester	
Polypropylene	
Polystyrene	
Neoprene	
Vinyl	
Polyurethane	

TABLE 4

FIRE TEST

Characteristics	Thermoplastics	Thermosets
No burn		Melmac (chars)
Self-extinguishing	Amides/Nylon Polyester Neoprene Vinyl-pellets & film Polyurethane, polyester pellets	Phenolic
Burns	Acetal (low white/light blue) Acrylic (light yellow/orange blue bottom, sputters) Cellulose Acetate (bright yellow) Polyethylene (low yellow, gentle) Polypropylene (large yellow) Polystyrene (light orange) Polyurethane foam (large yellow)	Epoxy (yellow/ orange, sputters) Silicone (low white, sputters)
Smokes	Cellulose Acetate Polypropylene Polystyrene (black stream) Neoprene Polyurethane foam	Epoxy Silicone (low, white)
Odor	Acrylic Nylon Cellulose Acetate Polyester Polypropylene Polystyrene	Amides/Melmac Epoxy Phenolic Silicone

TABLE 4--(Continued)

Characteristics	Thermoplastics	Thermosets
Odor (Continued)	Vinyl Polyurethane foam	
Drips	Polyethylene Polypropylene Polystyrene	Epoxy

Effects of Solvents

The effects of solvents test marked the third breakdown for the composition of the dichotomous key. Samples were listed under the solvents that caused them to react during testing.

Specific Gravity

A final determinant for each plastic, its specific gravity, was also listed. (The specific gravity measurements in parenthesis were taken from published sources.)

Asterisks were used in the dichotomous key to signify an end to the characteristics identification process for each sample. Those plastics with an asterisk behind them in the fire test level of the key were unaffected by solvents. Specific gravity measurements for the plastics were then placed behind the asterisks.

Tables 5 and 6, respectively, contain the data obtained from the effects of solvents and specific gravity tests.

TABLE 5

EFFECTS OF SOLVENTS

Acetone
Neoprene (softens outer edge)
Vinyl film (becomes more pliable)
Polystyrene (sticky outer layer)
Benzene
Neoprene (sticky outer layer)
Vinyl film (becomes more pliable)
Polystyrene (sticky outer layer)
Ethylene Dichloride
Neoprene (sticky outer layer)
Vinyl--pellets (softer, more rubbery)
Vinyl--film (becomes more pliable)
Acrylic (sticky on outside)
Cellulose Acetate (plastic softens)
Polystyrene (sticky outer layer)
Epoxy (softens greatly, becomes pliable)
Toluene
Neoprene (sticky outer layer)
Vinyl--film (becomes more pliable)
Polystyrene (sticky outer layer)
Epoxy (edges soften, slippery feeling all around)

TABLE 6

SPECIFIC GRAVITY

Plastics Tested Sp. Gr. @ approx. 20° C (68° F)		Measurements from *Modern Industrial Plastics* Sp. Gr. @ 23° C (73.4° F)
Acetal	1.88	1.40 - 1.45
Acrylic	1.07	1.17 - 1.20
Amides/Nylon	1.09	1.09 - 1.14
Cellulosics/ Cell. Acetate	0.11	1.15 - 1.40
Epoxies	1.20	1.18 - 1.80
Polyolefins/ Polyethylene	1.01	0.91 - 0.97
Phenolics	1.36	1.25 - 1.55
Polyesters	1.21	1.30 (0.99 - 1.21)*
Polyolefins/ Polypropylene	1.05	0.91 - 0.97
Silicones	1.32	1.60 - 2.00
Polystyrene	1.09	0.98 - 1.10
Vinyls:		
Film	1.00	1.20 - 1.55
PVC Pellets	1.18	1.16 - 1.35**
Urethane/ Polyurethane Pellets	1.24	1.11 - 1.25**

*A Concise Guide to Plastics 1963.

**Plastics Laboratory Procedures 1980.

Dichotomous Key Model

The dichotomous key's evolution process began with the realization that the plastics industry was rapidly expanding in its information and knowledge of plastics. To grasp just a part of this information, it was decided that the 15 most familiar plastics would represent the basis for this model dichotomous key.

In keeping with the definition of a dichotomous key, there had to be a "choice between two alternative characteristics" that would lead to classification. These alternatives, as determined by the effects of heat test, were the thermoplastics or the thermosets. From that point, additional tests were designed, conducted, and arranged in the dichotomous key format to provide for further clarity in the plastics identification process.

This model dichotomous key represents a means for classifying new plastics as they become available. (See Figure 1.)

How to Use the Plastics Dichotomous Key

The plastics dichotomous key is composed of a series of steps. The ending step, or the point at which the plastics sample is identified, is reached by conducting four tests. The effects of heat is the first test. When it has been determined whether the sample is a thermoplastic or a thermoset the experimenter procedes along the appropriate branch of the key to the next step; the fire test. Samples

Figure 1

Plastics Dichotomous Key

PLASTICS DICHOTOMOUS KEY

SAMPLE

Thermoplastics	Test	Thermosets
Acetal Acrylic Amides/Nylon Cellulose Acetate Polyethylene Polyester Polypropylene Polystyrene Neoprene Vinyl Polyurethane	Effects of Heat	Aminos/Melmac Epoxy Phenolic Silicones

Burns	Self-Ext.	Test	Burns	Self-Ext.	No Burn
Acetal* Acrylic Cellulose Acetate Polyethylene* Polypropylene* Polystyrene Polyurethane Foam*	Amides/Nylon Polyester* Neoprene Vinyl- (pellets & film) Polyurethane- polyester pellets*	Fire Tests *(See page 2 & 3 of Key)*	Epoxy Silicones*	Phenolic*	Aminos/ Melmac*

Acetone	Benzene	Toluene	Eth. Dic.	Test	Acetone	Benzene	Toluene	Eth. Dic.
Neoprene Vinyl-film Polystyrene	Neoprene Vinyl-film Polystyrene	Neoprene Vinyl-film Polystyrene	Neoprene* Vinyl-film and pellets* Acrylic* Cell. Ace.* Polystyrene*	Effects of Solvents *Specific Gravity *(See page 3 & 4 of Key)*			Epoxy	Epoxy*

PLASTICS DICHOTOMOUS KEY

Effects of Heat

Thermoplastics

Acetal
Acrylic
Amides/Nylon
Cellulose Acetate
Polyethylene
Polyester
Polypropylene
Polystyrene
Neoprene
Vinyl
Polyurethane

Thermosets

Aminos/Melmac
Epoxy
Phenolic
Silicones

Fire Test

Thermoplastics

Self-Extinguishing:

- Amides/Nylon
- Polyester
- Neoprene
- Vinyl--pellets & film
- Polyurethane, polyester pellets

Burns:

- Acetal (low white/light blue)
- Acrylic (light yellow/orange, blue bottom, sputters)
- Cellulose Acetate (bright yellow)
- Polyethylene (low yellow, gentle)
- Polypropylene (large yellow)
- Polystyrene (light orange)
- Polyurethane foam (large yellow)

Thermosets

No burn:

- Melmac (chars)

Self-Extinguishing:

- Phenolic

Burns:

- Epoxy (yellow/orange, sputters)
- Silicone (low white, sputters)

Smoke:

- Epoxy
- Silicone (low, white)

Odor:

- Amides/Melmac
- Epoxy
- Phenolic
- Silicone

Fire Test--(Continued)

Thermoplastics	Thermosets
Smokes:	Drips:
Cellulose Acetate	Epoxy
Polypropylene	
Polystyrene (black stream)	
Neoprene	
Polyurethane Foam	
Odor:	
Acrylic	
Nylon	
Cellulose Acetate	
Polyester	
Polypropylene	
Polystyrene	
Vinyl	
Polyurethane Foam	
Drips:	
Polyethylene	
Polypropylene	
Polystyrene	

Effects of Solvents

Acetone

Neoprene (softens outer edge)
Vinyl film (becomes more pliable)
Polystyrene (sticky outer layer)

Benzene

Neoprene (sticky outer layer)
Vinyl film (becomes more pliable)
Polystyrene (sticky outer layer)

Ethylene Dichloride

Neoprene (sticky outer layer)
Vinyl--pellets (softer, more rubbery)
Vinyl--film (becomes more pliable)
Acrylic (sticky on outside)
Cellulose Acetate (plastic softens)
Polystyrene (sticky outer layer)
Epoxy (softens greatly, becomes pliable)

Effects of Solvents--(Continued)

Toluene

Neoprene (sticky outer layer)
Vinyl--film (becomes more pliable)
Polystyrene (sticky outer layer)
Epoxy (edges soften, slippery feeling all around)

Specific Gravity

Plastics Tested		Measurements from *Modern Industrial Plastics*
Sp. Gr. @ approx. 20° C (68° F)		Sp. Gr. @ 23° C (73.4° F)
Acetal	1.88	1.40 - 1.45
Acrylic	1.07	1.17 - 1.20
Amides/Nylon	1.09	1.09 - 1.14
Cellulosics/ Cell. Acetate	0.11	1.15 - 1.40
Epoxies	1.20	1.18 - 1.80
Polyolefins/ Polyethylene	1.01	0.91 - 0.97
Phenolics	1.36	1.25 - 1.55
Polyesters	1.21	1.30 (0.99 - 1.21)*
Polyolefins/ Polypropylene	1.05	0.91 - 0.97
Silicones	1.32	1.60 - 2.00
Polystyrene	1.09	0.98 - 1.10
Vinyls: Film	1.00	1.20 - 1.55
Vinyls: PVC Pellets	1.18	1.16 - 1.35**
Urethane/ Polyurethane Pellets	1.24	1.11 - 1.25**

*A Concise Guide to Plastics 1963.

**Plastics Laboratory Procedures 1980.

are recorded as being self-extinguishing, nonburning, or those that will burn. Supplementary characteristics such as smoking, odors, or dripping are noted as well. Thirdly, the sample is tested as to the effects of solvents. The sample is recorded under the name of any solvent that reacts with the sample. Data recorded for each test is compared to the corresponding information at each level on the dichotomous key. Upon completion of the tests and comparison of the data, the experimenter should have a good idea as to the name of the plastic being investigated. To further verify its identity, a specific gravity test is conducted. The measurement is also compared for a likeness against the figures found on page 2 of the dichotomous key. The asterisk symbolizes the ending point; the moment at which the plastics sample may be identified. Asterisks in the fire test level signify those plastics that did not react with any of the solvents.

Summary

In this chapter, Table 2 listed the manufacturers who contributed testing samples for this study. The plastics provided were also noted.

The test data was analyzed and categorized. Subheadings and supplementary characteristics were used for each test to provide further breakdowns. This allowed for a more thorough identification process. These tests, their subheadings and supplementary characteristics included:

1) effects of heat--thermoplastic plastics, thermosetting plastics;
2) fire test--burn, didn't burn, self-extinguishes, smokes, odor, drips;
3) effects of solvents--acetone, benzene, ethylene dichloride, toluene; and
4) specific gravity.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Restatement of the Problem

The purpose of this study was to investigate selected plastics when treated by means of heat, fire, solvents, and specific gravity tests for the development of a model dichotomous key.

Summary

The plastics used in this study were limited to a list of 15 of "the most familiar groups of plastics" taken from the Plastics Engineering Manual (p. 14)--Lionel Engineering Series.

The review of literature furnished a brief historical overview of plastics, examined their uses and advantages, and delved into their chemical make up. In addition, four tests were selected that would reveal characteristics of the plastics. The procedures, equipment, and materials needed for each test were described in the chapter on methodology. Once the tests were conducted, the data was analyzed and the samples were listed under the appropriate categories that were selected to make up the dichotomous key.

Page 1 of the dichotomous key was a visual model of the key. (See Figure 1.) This was constructed by arranging the categories in a stepped sequence. Pages 2, 3, and 4 are the supplementary characteristics for the plastics found in Tables 3 through 6 of this study.

Conclusions

Conclusions for this study were derived from the review of literature, testing procedures, and the analysis of data.

1. Because the majority of the people are still unfamiliar with even the most common types of plastics used today, a form of media is needed to help them identify these plastics. The writer concludes that this form of media may well be the plastics dichotomous key.
2. The propane torch used in the fire test may have been too powerful of a flame source to properly allow some materials to catch fire and burn.
3. In the fire test, discrepancies in the colors of the flames arose between the writer's findings and reports from other sources. This is because the writer concentrated primarily on the color of the upper part of the flame, whereas, the other sources noted the color at the base of the flame as well.
4. Contaminated solvents, due to repeated use, may have caused difficulties in determining effects on some of the plastics.
5. Specific gravity results may have been affected

by inaccurate readings from the balance scale and graduated cylinder.

Recommendations

Recommendations for this study were based primarily on difficulties encountered in the test procedures. Additional recommendations explain how the dichotomous key is used and what further study should be done on the key.

1. A gentler flame source should be used in the fire test. One alternative would be a Bunsen burner flame.
2. Note all colors of the flame for the fire test. This requires attention to both the top and bottom parts of the flame.
3. In determining the effects of solvents, fresh chemicals should be used for each test conducted.
4. Cellulose acetate should be tested in a form other than photographic film in the specific gravity test. Its tendency to curl and stick to the sides of the graduated cylinder may have been a hindrance in obtaining an accurate measurement.
5. To determine the identity of the plastics samples, testing and comparison of characteristics should follow the same order as that of the dichotomous key. A thorough recommendation on how to use the key may be found in Chapter IV.
6. A follow-up study should be conducted in which the

dichotomous key is used as a test instrument. Students enrolled in plastics/synthetics classes at the University of North Dakota would use the key to identify several plastics samples. The samples would be limited to those used in this study. The students would also fill out a questionnaire dealing with the ease, difficulty, and helpfulness of the key. Outcomes to the plastics identification test as well as answers to the questionnaire would be used to determine the validity of the dichotomous key.

APPENDIX A

TESTING PROCEDURES

TESTING PROCEDURES

A) EFFECTS OF HEAT--THERMOPLASTIC/THERMOSETTING IDENTIFICATION

Equipment and Materials:

1. Plastics samples
2. Pencil soldering gun

Procedures:

1. Plug in the electric soldering gun. Let it heat.
2. Hold the hot soldering gun against the sample for 3 or 4 seconds. Thermoplastics should melt, darken, and become sticky in the heated area. Thermosets should char, but not melt in the heated area.

B) FIRE TEST--COLOR OF FLAME, SMOKE, ODOR, SELF-EXTINGUISHES, DRIPS, SPARKS, DOESN'T BURN

Equipment and Materials:

1. Plastics samples
2. Clamp to hold plastics samples
3. Propane torch and striker
4. Metal sheet to catch drippings from burning plastics

Procedures:

1. One end of a ¼" x ½" x 5" horizontal bar of the plastic is held in a propane torch flame for 10 seconds.
2. If it does not ignite after the first 10 seconds, the test is repeated.
3. Examine and record the colors of the flames and the smoke, the amount of smoke given off, odors, sputtering or crackling noises, burning drips, and the plastics that were self-extinguishing.

C) EFFECTS OF SOLVENTS

Equipment and Materials:

1. Plastics samples

2. Acetone, benzene, toluene, ethylene dichloride
3. Glass jars
4. Graduated cylinders

Procedures:

1. When making solvent tests, use a ratio of one volume of plastics samples to 20 volumes of boiling or room temperature solvent.
2. Measure the required amounts of each solvent and pour into separate jars.
3. Place a sample of each plastic in each of the 4 solvents (one sample at a time).
4. After 5 minutes remove the samples using rubber gloves and record the results.

D) SPECIFIC GRAVITY

Equipment and Materials:

1. Plastics samples
2. Balance beam scale
3. Graduated cylinder
4. Water

Procedures:

1. Use the specific gravity formula and fill in the appropriate information.

$$\text{Sp. Gr.} = \frac{W_1}{W_2} = \frac{\text{weight of sample (grams)}}{\text{weight of water displaced (ml)}}$$

*(Note: 1 gram = 1 ml)

2. Weigh the plastics samples on the balance beam scale (W_1).
3. Add water to a graduated cylinder. Record the water's height.
4. Place the sample in the graduated cylinder. Record the water's height.
5. Record the difference of the two readings as W_2.
6. Solve the equation to determine the specific gravity.

APPENDIX B

LETTER TO PLASTICS MANUFACTURERS

November 11, 1983

Dear Sirs:

Your assistance is needed in obtaining specific plastic materials. As a graduate student at the University of North Dakota, I am focusing my thesis work on plastics. More specifically, my goal is to put together a dichotomous key for plastics--a guide to identifying the more common plastics.

Data for this key will be obtained from several tests conducted on the samples. I have need of the following plastics:

Acetals (Delrin)
Acrylics
Amides (Nylons)
Amino resins (Urea, Melamine, Melmac)
Cellulosics (Cellulose acetate)
Epoxy resins
Polyethylene
Phenolics
Polyester resins
Polypropylene
Silicones
Polystyrene
Synthetic rubbers (Neoprene)
Vinyl
Polyurethane

The approximate size of the samples needed for testing purposes is ½" x 3/4" x 5". (Samples sent need not be cut to size.)

In exchange for your contributions, I would gladly send you a copy of my findings.

Thank you very much.

Sincerely,

Diane Burnham
Graduate Teaching Assistant

Dr. Myron Bender
Chairman of Thesis Committee

APPENDIX C

PLASTICS MANUFACTURERS

PLASTICS MANUFACTURERS

Current, Inc.
34 Tyler Street
East Haven, Conn. 06512

Uniroyal, Inc.
Middlebury, Conn. 06749

Plastic Materials Co., Inc.
638 S. Marshall Street
Milford, Del. 19963

Atlas Fibre Co.
6970 N. Central Park Ave.
Chicago, Ill. 60645

Engineered Plastic Products Corp.
4655 N. Elston Ave.
Chicago, Ill. 60630

Union Carbide Corp.
120 South Riverside Plaza
Chicago, Ill. 60606

American Louver Co.
7700 Austin Ave.
Skokie, Ill. 60077

Continental Plastic Co.
Div., CPI, Inc.
452 - T Diens Drive
Wheeling, Ill. 60090

Rostone
2773 S. Concord Rd.
Lafayette, Ind. 47903

Polymer Engineering, Inc.
U.S. 421 N.
Reynolds, Ind. 47980

Fawn Plastics Co., Inc.
226 - T Schilling Circle
Hunt Valley, MD 21031

Glendale Plastics, Inc.
406 State Street
Ludlow, Mass. 01056

New England Plastics Corp.
308 Salem Street
Woburn, Mass. 01801

Total Plastics, Inc.
5273 Wynn Road
Kalamazoo, Mich. 49001

Ram Products Co.
1113 N. Centerville Road
Sturgis, Mich. 49091

Star-Tex Corp.
8233 - 220th Street
Lakeville, Minn. 55044

Airtex Industries, Inc.
3558 Second Street
N. and 36th Ave.
Minneapolis, Minn. 55412

Sheldahl
P. O. Box 150
Northfield, Minn. 55057

Industrial Specialties
Div./3M
220-7E-01 3M Center
St. Paul, Minn. 55144

Rummel Fibre Co., Inc.
82 Progress Street
Union, New Jersey 07083

Plastics Associates
Div. of P-A Industries, Inc.
43-T Drexel Drive
Bay Shore, New York 11706

Reed Plastics Corp.
Holden Industrial Park
Holden, Mass. 01520

UniRubber, Inc.
60 Warren Street
New York, New York 10007

Accurate Plastics, Inc.
16 Morris Place
Yonkers, New York 10705

Goodyear Tire and Rubber Co.
Chemical Division
P. O. Box 9115-T
Akron, OH 44305

Clifton Plastics, Inc.
559 E. Baltimore Pke.
Clifton Heights, PA 19018

Solidur Plastics Co.
201 Plum Industrial Court
Pittsburgh, PA 15239

Delford Industries, Inc.
87 Washington Street
Middletown, New York 10940

Great Lakes Plastics Co., Inc.
2373 Broadway Terrace
Buffalo, New York 14212

Commercial Plastics and Supply Corp.
98-31 B. Famaica Ave.
Richmond Hill, New York 11418

Aitna Plastics Corp.
17th and St. Clair Ave.
Cleveland, OH 44114

Westlake Plastics Co.
P. O. Box 127
161 W. Lenni Road
Lenni, PA 19052

Airo Rubber Co., Inc.
P. O. Box 1409 - T
7501 W. 99th Place
Bridgeview, Ill. 60455

United Rubber Supply Co., Inc.
56 Warren Street
New York, New York 10007

APPENDIX D

COMPREHENSIVE DATA FORM

COMPREHENSIVE DATA FORM

Plastics	Heat	Color	Self-Ext.	No Burn	Smoke	Odor	Drips	Sp. Gr.

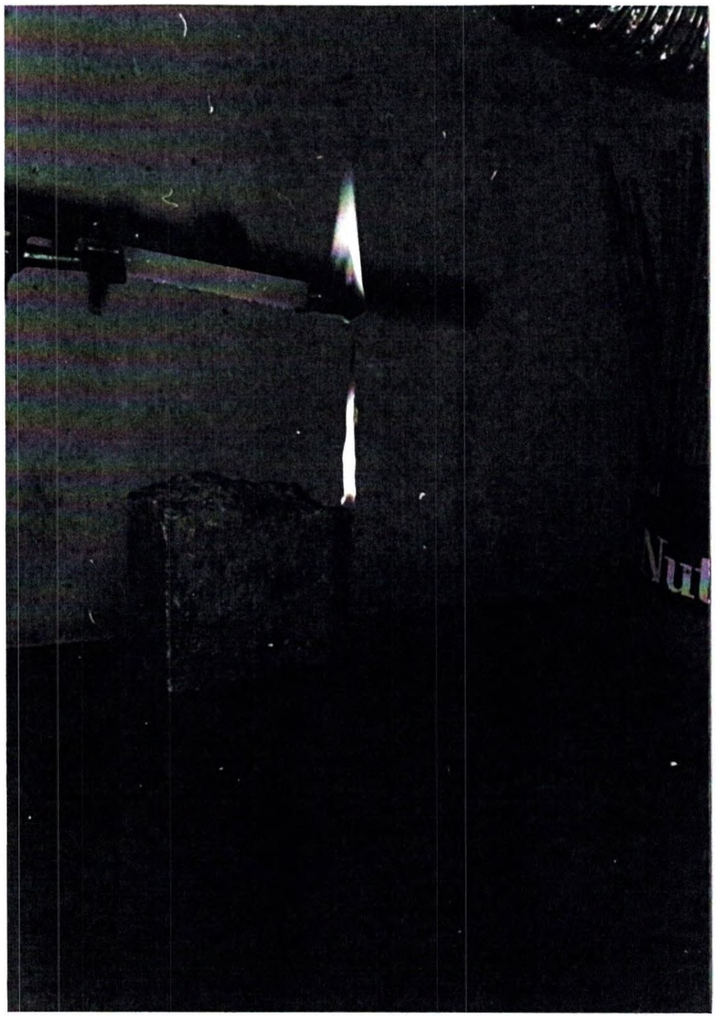
COMPREHENSIVE DATA FORM

Plastics	Acetone	Benzene	Toluene	Ethylene Dichloride

APPENDIX E

BURNING DRIPS ILLUSTRATION

FIGURE 2



BURNING DRIPS

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