WAITKUS, Lorin Victor, 1932-
CONCEPTUALIZING A BODY OF KNOWLEDGE OF
SOLID MATERIALS PROCESSING WITH IMPLICATIONS
FOR CURRICULUM DEVELOPMENT.

The Ohio State University, Ph.D., 1971
Education, industrial

University Microfilms, A XEROX Company, Ann Arbor, Michigan

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CONCEPTUALIZING A BODY OF KNOWLEDGE OF SOLID MATERIALS PROCESSING WITH IMPLICATIONS FOR CURRICULUM DEVELOPMENT

DISSERTATION

Presented in Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy in the Graduate School of The Ohio State University

By

Lorin Victor Waitkus, B.S., M.Ed.

* * * * *

The Ohio State University
1971

Approved by

[Signature]
Adviser
Faculty of Industrial Technology
College of Education
Sincere appreciation is expressed to the members of the writer's committee, Professors Darwin B. Close, Willis E. Ray, and Gregory L. Trzebiatowski for their help and assistance. Special appreciation is expressed to Professor Donald G. Lux for his guidance, understanding, and encouragement during the writer's graduate program and development of the research project.

Appreciation is expressed to the Career Development Committee and the Young Members Committee of the American Society for Metals. Appreciation is due to David W. Guerdat, Career Development Coordinator, of the American Society for Metals, for his generous help, criticism, and suggestions in the development of the classifications for this study.

Appreciation is expressed to Miss Cecilia Marsh for proof-reading the manuscript.

Lastly, is the debt owed to Zivile for typing the manuscript and to the children, Donna, Peter, and Edward for their patience and support.
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<td></td>
<td>Willis E. Ray</td>
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<td>Minor Fields</td>
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<td>Professor Darwin B. Close</td>
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<td>Educational Research and Development</td>
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CHAPTER I

INTRODUCTION

Overview

Within the last ten years, the U. S. Office of Education has supported projects for the improvement of industrial arts curriculum. The Industrial Arts Curriculum Project (IACP), one of the funded projects, was developed at The Ohio State University in cooperation with the University of Illinois.

The major objective of the IACP was to develop, evaluate, improve, and institutionalize an innovative and relevant instructional program in industrial arts for junior high school youth. The efforts of the IACP focused on the concept of industrial technology, the knowledge of practices that man uses to satisfy his wants for material goods. Two activities in which man uses this knowledge are in constructing and in manufacturing. In order to provide an understanding in these technologies, two courses were developed. The first course developed for junior high students was "The World of Construction" and the second, "The World of Manufacturing."

Through a study of "The World of Construction,"
students learn how roads, bridges, tunnels, dams, and buildings are made by a management-personnel-production system. In "The World of Manufacturing," students learn how a management-personnel-production system produces manufactured goods.

The two industrial arts courses were a result of six years of researching, developing, field testing, and revising. The course materials have been reviewed by individuals from industry and education. Over 20,000 students successfully completed the program during field testing (Buffer, Lux, & Ray, 1971, p. xv).

The program that evolved from the IACP was relevant and well received on a national basis. As these two programs became institutionalized, it was generally agreed by educators that continuity should be provided in industrial technology education from grades K-12. The need for relevant curriculum in industrial technology at all levels of education is of paramount importance in order that citizens have the opportunity to gain knowledge of the man-made world (Buffer, Lux, & Ray, 1971, p. 207).

Various curriculum options have been considered by the IACP personnel. In a graduate class at The Ohio State University, options listed on a working paper ranged from the development of a more sophisticated and complex construction and manufacturing course to a modification of a curriculum structure which would provide a different working
The proposal of the development of "smaller elements of the body of knowledge," or subsystems of industrial technology, was considered to be a possible option. The smaller subsystems that were proposed were "woods processing technology," "metals processing technology," and "plastics processing technology" (Ray, 1969). However, a more complete subsystem in industrial technology could be considered such as solid materials processing technology.

Curriculum projects have followed certain procedures in developing course materials. Six general factors seem appropriate for developing course materials and selecting learning activities (Towers, Lux, & Ray, 1966, p. 237).

1. Structure the body of knowledge
2. Determine desired behavioral change or objectives
3. Consider the nature of the learner
4. Plan school facilities and materials
5. Implement instructional procedures and materials
6. Perform measurement and evaluation.

Clark and Guba (Stufflebeam, 1969, pp. 66-67) propose four steps for curriculum change in education: research, development, diffusion, and adoption. The objective of research is to advance knowledge, i.e., to conceptualize. The objective of development is to innovate, plan, build components, and assemble components. The
objective of diffusion is to create an awareness and provide an opportunity to examine the qualities of the development. The objective of adoption is to train, familiarize, operationalize, and assimilate the curriculum product.

The following statement was made by the National Conference on Research in Industrial Arts (Suess, 1969, p. 15): "The most important task facing industrial arts is continued research related to content selection at all levels." The first step in curriculum development, it would appear, is that of conceptualizing subject matter.

Statement of the Problem

There are two different phases to this study: (1) The development of a classification of content that may constitute a body of knowledge; and (2) the organization of the content or knowledge that may be effectively developed into learning experiences. Therefore, the principal purpose of this study is to develop a rationale and a structure for the teaching of solid materials processing technology. A further purpose is to delineate the implications of this body of knowledge for curriculum development.

Although the study involves the development of a body of knowledge of solid materials processing technology, other important questions to be answered are as follows:

1. What is the underlying reason for studying solid materials processing technology?
2. What are the materials that may be classified as solids?

3. What are the properties that solid materials may possess?

4. Can universal processes be applied to solid materials?

Hypotheses

1. The knowledge of solid materials processing technology can be identified and a classification of it can be developed to provide a basis for developing instructional programs.

2. The structured body of knowledge of materials processing has implications for industrial arts curriculum workers at many levels as well as for curriculum workers in other technical curricula, such as engineering.

Significance of the Study

The Industrial Arts Curriculum Project (IACP) provided a rationale for the study of industrial technology. The rationale established the concept of industrial technology, the knowledge of practices that man uses to satisfy his wants for material goods. Two courses which exemplified the implementation of this concept into instructional systems were called "The World of Construction" and "The World of Manufacturing."
The IACP was successful in providing these instructional programs for the junior high school grades. As previously stated, educators have advocated the importance of providing a continuity of relevant industrial technology instructional programs from grades K-12. These programs are important in order to provide industrial literacy for all citizens.

In this study an attempt will be made to develop a knowledge of solid materials processing technology, comprised of a classification of solid materials, a classification of properties of solid materials, and a classification of processes, with implications for curriculum development. This would comprise the first step in curriculum development, that of conceptualizing subject matter. If the study is successful, it will provide suggestions for a curriculum of solid materials processing technology. Thus, it will provide the basis for developing the continuity of relevant instructional programs in industrial technology.

There are other benefits to be derived from this study:

1. It will make a contribution to the body of knowledge in industrial technology.
2. It will provide a method for other researchers to follow in deriving curriculum content.
3. It will provide a direction for programmatic research of subsystems in industrial technology.
4. It will provide a basis for developing instruction which can provide industrial literacy in solid materials processing technology.

**Assumptions**

1. Every industrial product is ultimately expressed in a material structure.
2. Processed solid materials are a major product class of industry.
3. Man changes the shapes of materials by forming, separating, and/or combining.
4. The study of solid materials processing is important in the man-made world.
5. Solid materials processing technology is a major component of industrial technology.
6. The structured body of knowledge of solid materials processing technology can be studied as a technology.
7. The study of solid materials processing logically follows the Industrial Arts Curriculum Project courses of manufacturing and construction.

**Delimitations**

The following list comprised the delimitations of the research study:

1. Only solid materials will be considered.
2. Properties of materials depend upon the nature of the material; however, properties of materials will be studied in relation to intended processing rather than as abstract physical phenomena.

3. Only a classification of materials and properties will be developed.

4. Since materials can combine in an infinite number of ways to produce new and different materials with varied properties, only a third-, fourth-, or fifth-order classification will be developed.

5. Materials processing technology will be limited to two basic production stages.
   A. Processing raw material into standard sizes, shapes, and weights called standard stock.
   B. Processing standard stock into finished products.

6. The curriculum development implications of the structured body of knowledge will be pointed out for solid materials processing technology only and not for management or personnel technologies as they relate to solid materials processing technology.
7. The curriculum development implications of the structured body of knowledge will be pointed out for the study of processing raw materials into standard stock and the processing of standard stock into finished products only.

Limitations

This study had limitations inherent in the classification of content that may constitute a body of knowledge.

1. The researcher had opinions relative to the development of a classification of solid materials and properties. To avoid opinions from affecting the results, two committees of expert reviewers were employed to evaluate the classifications.

2. Since two committees were selected from one professional society to act as the expert reviewers, there may exist a possible bias in the evaluation of the classifications.

3. Processing classifications developed by the IACP will be used in this study.

Definition of Terms

Words have different meanings to individuals in different environments. Within the limits of a reasonable
statement of meaning, the following list of words are defined as they will be used in the study.

**Materials** are defined as gases, liquids, and solids.

**Solids** are defined as those materials which possess the property of retaining their shape without being held in a container, will not flow during the period of time required for making observations, and will not expand to fill the available volume in which they are found.

**Processing** is defined as a technology of changing the form utility of solids to increase their value.

**Industry** is defined as constructing and manufacturing.

**Construction** is defined as the element of industry which produces goods which are fixed on a site.

**Manufacturing** is defined as the element of industry which produces goods for use elsewhere.

**Technology** is defined as the science of the application of knowledge to practical purposes.

**Industrial arts** is defined as a school program in which students study industrial technology.

**Concept** is defined as an interpretation of an event or data by use of a word or symbol.

**Structured knowledge** is defined as ordered knowledge which facilitates instruction.
**Steps to the Solution of the Problem**

A graphic representation of work flow can have several forms. The choice of the appropriate form can be made when a plan is ascertained to be either deterministic or probabilistic (Cook, 1969).

A project such as the construction of a building would be deterministic since well known information is available to develop the work flow plan. A developmental project, however, would be probabilistic since previous knowledge is not available in developing a work flow plan.

The sequential steps to be taken for this developmental project, which is probabilistic in nature, are typified by the following chart. See Figure 1. Program Evaluation and Review Technique (PERT) (Cook & Trzebiatowski, 1970) can be applied to the logical planning of this study. The following PERT network illustrates the steps in the content analysis necessary to complete this research project.

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>00 - 01</td>
<td>Begin research project</td>
</tr>
<tr>
<td>01 - 02</td>
<td>Plan research project</td>
</tr>
<tr>
<td>02 - 04</td>
<td>Review project with IACP and American Society for Metals (ASM) staffs</td>
</tr>
<tr>
<td>04 - 05</td>
<td>Refine research project</td>
</tr>
</tbody>
</table>

**ANALYZE FOR A PRELIMINARY CLASSIFICATION OF MATERIALS AND PROPERTIES**

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>05 - 06</td>
<td>Analyze literature at ASM library</td>
</tr>
</tbody>
</table>
05 - 07  Analyze industrial arts materials curricula
05 - 08  Review and analyze card catalog sources
06 - 10  Dummy
07 - 10  Dummy
08 - 10  Dummy
10 - 11  Dummy

DESIGN AND DEVELOP PRELIMINARY CLASSIFICATIONS

11 - 12  Dummy
11 - 13  Dummy
11 - 14  Dummy
11 - 15  Dummy
11 - 16  Dummy
12 - 19  Write cover letter
13 - 20  Obtain IACP description
14 - 21  Write forms for materials review
15 - 22  Write forms for properties review
16 - 23  Write directions
19 - 25  Dummy
20 - 25  Dummy
21 - 25  Dummy
22 - 25  Dummy
23 - 25  Dummy

SYNTHESIZE A PRELIMINARY CLASSIFICATION OF
MATERIALS AND PROPERTIES

10 - 18  Record constituents of materials and properties
Figure 1

PERT Network of Activities to Complete Research Project
<table>
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<th>Time Frame</th>
<th>Task Description</th>
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<tr>
<td>18 - 24</td>
<td>Classify constituents of materials and properties</td>
</tr>
<tr>
<td>24 - 26</td>
<td>Refine classification of materials and properties</td>
</tr>
<tr>
<td>26 - 27</td>
<td>Review classification of materials and properties</td>
</tr>
<tr>
<td>27 - 28</td>
<td>Type and duplicate classification of materials and properties</td>
</tr>
<tr>
<td>25 - 29</td>
<td>Duplicate all communications</td>
</tr>
<tr>
<td>28 - 29</td>
<td>Dummy</td>
</tr>
<tr>
<td>29 - 30</td>
<td>Assemble papers for sending</td>
</tr>
<tr>
<td></td>
<td><strong>REFINE THE PROPOSED CLASSIFICATIONS OF MATERIALS AND PROPERTIES</strong></td>
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<td>30 - 31</td>
<td>Career Development Committee, ASM, receives papers</td>
</tr>
<tr>
<td>31 - 32</td>
<td>Committee evaluates classifications</td>
</tr>
<tr>
<td>32 - 33</td>
<td>Committee members revise classifications</td>
</tr>
<tr>
<td>33 - 37</td>
<td>Committee members return additions and corrections</td>
</tr>
<tr>
<td>30 - 34</td>
<td>Young Members Committee, ASM, receives papers</td>
</tr>
<tr>
<td>34 - 35</td>
<td>Committee evaluates classifications</td>
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<tr>
<td>35 - 36</td>
<td>Committee members revise classifications</td>
</tr>
<tr>
<td>36 - 37</td>
<td>Committee members return additions and corrections</td>
</tr>
<tr>
<td>37 - 38</td>
<td>Analyze reactions</td>
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<td>38 - 40</td>
<td>Add missing elements to proposed classification of materials and properties</td>
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<td>40 - 41</td>
<td>Refine proposed classifications</td>
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<tr>
<td>41 - 42</td>
<td>Review with ASM staff liaison</td>
</tr>
<tr>
<td>42 - 45</td>
<td>Final refinement of proposed classification of materials and properties</td>
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Chapter Summary

The purpose of Chapter I was to present an overview or background of the problem. The statement of the problem, the hypotheses, and significance of the research were reported. Assumptions, delimitations, and limitations were also presented. Important terms that had special meaning in the area of industrial technology were defined. A PERT chart showed the methodology for planning the various activities necessary to complete this research study.
CHAPTER II

REVIEW OF RELATED LITERATURE

The review of the literature will be reported in three main sections. The first section reports information about the status of materials processing technology as an element of traditional industrial arts curricula. Selected efforts of individuals who guided and set the stage for change through contemporary innovative programs also will be reviewed.

The second section of this chapter reports a review of major contributions and influences related to newer developments in conceptualizing and organizing studies of materials processing technology.

The third section of this chapter reports of two selected programs in which improved solid materials processing technology studies may be adapted.

Traditional Industrial Arts Programs

Traditional industrial arts programs have tended to approach the study of the body of knowledge of materials processing technology through disjointed courses. Schmitt and Pelley (1966), in a national survey, classified industrial arts course titles according to instructional
content as follows:

1. General Industrial Arts
2. General Woods
3. Drafting
4. General Metals
5. Graphic Arts
6. Electricity-Electronics
7. Crafts
8. Power Mechanics
9. Home Mechanics
10. Photography
11. Ceramics
12. Industrial Arts, Mathematics, and Science
13. Plastics
14. Textiles
15. Transportation
16. Others -- (This category included Brick Masonry and Layout, Building Trades, Farm Shop, Gardening, and Preengineering Shop.)

The greatest number of students were enrolled in the General Industrial Arts program. It is important to note that the instructional time was devoted as follows:

26.6% to Woodworking, 19.0% to Metalworking, 15.5% to Drafting, 10.8% to Electricity, 8.0% to Leather, 6.6% to Plastics, 3.0% to Ceramics, 2.0% to Power Mechanics, 2.1% to Graphic Arts, 1.7% to Handicraft, .2% to Textiles
and 4.5% to Others (Schmitt & Pelley, 1966, p. 24).

The study further revealed subject content in industrial arts to be centered mostly around woodworking, drafting and metalworking. Course offerings were narrow and instructional content was not as broad as some professionals in the field would have preferred.

The greatest efforts, using both enrollment and content as a measure, were made through the medium of woodworking.

The individuals who were surveyed in the Schmitt and Pelley study recommended that course offerings be expanded and that instructional content be improved, but no specific statement was made that the study of materials processing technology should be included. However, in a list of "ten purposes of industrial arts education" identified on the survey form, industrial arts teachers and principals ranked the following as one of the four most important purposes: the ability "to develop problem-solving skills relating to materials and processes" (Schmitt & Pelley, 1966, p. 28).

Although the study was a status report on industrial arts education in public secondary schools of the United States, this fact was eminent: "The current industrial arts curriculum does not even measure up to the program recommended by the profession 10 to 20 years ago" (Schmitt & Pelley, 1966, p. 30). The derivation of
curriculum seemed to be based upon or oriented to trade and job analysis techniques.

The outlook appeared to be the same for books dealing with materials. The concern was with specific materials such as, plastic (Arnold, 1968), silver (Butts, 1967), glass (Huether, 1963), food (Duncan, 1943), etc. The textbooks may have been written for use in specific courses such as, woodworking, metalworking, plastics, etc. Other text authors, however, were concerned with broader classes or groups of materials such as, polymers (Winding & Hiatt, 1961), metals (Sullivan, 1966), and ceramics (Kingery, 1967). Nevertheless, the textbooks generally represent an unintegrated body of knowledge in regard to the technology of solid materials processing.

An examination of the purposes and content of industrial arts education was proposed as early as the first decade of this century by leaders such as Charles Richards, Charles Bennett, and Frederick Bonser (Ray, 1964). The trade analysis technique was not sufficiently broad to provide an adequate structure for encompasses the practices of man.

Various individuals were concerned with curriculum structures in industrial arts and proposed major categories of study derived from industry. William E. Warner (1965) and a group of graduate students, as early as 1947, proposed the following subject matter classifications for
industrial arts education:

1. Power
2. Transportation
3. Manufacturing
4. Construction
5. Communication

As content was derived from the broader area of industry, more appropriate methods were needed to categorize the components.

Three principles for analyzing a curriculum area were used. The principle of exhaustiveness required that there be sufficient categories of a classification to include all possible items. The principle of exclusiveness required that categories not overlap. The principle of being univocal required that categories have only one basis of classification. A fourth criterion could be employed for evaluating a curriculum. It is the extent to which the program is workable or the extent to which it could be implemented. These criteria can be used to examine the base or framework of curricula and the method by which the content is derived. Warner had derived the content for his proposed industrial arts curriculum from industry by means of a socio-economic analysis and not by means of the trade or job analysis method which had been commonly used before.

The manufacturing division, for example, included
nine basic industries that changed raw materials into finished products. The nine manufacturing headings were sub-divided in the following manner:

1. Food
2. Textiles
3. Rubber
4. Chemical
5. Cellulose Fiber
6. Leather
7. Metal
8. Ceramic
9. Miscellaneous

A functional outline provided the method of inquiry into each manufacturing area previously mentioned. The five topics in the outline were as follows:

A. History
B. Raw Materials
C. Fabrication
D. Consumption
E. Application

The following completed outline represents how the Food Industry might be studied.

Food Industries

A. History
B. Materials: Animal matter, plant life
C. Fabrication

1. Chemical
   a. Fermentation
   b. Preservation
   c. Flavoring
   d. Coloring

2. Physical
   a. Cooking
   b. Preparation
   c. Storage
   d. Freezing

D. Consumption: Industrial, Ultimate

E. Applications

1. Outside aids
   a. Visual
   b. Literary

2. Field trips
   a. Sources of supply
   b. Preparation areas
   c. Distributive organizers
   d. Preservative factories

3. Experiments
   a. Preservation
   b. Experimental handling
   c. Packaging
   d. Distributive aids

4. Projects
   a. Take-home products
      (1) Preservative devices
      (2) Informational aids
      (3) Testing techniques
   b. Group developments
      (1) Tests
      (2) Consumer appreciation
5. Lectures

a. Sources of supply
b. Seasonal information
c. Industrial opportunities

(Warner, 1965, pp. 34-35)

Although materials were specifically considered in the curriculum, the various categories of materials tended to overlap, suggesting that the property of mutual exclusiveness was not considered in the analysis. Warner's curriculum proposal advocated that industry was the source of content and the major purpose was to "reflect technology." The proposal broadened the source from which content was derived but did not emphasize praxiology, the knowledge of practice of man, or the science of efficient action. No structure seemed to be present to suggest a deliberate plan for the study of man's actions in materials processing. Further, the study really did not define the meaning of technology. There was no evidence to suggest that there was wide implementation of Warner's curriculum ideas.

Delmar W. Olson (1957) also stated that an understanding of industry should serve as a source of subject matter for industrial arts. Olson identified eight major categories of industry:

1. Manufacturing
2. Construction
3. Power
4. Transportation
He included the following areas in manufacturing:

a. Ceramics
b. Chemicals
c. Foods
d. Graphic arts
e. Leather
f. Paper
g. Plastics
h. Metals
i. Rubber
j. Textiles
k. Tools and machines
l. Woods.

Olson's system of classification was a grouping of materials (wood, leather, paper etc.), products (tools and machines) and processes (graphic arts). The categories within the classification did not meet the properties of being mutually exclusive or operationally feasible. The program has not been widely implemented. However, Olson, like Warner, contributed new thoughts to the framework of industrial arts.

Contemporary thinking and theorizing within the
profession began to support the idea that industry was the source of content for industrial arts. The terms "industry" and "technology" tended to be defined very loosely. The looseness of definitions has led to confusion and lack of communication between members of the profession.

This was pointed out by Willis E. Ray (1970) who stated that there would be little argument within the profession that "Industry is the source of content for industrial arts." However, the accuracy of the definition of "technology" by members of the profession would lack the same precision [p. 96]. Warner and Olson had conceptualized industry as "reflecting technology."

Paul W. DeVore (1964), on the other hand, viewed industrial arts broadly as a discipline of technology. In addition, he stated:

An organizational structure is easily identified, however. It is a structure having both durability and continuity and is easily determined by a review of man's major technical endeavors through the centuries of his technological development.

His major areas of technical endeavor identify man (1) as a builder, (2) as a communicator, (3) as a producer, (4) as a transporter, (5) as a developer, (6) as an organizer and manager of work, and (7) as a craftsman (DeVore, 1964, p. 14).

In summary, the ability to develop skills in materials processing was considered important by traditional industrial arts teachers and curriculum theorists. As more precise definitions of industry and technology
were derived by theoreticians, the study of materials became an important concern of industrial arts curriculum planners. However, a logically-defensible and comprehensive structuring of the body of knowledge of materials processing technology was not advanced with the result that studies of materials processing technology continue to be offered in narrowly-conceived and disjointed collections of specialized courses.

**Major Recent Innovative Efforts in Reshaping Materials Curricula**

The importance of a knowledge of industrial materials has been recognized at the national level. Several institutes were held to develop curriculum units in this area of study.

Instructional units for industrial materials were prepared at San Jose State College under the direction of Ralph Bohn and Louie Melo (1968), with National Defense Education Act, Title XI, support.

"The emphasis was on the integration of industrial materials as a part of the existing program, rather than the establishment of new ones (Bohn & Melo, 1968, p. 1)."

Instructional units for industrial materials were in the following areas:

- General information about materials
- Metals
- Forest products
Similarly, an institute of advanced study in industrial arts investigated materials instruction. An institute entitled, "Materials Science in Technology for Industrial Arts Teachers," conducted at Kent State University, under the direction of Frank J. Marschik (1969) provided curricular aids in the following areas:

- Atomic Structure and Bonding
- Materials Science for Plastics
- Metals Structures and Reactions
- Ceramics
- Materials Testing

The instructional units developed at both institutes were intended for implementation in present industrial arts programs. There was no apparent attempt for the structuring of materials, properties, or processes. The definitions of the terms "technology" and "industry" were not stated in the instructional units. However, the resources provided at the national level for the development of instructional units for the study of industrial materials demonstrated the interest and importance of this body of knowledge to industrial arts education.

Recently, individual contributions in curriculum
development at the undergraduate level have been made in the area of materials study. Two major efforts in materials teaching have been proposed by Melo of San Jose State College and Syd K. Lee of the University of British Columbia.


To understand work effectively in a modern industrial environment, it is extremely important that the practitioner (in education or industry) develop significant insight into the science of modern materials. The era of being concerned only with observable forming, shaping, blending and/or joining problems has given way to the inclusion of a more comprehensive study of materials in terms of their characteristics in addition to their expected performance (Melo, 1970, p. 264).

He maintained that laboratory sessions should be designed to show relevant variables of materials subjected to various environments where they are to perform.

Lee (1970), reporting on the materials program at the University of British Columbia, advocated that materials courses also be lab-oriented. Experimentation should bridge the gap between theory and need. The collegiate program is referred to as "materials science." Lee points out a current problem, "... it is not surprising to see some educators in university or college industrial education departments teaching materials courses which lean very heavily toward the theoretical." This "textbook and chalkboard" approach is not what we need in industrial

Both of these noteworthy programs (Melo and Lee) tend to deal with the study of materials as an applied science. Both individuals pointed out the importance and the problems in the teaching and/or learning of materials in the industrial technology area. The programs are internationally known, but they did not explicitly describe a structure for the study of materials processing technology in terms of properties or processes.

Instruction in "materials" on the undergraduate level has also come under close examination in recent years by various groups concerned with engineering in general and with materials in particular.

Conferences have been held in order to reach a consensus about undergraduate materials courses. The following remarks were made in 1965 in reference to the revising of an engineering curriculum.

Therefore the simple replacement, at the undergraduate level, of the old-fashioned descriptive and empirical course in "Engineering Material" or "Material Properties" by a course in modern Solid State Physics, without any real thought or recommendation as to how such a course is to be integrated with the other (preceding, accompanying and following) courses to which it is or should be related, may do more harm than good, by further unbalancing the engineering curriculum in the wrong direction. The recently proposed "engineering science" programs constitute a trend in the direction away from engineering as an activity concerned with evaluating reality prior to effective action, and towards an approach in which the main purpose seems to be contemplation.
and abstraction of reality rather than its evaluation
for the purpose of a specific action. In other words
these programs lose sight of the fundamental act that
an engineering education should produce, not physi­
cists or mathematicians, but engineers (Liebowitz &

It should be emphasized that the conference
participants were careful not to confuse engineering science
with engineering. The problems that this group noted can
serve as an important guiding element for developing a
materials instructional program. Courses in materials
processing should not constitute a trend to the applied
science and away from industrial technology as the knowledge
of man's practices in construction and manufacturing.

A "Materials Fabrication and Testing Program" has
been reported at the Plantation Senior High School, Fort
Lauderdale, Florida. It would appear from the report that
a materials processing course can provide continuity in a
secondary school industrial arts program.

This innovative program is intended to be
conceptual in nature rather than facts or
skills oriented. The laboratory has been specifi­
cally designed for a comprehensive study of
technology, with materials testing playing a key
part in the objectives of the program. Courses
have been established for a three-year program cov­
ering the major headings of materials, processes,
and fabrication for the ninth grade level and

An approach to the study of solid materials was
developed for use in science programs. The opportunity for
the investigation of the principles of solid state chemistry
were not present in the current science curriculum. To
alleviate this bias, Parker, Davis, & Langer (1968), under the auspices of the American Society for Metals (ASM), developed an instructional unit in solid state chemistry.

The chemistry of our current science curriculum is almost totally fluid oriented and implies by negation that, indeed, Aristotle’s assumption is correct. Some will admit the existence of chemical activity in the solid state but feel it is so minor in quantity and importance as to deserve little consideration. Others suggest that the basic principles of chemistry are equally applicable to all states of matter and are easier to illustrate in solutions (Parker, et al., 1968, p. 1).

In the unit of instruction called Solid State Structure and Reactions (SSSR) the following study outline was suggested:

1. Introduction
2. Nature of Solids
3. Solid Solutions
4. Non-metallic Solids
5. Atomic Level of Materials
6. The Crystalline Nature of Solids
7. Allotropic Change
8. Plastic Flow
9. Electrical Properties
10. Energy Considerations
11. Bonding in Solids
12. Bonding Structure & Properties
13. Reactions in Solids
14. Diffusion in Solids
15. Phases in Solids
The unit was taught by selected secondary school science teachers. The unit was favorably accepted by the instructors, students, and schools. It was determined to be effective in developing concepts of solid state science.

The unit was developed explicitly for science classes. Although the content is valuable as a science unit in solid materials, it is not developed as a discipline for the technology of solid materials processing. However, the need for a unit of instruction in solid materials was recognized. David W. Geurdat, (1970) Career Development Coordinator of the American Society for Metals, confirmed the importance of the discipline of "materials" at the secondary school level [p. 262].

This same period of time saw an emphasis on presenting subject matter more effectively--that is, with regard to structure (Bruner, 1960, p. 2). With the knowledge explosion and the advancement of technology, curriculum efforts in industrial arts education were further influenced by this approach which emphasized the importance of structuring knowledge.

...the past fifteen years have seen a decided shift toward an approach that emphasizes subject matter--not however, subject matter as it is traditionally known, but the emphasis now is on the structure of knowledge (Towers, Lux, & Ray, 1966, p. 239).

Jerome S. Bruner (1960) suggested four claims that could be made for teaching the fundamental structure of a discipline.
1. Understanding fundamentals makes a subject more comprehensible.

2. Perhaps the most basic thing that can be said about human memory, after a century of intensive research, is that unless detail is placed into a structured pattern, it is rapidly forgotten.

3. The understanding of fundamental principles and ideas appears to be the main road to adequate transfer of training.

4. The knowledge lag in a field is reduced when principles in the field are examined, since principles stand the test of time better than do the facts (Bruner, 1960, pp. 23-26).

Phillip H. Phenix (1962) proposed three fundamental features of discipline as curriculum content.

(1) Analytic simplification — The primal essential for effective teaching is simplification. ...learning consists in the growing ability to sort and select, that is, to simplify.

(2) Synthesis — A discipline is a conceptual structure whose function is not only to simplify understanding but also reveal significant patterns and relationships.

(3) Dynamism — A discipline is a living body of knowledge, containing within itself a principle of growth (Phenix, 1962, pp. 273-280).

Both Bruner and Phenix stated that an analysis of knowledge might contribute to decision making about curriculum.
However, the categorization or structuring of knowledge in solid materials processing technology did not reach full realization.

It should be pointed out that professional societies have found it necessary to categorize or structure materials as an aid for discussion within the industry and as an aid in communicating to individuals outside of the industry. Two recently developed classifications selected for review are the classification proposed by the American Ceramics Society and the classification proposed by the Society of Manufacturing Engineers.

Loran S. O'Bannon (1971, pp. 273-280), in discussing the ceramics industry as a career, used the following categories within the classification:

1. Glass
2. Refractories
3. Electronic and Electrical Ceramics
4. Ceramics Coating
5. Aerospace Ceramics
6. Nuclear Ceramics
7. Architectural Ceramics
8. Consumer Ceramics
9. Abrasives
10. Carbon Ceramics
11. Special Ceramics
The categories were not mutually exclusive nor did the classification appear workable in considering the technology of solid materials processing for curriculum purposes. The categories represented a suitable classification of industrial products but not for materials.

A classification of materials, for efficiency of discussion, was considered by the "Engineering Materials Division" of the Society of Manufacturing Engineers. They subdivided the area of material in the following manner:

- Plastics and Natural Materials
- Powdered Materials
- Composite Materials
- Ceramics, Glasses and Abrasives
- Iron and Steel
- Manufacturing/Design Assurance

The "Ceramics, Glasses and Abrasives" subdivision consisted of four groups:

1. Carbon and Graphite
2. Glass and Quartz
3. Ceramics
4. Diamonds and Abrasives

The breakdown of materials in this fashion was to increase efficiency of consultation and advisement (Society of Manufacturing Engineers, 1971, p. 1). The categories were not mutually exclusive and did not appear
structured for instructional purposes. The effort to structure does suggest that a classification was important for discussion purposes: classifications based on different categories, however, may be needed for instructional purposes.

In summary, the second section of this chapter was a review of major contributions and influences related to newer developments in conceptualizing and organizing studies of materials processing technology. Institutes established at the national level for the development of instructional units in "materials" demonstrated the continuing interest in materials processing as a part of industrial arts curriculum content. Also, efforts of curriculum workers and others have been devoted to structuring or classifying materials.

**Selected Materials Curricula**

Two selected programs that have proposed a base and considered the study of materials are the Alberta Plan and the American Industry Project (AIP). Both programs proposed areas of materials study and developed these areas to some extent.

A technology oriented industrial arts program developed by Henry R. Ziel (1966) at the University of Alberta conceived industrial arts as a synthesizing process conducted in a multiple activity environment.
The multiple activity introduced students into a number of experiences which would interpret the contemporary production society.

The Program was envisioned as having four phases. See Figures 1 and 2.

An awareness and appreciation of machines, materials, tools, processes are introduced in Phase I through instruction in six areas: ceramics, graphic arts, plastics, woods, metals, and electricity.

The learning activities in Phase II extended the concepts learned in academic subjects of industrial applications of basic science. The synthesizing experience was intended in this phase. The major objective was an awareness of the application of scientific knowledge through the use of prototypes, simulated systems and experimental applications.

The experiences in Phase III demonstrated the role man plays in the industrial organization in relation to technological demands imposed upon organizations as they function in an industrial society.

Phase IV provides the student an opportunity to pursue a cluster of technologies in greater depth.

Industrial Arts as it is conceived at the University of Alberta is a synthesizing educational
Phase I and Phase II of the Industrial Arts in General Education Program as conceived at The University of Alberta (Ziel, 1966, pp. 10-11).
Phase III and Phase IV of the Industrial Arts in General Education Program as conceived at The University of Alberta (Ziel, 1966, pp. 12-13).
process conducted in a multiple activity environment. The general concept is predicated upon the fact that no profession or occupation operated in a vacuum. The interrelationships of functions, processes and technologies are very evident in contemporary occupations. The program is designed to make an articulate contribution to secondary general education,... (Ziel, 1966, p. 8).

The four phases developed at Alberta conceived industrial arts as the synthesizing factor in general education. The study of materials was recognized as an important subelement in all four phases. Technology in the program was defined as the application of basic science to the industrial setting rather than knowledge of man's practices. For this reason, curriculum implications for this study may not readily be derived from the Alberta Plan.

The aim of the American Industry Project (Face & Flug, 1965) was to identify and develop concepts which applied to American industry. The source of content for the American Industry Project was industry and not technology as in the Alberta Plan. Because of this assumption, the objectives of the program were (1) to develop an understanding of industry and (2) to develop the ability to solve industrial problems.

Three levels were developed in the American Industry Project. Level I focused on the broad understanding of the major concepts and relationships of
American industry. Level II emphasized the deeper understanding of those concepts and Level III provided an opportunity to investigate in depth or related clusters concepts of the total American Industry Project.

The American Industry Project considered the importance of concept learning for the following reason:

The concentration upon the acquisition of concepts, rather than emphasis on specifics, should however, enhance the possibility of retention, transfer, and application of knowledge to new and different situations (Face & Flug, 1965, p. 8).

A major difficulty with the base of this project was that American industry was equated with the entire economic institution; however, entertainment and agriculture seemed to be omitted from the project. Deliberate emphasis upon "American Industry" seems to make it different from industry that might be carried on in another country. If so, the conceptual approach may tend to lack universality or exhibit the property of exhaustiveness. The problem of the selection of these concepts and not other concepts could be questioned. The criterion of mutual exclusiveness appears to be violated among and between the thirteen concepts. For example, procurement is a management function and processes and production seem to overlap. See Figure 4.

"Materials" was considered to be one of thirteen major concepts. Each major concept was refined to sub-concepts as the major concepts were investigated. The staff
Figure 4

A Conceptual Structure of the Knowledges Necessary to Understand American Industry
(American Industry Project, 1965)
defined materials as "anything in the universe that is made up of matter and has substance in gross structural forms or constituents at the macroscopic level (Halston, 1967, p. 3)."

Materials were grouped on the basis of their sources. The recognized sources of all materials were water, air, plant, animal, and mineral. It was maintained that (1) all materials are part of the grouping, (2) the categories are well understood and (3) a workable breakdown of subconcepts is possible.

The experimental classification of materials proposed by the American Industry Project staff recognized monolithic and composite materials. See Figure 5. Monolithic materials may be elements or alloys. Composites may be classified as constituents, interface, or distribution.

Service properties consisted of the following:

- processing characteristics
- mechanical
- weight, density and volume
- environmental exposure
- electrical
- insulative
- esthetic
- nuclear
Figure 5

The classification represented a concept model and definition.

It would seem, however, that knowledge of the properties and characteristics of materials rather than their sources might be a more feasible approach to a conceptual development of materials. It has been assumed that a workable breakdown of subconcepts is possible; however, this has not been demonstrated at this time.

The subconcepts selected by the AIP for "materials" may lack the property of mutual exclusiveness. A material can be completely described by specification of its properties; however, the properties selected to describe subconcepts seem to overlap.

The processing of materials in industry may depend more upon other criteria or concepts than their source of the materials. No information is available at this time to substantiate the workability for the instruction of the "materials concept" in the classroom.

The two instructional programs just reviewed have considered materials as a subsystem of industrial knowledge and have developed them to some extent for instructional purposes. However, there do appear to be inadequacies in their conceptualizations. Despite this, they provide a ready example of the need for and application of this study. One further concern with these two programs is that they
lack specific recognition of the placement of materials processing technology as a subsystem of the knowledge of industrial technology—the knowledge of man's practices in construction and manufacturing.

**Chapter Summary**

A review of the related literature in this chapter consisted of three parts. The first section reported information about traditional industrial arts programs and the efforts of selected individuals who set the stage for contemporary program innovation. The second section reported a review of major contemporary efforts to conceptualize and organize studies of materials processing technology. The third section reported selected programs in which improved materials processing technology studies may be adopted. The review of the literature revealed that the vast body of knowledge of materials processing appeared to be inadequately structured for instructional purposes and an adequate structure of solid materials processing technology is needed in industrial arts education.
CHAPTER III

DEVELOPMENT OF A CLASSIFICATION OF SOLID MATERIALS AND A CLASSIFICATION OF PROPERTIES OF SOLID MATERIALS

The purpose of this descriptive research study was to identify and classify a body of knowledge of solid materials processing technology. It was more than accumulating and recording data. In order that the research study be significant, it was also necessary to interpret the data collected.

This type of study can serve a very important purpose in research by providing a structure of knowledge to a field. This first step in the development of course materials, the structuring of knowledge, was supported by Towers, et al., (1966), Stufflebeam, (1969), and Saylor & Alexander, (1966). It can provide useful information for the improvement of industrial arts educational practices. J. W. Best (1970) maintained this position when he stated:

The process of descriptive research goes beyond mere gathering and tabulation of data. It involves an element of interpretation of the meaning or significance of what is described [pp. 102-103].

Sax (1968) stated "The purpose of content analysis is to classify and quantify relatively unstructured material...." Hayman (1968) regarded content analysis important to curriculum research.
Far too often, curriculum in a school system is only vaguely defined. Since no one knows the total content of the curriculum, no one knows if the goals of the system are being satisfied (Hayman, 1968, p. 82).

Procedure

The analysis of material for this study was derived using the following procedures outlined by Sax (1968).

A. Specifying objectives
B. Developing hypotheses
C. Sampling of information
D. Determining categories
E. Category analysis
F. Quantification
G. Standardizing the coding procedure
H. Reliability [pp. 274-279].

A. Specification of Objectives

There were two different phases to this study: (1) The development of a classification of content that may constitute a body of knowledge; and (2) the organization of the content or knowledge that may be effectively developed into learning experiences.

Although the study was the identification and classification of a body of knowledge of solid materials processing technology, other important questions to be
answered were as follows:

1. What is the underlying reason for studying solid materials processing technology?
2. What are the materials that may be classified as solids?
3. What are the properties that solid materials may possess?
4. Can universal processes be applied to the solid materials?

These have previously been stated in Chapter I.

B. Developing Hypotheses

1. The knowledge of solid materials processing technology can be identified and a classification of it can be developed to provide a basis for developing instructional programs.
2. The structured body of knowledge of materials processing has implications for industrial arts curriculum workers at many levels as well as for curriculum workers in other technical curricula, such as engineering.

The hypotheses have previously been stated in Chapter I.

C. Sampling of Information

The conceptualization of solid materials and properties of solid materials was produced by researching literature, conferring with materials specialists and meeting with teaching personnel affiliated with the American Society for Metals.
The library at the American Society for Metals, with its extensive volumes, was utilized in developing a reference list for conceptualizing solid materials and properties. Card index headings listing textbooks and reference books at The Ohio State University Education Library and the Cleveland Public Library were investigated for possible references to aid in the development of this study. Card index headings examined were the following:

- materials
- processes
- man-made materials
- synthetic materials
- polymers
- metals
- ceramics
- plastics
- foods
- textiles
- properties of materials
- cross references listed on the preceding cards

Information from the following sources was analyzed for a development of a structure of solid materials and structure of properties (this stage of the research project is found in the PERT Network, page 11, under the
heading, "Analyze for a preliminary classification of materials and properties"):

- professional society reports
- textbooks
- reference books
- journals
- syllabi
- courses of study
- letters
- proceedings of professional conferences

Records, reports, and proceedings of professional societies such as the Society of Manufacturing Engineers, the American Society for Metals, and the American Ceramics Society were examined for possible suggestions or sources of classifications. Further information was obtained from records and reports of curriculum committees within societies dealing with technical education.

Textbooks and reference books were also examined for possible classifications of materials and properties. Professional journals, syllabi and courses of study were reviewed for possible leads to aid in conceptualizing a classification of materials and properties.

The analysis of these kinds of sources of information served an important purpose in developmental research by providing useful information which would lead to the improvement of educational practices (Best, 1970).
Working papers, or the "Proposed Classification of Solid Materials" and the "Proposed Classification of Properties of Solid Materials," were developed and designed within the established limitations and in accordance with the definitions as set forth in Chapter I. These working papers were based on a synthesis of all the collected data regarding what could comprise an adequate structure of solid materials and their properties. The activities in this phase of the study were listed in the PERT Network, page 12, under "Design and develop preliminary classifications."

It was assumed that the development of a bibliography would be valuable to the completion of this developmental project. References could be cited for information on specific solid materials. There was difficulty in citing single references for broad groups of materials and their properties. The literature for these broad groups was written mostly from a scientific point of view rather than from a technological point of view, the science of the application of knowledge to practical purposes, as defined in this study. Literature identifying a body of knowledge of solid materials processing technology was generally non-existent. The interrelationship of processes specifically related to solid materials and their properties or technology of solid materials processing is a recent development which is currently receiving greater emphasis (Langer, 1968, p. 3).
There were several inherent difficulties in gathering material for this type of research project. Best (1970) listed these reasons as important factors to be considered:

1. The printed word may not necessarily be trustworthy.
2. Documents used for the structure must be evaluated.
3. Genuine information is important.
4. Content must be valid.
5. Proof lies with the person doing the research.

The following steps were taken to avoid the difficulties mentioned:

1. Printed matter was reviewed before being used as a reference in deriving a classification of solid materials and properties by staff liaison of the ASM. Staff liaison are personnel at the ASM headquarters who work closely with committees and provide assistance to committee members.

2. Documents selected to derive a classification of solid materials and properties were evaluated by staff liaison of the ASM.

3. Expert review also was used to help assure the accuracy of the emerging conceptualizations.

4. Members at the offices of the American Society for Metals reviewed and refined the preliminary classification of solid materials and properties in order to assure its validity.
5. The "Proposed Classification of Solid Materials" and the "Proposed Classification of Properties of Solid Materials" were reviewed and evaluated by two committees of experts in materials. See Appendix H and Appendix I for names of committee members.

D. Determining Categories

Descriptive data of solid materials that served as a basis for manufactured or constructed products were examined to determine a major type of category. A classification system was required that would aid in providing data on solid materials that were processed in manufacturing and construction and determine materials that could be classified as solids since a review of the literature had revealed that the vast body of knowledge of materials processing appeared inadequately structured for instructional purposes.

1. A product classification was considered but the following issues arose:

   a. Difficulty arose in determining whether to group products by component materials or by the purpose the product served.

   b. At what level would products be grouped, the final assembly or the component parts level?

   c. A workable way of curriculum implementation was not evident.
2. An organic-inorganic classification, as used in chemistry, was considered but it did not seem appropriate for industrial technology.
   a. There was a tendency that materials selected for a technology classification were not mutually exclusive.
   b. A classification did not seem workable.
   c. The plan did not lend itself to industrial arts curriculum implementation.

3. A natural-synthetic system was considered but rejected for the following reasons:
   a. Where natural materials cease and synthetic materials begin is difficult to determine.
   b. The categories may not be mutually exclusive.
   c. The list may not be workable for curriculum purposes in industrial technology.

4. Examination of electron bonding and atomic structure was feasible; however,
   a. The approach was meaningful for science curricula; however, not totally suitable for the technology of solid materials processing.
   b. The classification categories were better oriented to physics and chemistry courses.
   c. Science begins with knowledge of properties and characteristics of atoms; the subject would then generally end there since study
leads from simple description to detailed description of materials.

5. An **industrial** classification of materials seemed, at first, appropriate. But, the following major difficulties were not resolved:

   a. Although the term, industry, has a commonly accepted meaning with industrial arts curriculum personnel, different meanings are supported by personnel in different industries.

   b. There is a lack of understanding of the relationship of industry and the economic institution. The terms are sometimes used interchangeably.

6. A classification limited to **solid** materials was finally adopted.

   a. Materials have been previously classified as solids, liquids, and gases.

   b. A distinction can be made between different types of solid materials.

   c. A classification of solid materials appeared to be a workable one.

   d. Implications of solid materials for curriculum purposes seemed promising.

   In the processing of a solid material the properties can be altered.
These properties of solid materials can be determined and there are various ways that properties can be categorized. Chemists are interested in chemical properties, electrical engineers in electrical properties, etc.. However, mechanical and non-mechanical properties were selected as categories since the principles of logical analysis and criteria established in the study could be applied to all of the solid materials that were classified. These determined the properties that solid materials could posses.

E. Category Analysis

A conceptualization of a body of knowledge of solid materials processing was developed using the following principles of logic:

1. Categories should be well-defined.
   An important requirement of scientific findings is that they should be communicable to others.

2. Categories should be mutually exclusive.
   The lack of exclusiveness may mean some overlapping, interdependence, and failure to define the basis of classification.

3. Categories should be univocal.
   There should be one basis of classification.

4. Categories must be exhaustive.
The classification provides a place for all cases (Guilford, 1965, pp. 13-14).

These principles of analysis were affirmed by Sax, (1968), Best, (1970), Hayman, (1968), and VanDalen & Meyer, (1962) who emphasized that categories selected should support the principles of exhaustiveness, exclusiveness, and single classification.

F. Quantification

The quantification used in content analysis involves ascertaining the frequency with which a unit appears. In this study the frequency with which a solid material and its property appeared was irrelevant to this study. Several problems, however, were apparent in attempting to structure. First, the aspects of intensity were not relevant to the objectives or hypotheses of this study. Another problem was that what appeared in a printed book, journal, handbook, or curriculum guide was not necessarily reliable. Best (1970) stated that the credibility of a document is paramount and the validity of content is important.

G. Standardizing the Coding Procedure

After the categories had been established and components placed, it was necessary that the expert reviewers understand the purpose of the analysis or research study. The purpose was conveyed to the expert reviewers by a cover letter (Appendix A). The "Preliminary Classification
of Solid Materials" (Appendix J) and the "Preliminary Classification of Properties of Solid Materials" (Appendix K) were initially evaluated by staff liaison at the offices of the American Society for Metals. After evaluation, the preliminary classifications became the "Proposed Classification of Solid Materials" (Appendix B) and the "Proposed Classification of Properties of Solid Materials" (Appendix C). These were sent to the expert reviewers. Reaction Form I (Appendix D) and Reaction Form II (Appendix E) were also sent to committee members to evaluate the "Proposed Classification of Solid Materials" and the "Proposed Classification of Properties of Solid Materials." Reaction forms for all levels of both classifications were provided for evaluation of sub-categories within the major classifications.

H. Reliability

Two committees of expert reviewers reacted to and revised the "Proposed Classification of Solid Materials" and the "Proposed Classification of Properties of Solid Materials." The Career Development Committee was comprised of ten members. See Appendix H. The Young Members Committee was comprised of twelve members. See Appendix I.

After synthesizing the data, the preliminary classifications were developed. Before sending these to members of the Career Development Committee and the Young Members committee the preliminary classifications were reviewed by staff liaison at the offices of the American Society for
Individuals of the committees reacted to and revised, if necessary, the structures on Reaction Form I and Reaction Form II, Appendix D and Appendix E, respectively. The reactions, revisions, and additions were analyzed when the members returned the forms. Again, it was found that similar problems existed in evaluation at this point of the study as in the beginning of the analysis of content for the development of the structures. The responses or reactions of the committees had to agree within the established criteria of the structures that were stated in Chapter I. Only solid materials and the properties of solid materials were being classified. Revisions, deletions, and additions of component parts were then included in the classification. The refined structures were then reviewed by staff liaison of the American Society for Metals and the researcher. This was the method employed to establish reliability within the research study.

Reactions to Proposed Classifications of Solid Materials and Properties

After the "Preliminary Classification of Solid Materials" and the "Preliminary Classification of Properties of Solid Materials" were completed, the two classifications were reviewed by liaison staff at the offices of the
American Society for Metals. It was suggested that an "alloy steel" category be added to the classification (adapted from Clark & Varney, 1962, pp. 536-538). Several changes were made in the classification of non-ferrous metals. Radium was reclassified as a sub-category of heavy metals and alloys, and aluminum was reclassified as a sub-category of light metals and alloys. The property, "absorption," was changed to "water absorption" for greater clarity. When the revisions were completed, the "Proposed Classification of Solid Materials" and the "Proposed Classification of Properties of Solid Materials" were reviewed by members of the Faculty of Industrial Technology Education at The Ohio State University.

A packet consisting of the following items was then sent to the Career Development Committee and Young Members Committee of the American Society for Metals. See PERT Chart, page 12, activities 12 - 19, 13 - 20, 14 - 21, 15 - 22, and 16 - 23.

1. Cover letter (See Appendix A)

2. Classification Outline I -- Proposed Classification of Solid Materials (See Appendix B)

3. Classification Outline II -- Proposed Classification of Properties of Solid Materials (See Appendix C)

4. Reaction Form I -- Proposed Classification of Solid Materials (See Appendix D)
A major problem did occur in an analysis of the reactions submitted by the committees. The frequency with which an item appeared may not necessarily be reliable. This excluded the possibility of accepting or rejecting an item because of a predetermined percentage of responses. What had been written may not be reliable in terms of criteria established for determining the categories in the study.

Reactions to Proposed Classifications

All members of the Career Development Committee and Young Members Committee responded to the study. There were twenty-one responses by mail and one response by telephone. After four weeks a follow-up letter was sent to three members asking for their reactions. See Appendix G. Of the twenty-two responses, two reactions were not included in the data because one individual was no longer a member of the committee.
one individual did not react to the classifications since he felt he was not familiar with implications for curriculum development.

This comprised a total number of twenty reactions used in the study.

Three members proposed alternate classifications or subcategories and did not react to the proposed classifications on the forms provided. Some committee members did not react to all items; as a result, the sub-totals did not necessarily add up to twenty for all items. See Tables 1 and 2. The alternate classifications that were submitted by committee members did not meet all the criteria established in this study or fall within the definition established for solid materials and properties. However, the alternate classifications provided suggestions for curriculum implementation.

Reaction form responses were tabulated. Responses which showed disagreement were further reviewed on the reaction sheets where space had been provided for alternate titles or categories for Levels 1, 2, and 3 and Levels 4, 5, and 6. If the alternate titles or categories met the criteria and the basis of the alternate classifications were established, a revision, deletion, or addition was made of the proposed Classification Outlines. See PERT Network, p. 14, activity 37 - 38.

At this point, all alternate titles, categories or suggestions made by the two committees were jointly
<table>
<thead>
<tr>
<th>Categories</th>
<th>Disagree</th>
<th>Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 Metals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1 Ferrous</td>
<td>2</td>
<td>15</td>
</tr>
<tr>
<td>1.2 Non-ferrous</td>
<td>2</td>
<td>15</td>
</tr>
<tr>
<td>2.0 Non-metals</td>
<td></td>
<td></td>
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<tr>
<td>2.1 Pure elements</td>
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<td>16</td>
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<td>2.2 Ceramics</td>
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<td>16</td>
</tr>
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</tr>
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<td>2.3.2 Thermosets</td>
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<td>16</td>
</tr>
<tr>
<td>2.3.3 Rubbers</td>
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<td>15</td>
</tr>
<tr>
<td>2.4 Natural Organics</td>
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<td>2.4.2 Animals</td>
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<td>14</td>
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</tr>
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<tr>
<td>3.2 Dispersed</td>
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</tr>
<tr>
<td>3.3 Laminated</td>
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<td>15</td>
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<tr>
<td>3.4 Agglomerated</td>
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<td>3.5 Bonded</td>
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<tr>
<td>3.6 Fiber-reinforced</td>
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<td>1.4 Acoustical</td>
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<td>14</td>
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<tr>
<td>1.5 Optical</td>
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<td>1.6 Chemical</td>
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<tr>
<td>2.0 Mechanical</td>
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<td>16</td>
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<td>2.2 Ductility</td>
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<tr>
<td>2.3 Hardness</td>
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<td>13</td>
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<tr>
<td>2.4 Malleability</td>
<td>4</td>
<td>12</td>
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<tr>
<td>2.5 Fatigue</td>
<td>4</td>
<td>12</td>
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<tr>
<td>2.6 Shrinkage</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>2.7 Creep</td>
<td>3</td>
<td>12</td>
</tr>
</tbody>
</table>
reviewed by staff liaison of the American Society for Metals and the researcher. See PERT Network, page 14, activities 38 - 40, 40- 41, and 41 - 42. Changes were made to increase accuracy of classifications, validity of classifications, and maintain the currently accepted terminology. The Reaction Form responses were then tabulated on the Proposed Forms. Some disagreements in the "Proposed Classification of Solid Materials" and the "Proposed Classification of Properties of Solid Materials" were due, in effect, to a different proposed classification. Upon investigation of each suggested classification, it was found that the criteria established in the study were not always met.

The following are the changes that were made in the "Proposed Classification of Solid Materials" after analyzing the reactions of the expert reviewers.

**Revisions in 1.0 Metals**

- Revise 1.1.1 Steel to 1.1.1 Plain carbon steel
- Add 1.1.2.4 Precipitation hardening
- Place the Alloy steels category before the Cast iron category.
- Revise Titanium from Heavy metals and alloys to Light metals and alloys.
- Revise Titanium from Heavy metals and alloys to Precious metals and alloys.
- Revise 1.2.5.1 Niobium to 1.2.5.1 Columbium.
Revisions in 2.1 Pure elements

Add 2.1.2.1 Diamond and 2.1.2.2 Graphite to 2.1.2 Carbon.

Revisions in 2.2 Ceramics

Delete 2.2.1.1.2 Crystalline silica.

Revise 2.2.1.2.10 Talc to a separate subcategory under 2.2.1.3 Refractory raw materials as follows:

2.2.1.3.5 Talc

2.2.1.3.5.1 Pyrophyllite
2.2.1.3.5.2 Block talc
2.2.1.3.5.3 Asbestos

The refractory raw materials category was revised by adding Talc and Silica as subcategories of 2.2.1.3 Refractory raw materials.

Revise 2.2.1.2.13 Feldspar, 2.2.3.2.14 Wollastonite, and 2.2.1.2.15 Sillimanite to a separate category under 2.2.1.3.6 Silica as follows:

2.2.1.3.6 Silica

2.2.1.3.6.1 Feldspar
2.2.1.3.6.2 Wollastonite
2.2.1.3.6.3 Sillimanite

Add 2.2.3.3 Garnets to the 2.2.3 Magnetics subcategory.

Revisions in 2.3 Plastics

The sixth order of classification in 2.3 Plastics was deleted because of the complicating nature:

2.3.1.3.5.1 Polyvinyl alcohol
2.3.1.2.5.2 Acetals
Revise 2.3.2. Rubbers to 2.3.3. Elastomers

Revisions in 2.4 Natural Organics

Revise 2.4.1 Plants to 2.4.1 Vegetative materials
Revise 2.4.2. Animals to 2.4.2. Animal materials

Revisions in 3.0 Composites

Revise 3.1 Coated to 3.1 Integral coated
Revise 3.2 Dispersed to 3.2 Random dispersed
Revise 3.3 Laminated to 3.5 Laminar
Delete 3.4 Agglomerated
Delete 3.5 Bonded
Revise 3.6 Fiber-reinforced to 3.4 Fiber reinforced
Delete 3.7 Powder compacted
Delete 3.8 Diffused
Add 3.3 Oriented particle

The following are the changes that were made in the "Proposed Classification of Properties of Solid Materials" after analyzing the reactions of the expert reviewers.

Revisions in 1.0 Non-Mechanical

Delete 1.1.01 Water absorption
Revise 1.1.11 Damping to 1.4.3 Damping capacity in 1.4 Acoustical.

Delete 1.1.12 Durable
Add 1.1.12 Allotrophy
Add 1.1.13 Shrink
Delete 1.1.10 Radioactivity resistance
Delete 1.2.3 Warpage
Delete 1.2.7 Fire resistance
Delete 1.2.8 Heat resistance
Revise 1.2.9 Sintering temperature to 1.2.9

Temperature of fusion
Delete 1.3.7 Galvanic action
Add 1.3.7 Electrochemical potentials
Revise 1.4.1 Sound transmissivity to 1.4.1 Sound absorption

Delete 1.5.2 Light transmissivity
Revise 1.6.5 Oxidation to 1.6.2.1 Oxidation and 1.6.6 Reduction to 1.6.2.2 Reduction as subcategories of 1.6.2 Reactive ability
Add 1.6.5 Ignition temperature
Add 1.7 Nuclear
Add 1.8 Atomic structure

Revision in 2.0 Mechanical
Revise 2.1.5 Impact to 2.1.5 Fracture
Add 2.1.6 Bend
Add 2.1.7 Torsion
Revise 2.5 Fatigue to 2.1.8 Fatigue
Revise 2.5.1 Notch sensitivity to 2.1.8.1 Notch sensitivity
Revise 2.5.2 Cross Section to 2.1.8.2 Cross section
Add 2.1.8.3 Crack initiation
Add 2.1.8.4 Crack propagation

Revise 2.7 Creep to 2.1.9 Creep

Revise 2.3.2 Indentation to 2.3.2 Rebound

Delete 2.6 Shrinkage

Add 2.5 Elastic Module

Add 2.6 Machinability

When all suggestions which met the established criteria of the study had been added, revised, or deleted to the Proposed Classification Outlines, the Revised Classification Outline was reviewed again by staff liaison of the American Society for Metals and the researcher. This activity completed this phase of the study. See PERT Chart, page 14, activity 42 - 45.

The "Classification of Solid Materials" and the "Classification of Properties of Solid Materials" comprised the answer to two of the four questions raised in the study—namely, "What are the materials that may be classified as solids" and "What are the properties that solid materials may possess?"

The "Classification of Solid Materials" that resulted is found on page 71. The "Classification of Properties of Solid Materials" that resulted is found on page 77. Definitions of the terms begin on page 79.
A Classification of Solid Materials

1.0 Metals

1.1 Ferrous

1.1.1 Plain carbon steel
   1.1.1.1 Low carbon
   1.1.1.2 Medium carbon
   1.1.1.3 High carbon

1.1.2 Stainless steel
   1.1.2.1 Ferritic
   1.1.2.2 Austenitic
   1.1.2.3 Martensitic
   1.1.2.4 Precipitation hardening

1.1.3 Alloy steel
   1.1.3.1 Manganese steels
   1.1.3.2 Nickel-chromium steels
   1.1.3.3 Molybdenum steels
   1.1.3.4 Chromium-molybdenum steels
   1.1.3.5 Nickel-chromium-molybdenum steels
   1.1.3.6 Nickel-molybdenum steels
   1.1.3.7 Chromium steels
   1.1.3.8 Chromium-vanadium steels
   1.1.3.9 Nickel-chromium-molybdenum-
      Triple-alloy steels
   1.1.3.10 Silicon-manganese steels
   1.1.3.11 Boron steels

1.1.4 Cast iron
   1.1.4.1 Gray
   1.1.4.2 White
   1.1.4.3 Ductile or nodular
   1.1.4.4 Malleable

1.2 Non-ferrous

1.2.1 Light metals and alloys
   1.2.1.1 Lithium
   1.2.1.2 Beryllium
   1.2.1.3 Sodium
   1.2.1.4 Magnesium
   1.2.1.5 Potassium
   1.2.1.6 Calcium
   1.2.1.7 Rubidium
1.2.1.08 Strontium
1.2.1.09 Barium
1.2.1.10 Aluminum
1.2.1.11 Titanium

1.2.2 Heavy metals and alloys
1.2.2.01 Scandium
1.2.2.02 Vanadium
1.2.2.03 Chromium
1.2.2.04 Manganese
1.2.2.05 Cobalt
1.2.2.06 Nickel
1.2.2.07 Copper
1.2.2.08 Yttrium
1.2.2.09 Zirconium
1.2.2.10 Technetium
1.2.2.11 Hafnium
1.2.2.12 Radium

1.2.3 White metals and alloys
1.2.3.01 Zinc
1.2.3.02 Germanium
1.2.3.03 Cadmium
1.2.3.04 Indium
1.2.3.05 Tin
1.2.3.06 Antimony
1.2.3.07 Thallium
1.2.3.08 Lead
1.2.3.09 Bismuth
1.2.3.10 Polonium

1.2.4 Precious metals and alloys
1.2.4.1 Ruthenium
1.2.4.2 Rhodium
1.2.4.3 Palladium
1.2.4.4 Silver
1.2.4.5 Osmium
1.2.4.6 Iridium
1.2.4.7 Platinum
1.2.4.8 Gold
1.2.4.9 Rhenium

1.2.5 Refractory metals and alloys
1.2.5.1 Columbium
1.2.5.2 Molybdenum
1.2.5.3 Tantalum
1.2.5.4 Tungsten

1.2.6 Rare earth
1.2.6.1 Lanthanide series
1.2.6.2 Actinide series
1.2.7 Metalloids
1.2.7.1 Boron
1.2.7.2 Silicon
1.2.7.3 Arsenic
1.2.7.4 Tellurium
1.2.7.5 Astatine

2.0 Non-metals

2.1 Pure elements

2.1.1 Iodine
2.1.2 Carbon
   2.1.2.1 Diamond
   2.1.2.2 Graphite
2.1.3 Phosphorus
2.1.4 Sulfur
2.1.5 Selenium

2.2 Ceramics

2.2.1 Dielectrics
   2.2.1.1 Glass
      2.2.1.1.1 Silica
      2.2.1.1.2 Soda silica

   2.2.1.2 Clays
      2.2.1.2.1 Kaoline clay
      2.2.1.2.2 Ball clay
      2.2.1.2.3 Fire clay
      2.2.1.2.4 Flint clay
      2.2.1.2.5 Pottery clay
      2.2.1.2.6 Shale clay
      2.2.1.2.7 Vitrifying clay
      2.2.1.2.8 Brick clay
      2.2.1.2.9 Slip clay

2.2.1.3 Refractory raw materials
   2.2.1.3.1 Alumina
   2.2.1.3.2 Magnesia
   2.2.1.3.3 Dolomite
   2.2.1.3.4 Chrome
   2.2.1.3.5 Talc
      2.2.1.3.5.1 Pyrophyllite
      2.2.1.3.5.2 Block talc
      2.2.1.3.5.3 Asbestos
   2.2.1.3.6 Silica
      2.2.1.3.6.1 Feldspar
      2.2.1.3.6.2 Wollastonite
      2.2.1.3.6.3 Sillimanite
2.2.2 Ferroelectrics

2.2.2.1 Transducers
   2.2.2.1.1 Barium titanate
   2.2.2.1.2 Lead titanate

2.2.2.2 Ceramic semi-conductors

2.2.3 Magnetics

2.2.3.1 Ferrites
2.2.3.2 Spinels
2.2.3.3 Garnets

2.3 Plastics

2.3.1 Thermoplastics

2.3.1.1 Cellulose derivatives
   2.3.1.1.1 Regenerated cellulose
   2.3.1.1.2 Cellulose esters
   2.3.1.1.3 Cellulose ethers

2.3.1.2 Ethenic polymers
   2.3.1.2.01 Polyethylene
   2.3.1.2.02 Polypropylene
   2.3.1.2.03 Polyisobutylene
   2.3.1.2.04 Fluorocarbon polymers
   2.3.1.2.05 Polyvinyl acetate and its derivatives
   2.3.1.2.06 Vinyl chloride polymers and copolymers
   2.3.1.2.07 Polyvinylidene chloride
   2.3.1.2.08 Polystyrene
   2.3.1.2.09 Acrylic polymers
   2.3.1.2.10 Coumarone-indene polymers
   2.3.1.2.11 Polyvinyl ethers
   2.3.1.2.12 Polyvinyl ketones
   2.3.1.2.13 Polyvinyl amines
   2.3.1.2.14 Divinyl polymers

2.3.2 Thermosets

2.3.2.1 Phenolic resins
   2.3.2.1.1 Phenol-formaldehyde
   2.3.2.1.2 Phenol-furfural
   2.3.2.1.3 Resorcinol-formaldehyde

2.3.2.2 Amino resins
   2.3.2.2.1 Urea-formaldehyde
   2.3.2.2.2 Melamine-formaldehyde
2.3.2.3 Polyesters
2.3.2.4 Polyurethanes
2.3.2.5 Polyamides (Nylon)
2.3.2.6 Epoxides
2.3.2.7 Polyethers

2.3.3 Elastomers
2.3.3.1 Polyisoprene
2.3.3.2 Polybutadiene
2.3.3.3 Polychloroprene
2.3.3.4 Butadiene copolymers
  2.3.3.4.1 SBR
  2.3.3.4.2 Nitrile rubbers
2.3.3.5 Isobutylene-isoprene copolymers
2.3.3.6 Polysulfide rubbers
2.3.3.7 Chlorosulfonated polyethylene
2.3.3.8 Polyurethane rubbers
2.3.3.9 Silicone rubbers
2.3.3.10 Fluorine rubbers

2.4 Natural organics

2.4.1 Vegetative materials
2.4.1.1 Food
  2.4.1.1.1 Grains and cereals
  2.4.1.1.2 Legumes
  2.4.1.1.3 Vegetables
  2.4.1.1.4 Fruits
  2.4.1.1.5 Nuts
  2.4.1.1.6 Seeds
2.4.1.2 Fiber
  2.4.1.2.1 Cellulose
  2.4.1.2.2 Ligno-cellulose
2.4.1.3 Derivatives
  2.4.1.3.1 Resins
  2.4.1.3.2 Rosin
  2.4.1.3.3 Lignin

2.4.2 Animal materials
2.4.2.1 Food
  2.4.2.1.1 Meat
  2.4.2.1.2 Poultry
  2.4.2.1.3 Fish
    2.4.2.1.3.1 Fin back
    2.4.2.1.3.2 Shell back
  2.4.2.1.4 Dairy
  2.4.2.1.5 Eggs
2.4.2.2 Fiber
  2.4.2.2.1 Hide
  2.4.2.2.2 Fur
  2.4.2.2.3 Protein

2.4.2.3 Derivatives

3.0 Composites
  3.1 Integral coated
  3.2 Random dispersed particle
  3.3 Oriented particle
  3.4 Fiber-reinforced
  3.5 Laminar
A Classification of Properties of Solid Materials

1.0 Non-mechanical

1.1 Physical
  1.1.01 Dimensions
  1.1.02 Density
  1.1.03 Porosity
  1.1.04 Crystalline structure
  1.1.05 Atomic spacing
  1.1.06 Specific gravity
  1.1.07 Viscosity
  1.1.08 Weight
  1.1.09 Texture
  1.1.10 Shape
  1.1.11 Moisture content
  1.1.12 Allotropy
  1.1.13 Shrink

1.2 Thermal
  1.2.1 Thermal conductivity
  1.2.2 Specific heat
  1.2.3 Thermal expansion
  1.2.4 Melting point
  1.2.5 Contraction
  1.2.6 Deflection temperature
  1.2.7 Temperature of fusion

1.3 Electric and Magnetic
  1.3.1 Conductivity
  1.3.2 Magnetic permeability
  1.3.3 Dielectric strength
  1.3.4 Dielectric constant
  1.3.5 Dissipation factor
  1.3.6 Arc resistance
  1.3.7 Electrochemical potentials

1.4 Acoustical
  1.4.1 Sound absorption
  1.4.2 Sound reflectance
  1.4.3 Damping capacity

1.5 Optical
  1.5.1 Color
  1.5.2 Light reflectance
  1.5.3 Light refraction
  1.5.4 Light absorption
1.6 Chemical
   1.6.1 Corrosion resistance
      1.6.1.1 Acidity
      1.6.1.2 Alkalinity
   1.6.2 Reactive ability
      1.6.2.1 Oxidation
      1.6.2.2 Reduction
   1.6.3 Adhesion
   1.6.4 Cohesion
   1.6.5 Ignition temperature

1.7 Nuclear

1.8 Atomic structure

2.0 Mechanical

2.1 Strength
   2.1.1 Compressive
   2.1.2 Tensile
   2.1.3 Shear
   2.1.4 Flexure
   2.1.5 Fracture
      2.1.5.1 Toughness
      2.1.5.2 Brittleness
   2.1.6 Bend
   2.1.7 Torsion
   2.1.8 Fatigue
      2.1.8.1 Notch sensitivity
      2.1.8.2 Cross section
      2.1.8.3 Crack initiation
      2.1.8.4 Crack propagation
   2.1.9 Creep

2.2 Ductility
   2.2.1 Elasticity
   2.2.2 Plasticity

2.3 Hardness
   2.3.1 Penetration
   2.3.2 Rebound
   2.3.3 Scratch

2.4 Malleability
   2.4.1 Elasticity
   2.4.2 Plasticity

2.5 Elastic Moduli

2.6 Machinability
**Definitions of Major Solid Materials**

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 Metals</td>
<td>crystalline in nature, inorganic, opaque, have a luster, metallic bonded, good conductors of heat and electricity, readily give up electrons</td>
</tr>
<tr>
<td>1.1 Ferrous</td>
<td>metals and alloys with a primary base of iron</td>
</tr>
<tr>
<td>1.2 Non-ferrous</td>
<td>metals and alloys with a primary base other than iron</td>
</tr>
<tr>
<td>2.0 Non-metals</td>
<td>materials other than metals</td>
</tr>
<tr>
<td>2.1 Pure elements</td>
<td>not crystalline in nature, covalent or ionic bonded, non-metallic solids, occur as solids in their natural state</td>
</tr>
<tr>
<td>2.2 Ceramics</td>
<td>crystalline solids, ionic or covalent bonded, not good conductors of heat and electricity, generally high melting points</td>
</tr>
<tr>
<td>2.3 Plastics</td>
<td>solids composed of long molecular chains, Van der Waals forces, generally low melting points</td>
</tr>
<tr>
<td>2.4 Natural organics</td>
<td>plant and animal materials</td>
</tr>
<tr>
<td>3.0 Composites</td>
<td>combination of two or more dissimilar materials</td>
</tr>
<tr>
<td>------------------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>3.1 Integral coated</td>
<td>a material whose surface has been coated with another material</td>
</tr>
<tr>
<td>3.2 Random dispersed particle</td>
<td>a material in which particles lack a definite pattern</td>
</tr>
<tr>
<td>3.3 Oriented particle</td>
<td>a material in which particles possess a definite pattern</td>
</tr>
<tr>
<td>3.4 Fiber-reinforced</td>
<td>a material with threadlike structure</td>
</tr>
<tr>
<td>3.5 Laminar</td>
<td>a material composed of different layers</td>
</tr>
</tbody>
</table>
Definition of Properties of Solid Materials

1.0 Non-mechanical characteristics that describe a material in which external forces have not been applied

1. Physical properties that pertain to the physical characteristics of a material

1.1.01 Dimensions characteristics as thickness, width, and length

1.1.02 Density mass per unit volume

1.1.03 Porosity vacancies within a material

1.1.04 Crystalline structure long range order of atoms in a periodic manner

1.1.05 Atomic spacing distance between atoms

1.1.06 Specific gravity ratio of a density of a material to density of water

1.1.07 Viscosity flow properties

1.1.08 Weight relative heaviness

1.1.09 Texture surface characteristics of a material

1.1.10 Shape form of a material

1.1.11 Moisture content amount of water in a material

1.1.12 Allotrophy a change in crystalline structure with change in temperature

1.1.13 Shrink contraction of a material
1.2 Thermal

1.2.1 Thermal conductivity

1.2.2 Specific heat

1.2.3 Thermal expansion

1.2.4 Melting point

1.2.5 Contraction

1.2.6 Deflection temperature

1.2.7 Temperature of fusion

1.3 Electric and Magnetic

1.3.1 Conductivity

1.3.2 Magnetic permeability

1.3.3 Dielectric strength

transformations within a material by heating or cooling

movement of heat through a material

ratio of quantity of heat to raise temperature of material one degree

expansion due to change in temperature

point at which solid becomes liquid

shrinkage during lowering of temperature

temperature at which a material expands and contracts in phase transformation

temperature at which two materials form a common bond

reaction of a material to electric or electro-magnetic forces

ease of movement of electrons due to electromotive force

ease of magnetization of a material

ability of an insulating material to resist breakdown
<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.3.4</td>
<td>Dielectric constant: measure of power to reduce force between two separated</td>
</tr>
<tr>
<td></td>
<td>electric charges</td>
</tr>
<tr>
<td>1.3.5</td>
<td>Dissipation factor: ratio of conductance to susceptance</td>
</tr>
<tr>
<td>1.3.6</td>
<td>Arc resistance: resistance of a surface of a material to breakdown under</td>
</tr>
<tr>
<td></td>
<td>electric stress</td>
</tr>
<tr>
<td>1.3.7</td>
<td>Electrochemical potentials: voltage attributed to reactions of materials</td>
</tr>
<tr>
<td>1.4</td>
<td>Acoustical: characteristics that a material exhibits to sound waves</td>
</tr>
<tr>
<td>1.4.1</td>
<td>Sound absorption: ability of a material to take in sound waves</td>
</tr>
<tr>
<td>1.4.2</td>
<td>Sound reflectance: ability of material to deflect sound waves</td>
</tr>
<tr>
<td>1.4.3</td>
<td>Damping capacity: ability of a material to diminish vibration and oscillation</td>
</tr>
<tr>
<td>1.5</td>
<td>Optical: characteristics of a material to transmit or reflect light</td>
</tr>
<tr>
<td>1.5.1</td>
<td>Color: specific light being reflected when white light shines on material</td>
</tr>
<tr>
<td>1.5.2</td>
<td>Light reflectance: measure of brightness of material</td>
</tr>
<tr>
<td>1.5.3</td>
<td>Light refraction: ability of material to deflect light from path</td>
</tr>
<tr>
<td>1.5.4 Light absorption</td>
<td>ability of material to take in light</td>
</tr>
<tr>
<td>------------------------</td>
<td>--------------------------------------</td>
</tr>
<tr>
<td>1.6 Chemical</td>
<td>characteristics that describe reaction, corrosion, solubilities, etc. of a material</td>
</tr>
<tr>
<td>1.6.1 Corrosion resistance</td>
<td>resistance of a material to deterioration by chemical or electrochemical reaction</td>
</tr>
<tr>
<td>1.6.1.1 Acidity</td>
<td>measure of acid</td>
</tr>
<tr>
<td>1.6.1.2 Alkalinity</td>
<td>measure of base</td>
</tr>
<tr>
<td>1.6.2 Reactive ability</td>
<td>measure of rate a material is reactive to environment</td>
</tr>
<tr>
<td>1.6.2.1 Oxidation</td>
<td>lose of electrons</td>
</tr>
<tr>
<td>1.6.2.2 Reduction</td>
<td>gain of electrons</td>
</tr>
<tr>
<td>1.6.3 Adhesion</td>
<td>force of attraction between atoms of two phases</td>
</tr>
<tr>
<td>1.6.4 Cohesion</td>
<td>force of attraction between atoms within a single phase</td>
</tr>
<tr>
<td>1.6.5 Ignition temperature</td>
<td>flash point</td>
</tr>
<tr>
<td>1.7 Nuclear</td>
<td>reactions at the atomic level of material</td>
</tr>
<tr>
<td>1.8 Atomic structure</td>
<td>structure of atoms within a material</td>
</tr>
<tr>
<td>2.0 Mechanical</td>
<td>characteristics which describe a material in which external forces have been applied</td>
</tr>
</tbody>
</table>
2.1 Strength

2.1.1 Compressive
the ability of material to resist deformation
maximum compressive stress that material is capable of handling

2.1.2 Tensile
maximum strain that a material is capable of handling before pulling apart

2.1.3 Shear
resistance to fracture by opposing forces which would cause separation by sliding of planes

2.1.4 Flexure
relative performance of material under stress cycles

2.1.5 Fracture
maximum true stress at fracture

2.1.5.1 Toughness
ability to absorb shock

2.1.5.2 Brittleness
inability to absorb shock

2.1.6 Bend
measure of resistance to bending

2.1.7 Torsion
strain in a material created by twisting action

2.1.8 Fatigue
tendency of material to break under rotation

2.1.8.1 Notch sensitivity
measure of reduction of strength caused by presence of notch

2.1.8.2 Cross section
area across diameter

2.1.8.3 Crack initiation
start of a crack

2.1.8.4 Crack propagation
movement of crack
2.1.9 Creep  
- time dependent strain occurring under stress

2.2. Ductility  
- the amount a material can be permanently elongated

2.2.1 Elasticity  
- property of a material to return to original shape after deformation

2.2.2 Plasticity  
- property of material to become permanently deformed (related to elongation)

2.3 Hardness  
- the ability of a material to resist indentation

2.3.1 Penetration  
- indentation

2.3.2 Rebound  
- amount of energy a material will absorb in a dynamic test

2.3.3 Scratch  
- file hardness test

2.4 Malleability  
- ability of a material to deform permanently by hammering

2.4.1 Elasticity  
- property of a material to return to original shape after deformation

2.4.2 Plasticity  
- property of material to become permanently deformed (related to malleability)

2.5 Elastic Moduli  
- relation of stress to strain of a material
2.6 Machinability quality of a material which provides ease of separating

Chapter Summary

In this chapter the procedures for using techniques of content analysis were described. The development of a "Proposed Classification of Solid Materials" and a "Proposed Classification of Properties of Solid Materials" was explained. The procedure for evaluation of the proposed classifications by committees of experts was also described. The expert reactions were reported, along with resulting changes in classifications, and the final "Classification of Solid Materials" and "Classification of Properties of Solid Materials" were reported.
CHAPTER IV

IMPLICATIONS FOR CURRICULUM OF THE BODY OF KNOWLEDGE
OF SOLID MATERIALS PROCESSING TECHNOLOGY

IACP - A Rationale and Structure for
Industrial Arts Subject Matter

Every branch of man's work and technology has exponentially expanded. This advancement is obvious; what is not so obvious is the ability to assess these rapid changes. Various curriculum efforts have attempted to keep up with changes occurring in industry. The selected innovative curricula reported and reviewed, in Chapter II, have endeavored to supply a base which would provide more relevant knowledge of industry and technology.

The difficulty has not been in identifying industry as the source of content for industrial arts education. Generally it has been the problem of delineating an appropriate body of knowledge. One of the causes of this difficulty was that the terms, "industry" and "technology", were often used interchangeably; the terms had not yet been precisely defined for theoretical purposes in regard to curriculum construction. The lack of refinement in conceptualization has caused an insufficiently refined base or framework for industrial arts courses. The absence of this adequate base
prevented programs from being developed or expanded which could efficiently transmit a body of knowledge.

The challenge to deal with this formidable task was undertaken by the Industrial Arts Curriculum Project in 1965. Through a joint effort of the Ohio State University and the University of Illinois, funded by the Bureau of Research of the U. S. Office of Education, the task of developing a rationale and structure was begun. Specialists from industry, educators, historians, and philosophers began the development of a rationale and structure which would serve as a base for instructional programs in industrial arts education, with particular emphasis on industrial arts education.

At the outset of the project, three major assumptions were made concerning industrial arts education.

1. Industrial arts is a study of industry. It is an essential part of the education of all students in order that they may better understand their industrial environment and make wise decisions affecting their occupational goals.

2. Man has been and remains curious about industry, its materials (underlining is the author's), processes, organization, research, and services.

3. Industry is so vast a societal institution that it is necessary, for instructional purposes, to place an emphasis on conceptualizing a fundamental structure of the field, i.e., a system of basic principles, concepts, and unifying themes.
Additional assumptions were made:

1. For purposes of analysis, man's knowledge can be categorized and ordered logically.

2. To provide for the most effective and efficient transmission of knowledge, the educator must codify and structure disciplined bodies of knowledge.

3. The structure of a body of knowledge can be developed before the total curriculum is designed.

4. All domains of man's knowledge must be included in an effective general educational program (Towers, Lux, & Ray, 1966, pp. 2-3).

The important questions to be answered remained:

What is industry? Could there be a body of industrial knowledge or was there simply a body of knowledge which was used in industry, as well as in many other ways?

It was suggested by the IACP that man's knowledge could be ordered into the four domains as shown in Figure 6.

Man's Knowledge

- Formal
- Descriptive
- Prescriptive
- Praxiological

Figure 6
Man's Four Domains of Knowledge
The first domain was called formal knowledge. The disciplines included in this domain provide the tools with which all other knowledge can be ordered. Examples of these disciplines are logic, mathematics, and linguistics.

The second domain is called descriptive knowledge and includes the physical, biological, and behavioral sciences. The sciences seek to describe facts that exist of events, phenomena, and their relationships.

The third domain is called prescriptive knowledge and is composed of the literatures and philosophy, or broadly stated, the humanities. This is a system of knowledge which offers judgemental values of what ought to be; what is good, true, or beautiful.

The fourth domain, praxiology, traditionally has been considered to be applied science. Disciplines at the collegiate level would include law, engineering, medicine, etc.. Praxiology, the knowledge of practices, has recently received greater attention in curriculum planning.

Praxiology is derived from the Greek "praxis" which means the exercise or practice of an art. The suffix "ology" means "the science or knowledge of;" the total meaning of the term is thus, the science of man's practices. Kotarbinski (1965) defined praxiology as "the general theory of efficient action [p. 1]."

If technology is defined as "the science of the application of knowledge to practical purposes," then technology may
be equated with praxiology. Although the term "praxiology" communicates more thoroughly the concern of IACP, the term "technology" was used because of its wider use and acceptance. Technology, efficient action or practice, may be considered to be a body of knowledge.

As man developed through the centuries, so did man's practices or man's plans of action. As these actions became formalized, societal institutions developed. The economic affairs, for example, could no longer be handled efficiently by the family; political activity also became complex.

![Institutions of Man Diagram](image-url)

**Figure 7**

Societal Institutions of Man
The educational patterns gained greater significance because of the increased complexity of man's various social institutions. The IACP stated there were generally five basic institutions of man. See Figure 7.

Planning a curriculum in terms of the complex relationships of man and his practices within the societal institutions further suggested a system of human technological relationships. Since man had been so active, he had many technologies. The ordering of man's practices had not necessarily been consistently described. Previous curriculum attempts had generally omitted this important aspect or relationship.

This approach to industrial arts curriculum included knowledge of man's practices or technology. The remaining step was to identify the source of content appropriate for industrial technology. There had been general agreement that industrial arts education was the study of industry. One of the major difficulties had been in the definition of industry. Often, terms such as "agriculture," "business," and "industry" were taken collectively to describe all of man's economic activity. This broadness of use forced the delineation or scope of industry.

For the IACP, industry was considered a sub-element of the economic system as illustrated in Figure 8.
Economic Institution provides through Economic Goods:

- Communication
- Domestic
- Education
- Entertainment & Recreation
- Construction
- Manufacturing
- Finance, Insurance & Real Estate
- Health
- Legal
- Marketing
- Transportation
- Miscellaneous

Figure 8

Economic Institution
(Towers, Lux, & Ray, 1966, p. 73)
Within the economic institution, industry was considered a sub-category which substantially changed the form of the material products. The rigorous analysis employed by the IACP to arrive at a body of knowledge and source of content established a societal base from which curriculum could be derived.

The IACP redefined industrial arts as:

Industrial arts is an organized study of the knowledge of practice within that sub-category of the economic institution of society which is known as industry (Towers, Lux, & Ray, 1966, p. 43).

To facilitate communicating the body of knowledge, a matrix approach was utilized to represent the production and the management functions which affect material goods. See Figure 9.

Economic value of goods increased when efficient management and production practices were employed. Substantially changing the form of materials was of major importance in viewing industry and its relationships with other economic activities.

The body of knowledge and the source of content derived by the IACP permitted curriculum personnel to identify major sub-elements within the basic structure. The matrix approach provided a way of looking at the many dimensions of the body of knowledge. For example, the
Second Order Matrix of Industrial Technology Affecting Materials
(Towers, Lux, & Ray, 1966, p. 159)
industrial production axis could be expanded to a higher order while keeping hold of the generality of the lower order of the remaining axes. The axes could be varied to provide the many sub-systems of the body of knowledge. See Figure 10.

**Delineation of a Model for Solid Materials Processing Technology**

A study of solid materials and their properties can be considered as falling within the descriptive domain of knowledge, or study of science. See Figure 11. Sciences seek to establish facts about events or phenomena and their relationship. However, by adding a third axis, processing, it becomes possible for the consideration of a technological or praxiological domain of knowledge. See Figure 12. Where the sciences are concerned with facts and the investigation of reality, the technologies are concerned with artifacts and with the creation of a reality. More precisely, technology is man's knowledge of practice which enables him to produce more objects, with more features, and to produce them in a more efficient manner.

This disciplined approach to the technology of solid materials processing can simplify content, provide a structure, and provide a means for further study of that discipline. The processing of solid materials can be investigated in terms of efficient practices.
Figure 11
Axes of Materials and Properties

Figure 12
Matrix of Solid Materials, Properties, and Processes
Figure 12 represents a matrix of solid materials, processes, and properties which establishes a technology of solid materials processing.

Although the following practices are contained in the matrix of the IACP, separate or single practices can be individually investigated in greater depth as in Figure 9.

1. Industrial production practices affecting humans.
2. Industrial production practices affecting materials.
3. Industrial management practices affecting humans.
4. Industrial management practices affecting materials.

The establishment of the matrix for the technology of solid materials processing (Figure 12) permits a subsystem of knowledge, industrial production practices affecting materials, to be separately investigated as an interrelationship within the matrix of Industrial Technology of the IACP. Figure 13 represents a first order matrix of industrial technology. The industrial production technology axis depicts the sub-elements of pre-processing, processing, and post-processing. "Processing," as a sub-element of the industrial production practices affecting
Figure 13

Matrix of Industrial Technology with Second Order Production Axis
materials (item 2 above), provides the universal applications developed by the IACP. See Appendix L. The adoption of these processes constitutes an answer to one of the four questions raised in the study—specifically, "can universal processes be applied to solid materials?"

The derived curriculum sub-system illustrates the interrelationship of industrial material goods, processes, and industrial management practices affecting materials (item 4 above.) This knowledge, "properties of materials" is needed for practices affecting materials. The derived sub-system, Figure 14 may be considered as the First Order of solid materials processing technology. The sub-system being derived from Industrial Technology constitutes an answer to one of the questions raised in the study—namely, "what is the underlying reason for studying solid materials processing technology?"

Further, the technology of solid materials processing can embrace the "producing of the materials" as well as the "using of the materials" illustrated in Figure 15.

Primary manufacturers are concerned with producing raw materials (primary metals, pure elements, ceramics, plastics, natural organics, and composites). These materials are processed into standard sizes, shapes, and weights called standard stock. The standard stock becomes
Processes

Industrial Material Goods
or
Solid Materials

Figure 14
Sub-system of First Order of Solid Materials
Processing Technology
Figure 15
Model of a Technology of Solid Materials Processing
Figure 16

The Material Production Continuum
(Towers, Lux, & Ray, 1966, p. 75)
products or industrial materials for manufacturers and constructors.

Efficient practices of "producing materials" (separating, forming, and combining) are as important as efficient practices of "using materials." In the technology of solid materials processing (producing materials and using materials) practices are sought for more reliable, durable materials having more features.

While genetic and extractive production were considered to be economic activities, such as agriculture and mining, respectively, they were not regarded as activities which essentially change the form of materials. Figure 16 illustrates the relationship among the elements involved in the production of material goods. Although materials, processes, and properties can be separately investigated, it is the interrelationship of these components that provides the dynamics of solid materials processing technology. Properties may be considered as they relate to processes yielding material goods.

The matrix approach permits sub-elements to be investigated for instructional purposes. Instruction can lead from the general to the specific. See Figure 18. Where Figure 17 illustrated the Second Order Matrix of Solid Materials Processing Technology, Figure 18 illustrates a Third Order Matrix. These matrices permit various
Figure 17

Second Order Matrix of Solid Materials Processing Technology
Figure 18

Third Order Matrix of Solid Materials Processing Technology
levels of investigation depending on the specificity of the structure of knowledge desired.

The IACP classified these relationships.

The genetic or extractive material production of agriculture, forestry, fisheries, mining etc., may either provide materials to industry (construction and manufacturing) which substantially change the forms of these materials, or their production may be provided directly to the consumer. For example, peas may be sold fresh to the consumer or be processed in industry and then distributed to the consumer. Similarly, coal may be provided directly to the consumer or it may be manufactured into briquets or converted to kilowatts and then passed to the consumer. Gravel may be processed by manufacturing and construction to concrete and to a structure respectively (Towers, Lux, & Ray, 1966, p. 74).

The IACP further clarified the production stages:

First, a material can become a product at any time. It becomes a producer's product if it is used by another manufacturer or a constructor. It is a personal product if it is bought and used by an individual, for example, in his home. Second, materials that are processed by primary manufacturers (primary metals, textiles, petroleum, chemicals, energy, lumber and others) produce by-products. These become products for still other manufacturers ... Third, manufacturing production can be thought of as changing material from the general to the particular (Industrial Arts Curriculum Project Staff, 1970, p. 246).
It can be seen that genetic or extractive materials which require industrial processing before they reach the consumer can be considered to be substantially changed in form. While the primary responsibility of this study is directed to a course at the secondary school level, the matrix approach has applicability at all grade levels. Several criteria are proposed that would restrict the processing of materials in the laboratory:

1. Safety is a prerequisite in considering the processing of any solid materials. High temperatures are required for the processing of some materials. The attainment of these high temperatures may not be possible because of laboratory facilities, availability of equipment or maturity of students.

2. The availability of materials for standard stock production may be restrictive.

3. Some materials are highly reactive.

4. Some materials are toxic.

5. Some materials are unstable and do not remain in isolated form during the period of processing.

6. Cost of some materials may be extremely high.

It should be pointed out that the usefulness of the matrix approach is primarily as a conceptual model from which a structure for the body of knowledge of the technology of solid materials processing may be developed.
The assumption for structuring knowledge was that it would provide a means of more efficiently teaching and learning a body of knowledge. It follows then, that classifications should provide concepts for the learner, guides for thinking, and guides for designing learning experiences.

**Implications for Curriculum Development**

Three bases for curriculum development are proposed as a result of the development of the body of knowledge of solid materials processing technology:

1. The development of "a story of processing solid materials into standard stock."
2. The development of "a story of processing solid materials used in construction and and manufacturing."
3. The development of "procedures for efficient practices in processing solid materials."

"A story of processing solid materials into standard stock" may be generated for a material in any of the sub-categories of materials. The story-telling technique has been used successfully in the IACP courses "The World of Construction" and "The World of Manufacturing." Story telling in terms of sequences and practices may be generated for any of the following groups in the "Classification of Solid Materials."

1. Ferrous metals and alloys
2. Non-ferrous metals and alloys
3. Pure metals
4. Dielectric ceramics
In order to develop a syllabus to tell "a story of processing solid materials into standard stock," several questions must be answered. The first question deals with the least number of phases required to produce a certain given standard stock material. The second question deals with the activities or practices, within each phase, that would be required to produce the material.

An example of the story-telling technique of practices can be generated for aluminum. Tentative phases and activities are listed. Practices could be generated for the various activities.

Refining

1. Crush bauxite.
2. Mix with hot caustic soda solutions.
3. Caustic soda dissolves aluminum hydroxide.
4. Solution is filtered.
5. Aluminum hydroxide settles on cooling.
6. Crystals are washed.
7. Aluminum hydroxide crystals are heated.
8. Water evaporates leaving alumina.

Reduction

9. Alumina goes to reduction plant.
10. Aluminum is released from oxygen.
11. Aluminum is poured to form ingots.

Fabrication

12. Sheet and plate are formed.
13. Bar and rod are formed.
14. Wire is drawn.
15. Shapes are extruded.
16. Tube is drawn.

(adapted from Johnson & Weeks, 1966)

"A story of processing materials used in construction and manufacturing" can also be generated utilizing the "Classification of Properties of Solid Materials." This activity could provide students deeper understanding, skills, and attitudes concerning various materials that are used in construction and manufacturing.

Two options might be considered in this particular unit. In Option 1, the material or materials processed in "a story of processing solid materials into standard stock" to be used in construction or manufacturing could have been produced by a different class. The students would also have derived the properties for the materials. In Option 2, the practices involved for obtaining standard stock used in "a story of processing solid materials used in construction
and manufacturing" could be described in story form as a material progresses from a primary producer, to a producer, and to a consumer as the material changes in form.

Materials processed by a primary producer can be a product at any time. It is a producer's product if used by constructors and manufacturers before going on to the consumer. It is a consumer's product if used by an individual for personal use. Figure 19 illustrates how the product or output of one system becomes the product or input of another system. Students in Option 2 would have studied all the practices implied in Figure 19.

A matrix approach may be used in the development of "procedures for efficient practices in processing solid materials." This approach permits a unique way of viewing the multifaceted components. In the three-dimensional matrix, increasing levels of smaller elements may be added on any axis. The advantage is, of course, being able to go from general to specific knowledge of practices.

Decisions of a general nature regarding the processing of solid materials could be made by referring to the matrix in Figure 20. At this level, "plastics," has the following characterization:

2.3 Plastics - solids composed of long molecular chains, Van der Waals forces, generally have a low melting point.
Figure 19
Input-Output Scheme
Figure 20

SOLID MATERIALS

Non-metals

Natural Organics
Plastics
Ceramics
Pure Elements

PROCESSSES

Properties
A higher-ordered matrix or model depicting properties, processes, and solid materials can be utilized to determine appropriate processing techniques for materials of various properties. Rather than a general characterization of plastics, specific properties and processes for urea-formaldehyde can be disclosed. Appropriate characteristics of urea-formaldehyde plastics are enclosed in the parentheses:

**Material**

2.3.2.2.1 Urea-formaldehyde

**Properties**

1.0 Non-mechanical

1.1 Physical (varies, depends on fillers used)
   1.1.01 Dimensions (good stability)
   1.1.06 Specific gravity (1.4-1.6)
   1.1.11 Moisture content (absorption takes place, causes brittleness)
   1.1.13 Shrink (slight shrinkage following molding)

1.2 Thermal (thermosetting materials)

1.3 Electric - Magnetic
   1.3.1 Conductivity (good insulation)

1.4 Acoustical

1.5 Optical (no effect)
   1.5.1 Color (good)

1.6 Chemical
1.6.2 Reactive ability (good resistance to most solvents)

1.6.2.1 Oxidation (burns with difficulty)

1.7 Nuclear

1.8 Atomic structure

2.0 Mechanical

2.1 Strength

2.2 Ductility

2.3 Hardness

2.3.3 Scratch (scratch resistant)

2.4 Malleability

2.5 Elastic Moduli

2.6 Machinability

Process

2.3.1.10 Molding (plastics)

Since urea-formaldehydes are thermosetting, they are useful where heat resistance is important. They are an important material for tableware and crockery since they are hard, strong, and possess neither smell nor taste. As a molding material urea-formaldehyde is used for electrical equipment, buttons, plugs, bottle caps, toys, cabinets, and kitchen equipment.

This example represents an advantage of a matrix approach by being able to go logically from general to
specific information.

The three preceding examples illustrate the curriculum implementation as a result of the development of the body of knowledge of solid materials processing technology.

Plan for Designing Instructional Materials for Solid Materials Processing Technology

The delineation of a body of knowledge of "Solid Materials Processing Technology" is not to be assumed the final form for instruction in industrial arts laboratories. The conceptualization is important for instructional purposes in order to generate "a story of processing solid materials into standard stock," "a story of processing solid materials used in construction and manufacturing," and "procedures for efficient practices in processing solid materials."

The following are selected constraints and guidelines, from a more comprehensive listing, which were established by the IACP and which have been adapted to this study. These establish the parameters to be used in the design of a study of the technology of solid materials processing.

1. Basic technological concepts should be expanded, communicated via a textbook or comparable input component.

2. Workbook activities should be designed to reinforce these cognitive concepts.
3. A laboratory manual should be provided to guide laboratory work which would further reinforce these concepts through problem-solving of real or simulated technological problems.

4. A teacher's guide should provide the teacher with basic information for implementing and managing the course.

5. There should be periodic achievement tests.

6. Essential hardware and instructional aids should be provided.

7. Each course should be designed according to the instructional time which a school wishes to devote to it.

8. There should be measurable behavioral objectives for every unit of instruction.

9. Activities should be representative of each major technological concept at a level of specificity which is appropriate to the length of the course.

10. Program costs should be commensurate with existing school budgets for comparable kinds of courses.

11. Activities should have "student appeal" and be interesting. (Buffer, Lux, & Ray 1971, pp.25-26).
Overall objectives of the IACP, derived from the broad purposes of general education, should provide the framework for instruction. The "Classification of Solid Materials" and the "Classification of Properties of Solid Materials" serves as a source from which units of instruction can be derived.

The course in solid materials processing technology should be designed for the school year, 180 days, or instructional modules of a semester or quarter-year duration should be devised. The emphasis of the unit is to provide learning experiences in the technology of solid materials processing.

The plan for developing instructional materials could follow the procedure used by the IACP. Since potential activities have been indentified, educators and substantive experts could identify activities which represent concepts derived from this research study. Methods of instruction could also be provided. This step, "Formulation" is represented in Figure 21, the plan for instructional materials development.

Other important segments to the instructional program are the following:

Textbook - The major purpose of the textbook is to provide clear information about concepts of solid materials and properties. The units in the text should be presented
Plan for Instructional Materials Development
(Buffer, Lux, & Ray, 1971, p. 37)
in a story form version to aid the student in gaining information independent of the teacher.

Laboratory Manual - The major purpose of the laboratory manual is to provide meaningful activities for students in order that they understand practices and concepts. The manual should serve as a guide for solving problems and for learning practices. The laboratory manual would have the following information:

1. required equipment and supplies
2. time schedule for completing activities
3. complete directions

Teacher's Guide - The teacher's guide should provide the following information:

1. the behavioral objectives
2. time schedule - for pacing instruction
3. a list of all necessary teacher demonstration or presentation equipment and supplies
4. a list of student-used equipment and supplies and quantities
5. an overview of today's lesson or review of yesterday's lesson
6. a teacher presentation or demonstration
7. discussion questions and answers
8. laboratory management procedures
9. homework assignments
10. answers to workbook and laboratory manual questions and problems (Buffer, Lux, & Ray, 1971, p. 34).

Further criteria are imposed on the development of a technology of solid materials processing:

1. Materials selected must be of major significance.
2. Materials selected must be safe to process.
3. Materials selected must be interesting to students.
4. Students must be able to perform actual laboratory activities in school.
5. Students must be able to simulate actual industrial practices in school.
6. There must be a utilization of general equipment found in general industrial arts laboratories.
7. Story-telling laboratory activities follow text readings.
8. Students use laboratory manual to follow procedure.
9. Teachers are to use the tactics as described in Figure 22.

The instructional model is proposed for learning activities that will generally occur in one day for instruction of a principle or concept.

The model involves the several basic activities on the part of the students as shown in Figure 23:

1. reception
2. selection
3. problem solving
4. synthesis
5. evaluation
### Instructional Elements

<table>
<thead>
<tr>
<th>Instructional Elements</th>
<th>TEXTBOOK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instructions</td>
<td>Reading (before class)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OVERVIEW</th>
</tr>
</thead>
<tbody>
<tr>
<td>To provide frames of reference for classwork.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TEACHER PRESENTATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>To bring concepts within perceptual range of learner.</td>
</tr>
<tr>
<td>To clarify.</td>
</tr>
<tr>
<td>To relate.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DISCUSSION</th>
</tr>
</thead>
<tbody>
<tr>
<td>To verbally interact and expand meanings of concepts.</td>
</tr>
<tr>
<td>To verify transfer of information.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LABORATORY ACTIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>To apply concepts to a representative particular.</td>
</tr>
<tr>
<td>To verify ownership and application of knowledge.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>EVALUATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>To assess instructional elements.</td>
</tr>
<tr>
<td>To recommend changes and improvements.</td>
</tr>
</tbody>
</table>

### Teacher Functions

- Preparing for class: Review instructional elements, gathering supplies, assessing past procedures.
- Reviewing, previewing concepts, objectives, procedures for the day.
- Presenting information via presentation, visual aids, demonstrations. Relating, clarifying concepts, procedures.
- Loading, directing, controlling, correcting, interacting.
- Managing, organizing, procedures, materials, activities.
- Assessing instruction, activities, materials, procedures, objectives, evaluating, modifying.

### Learner Functions

- Reading text and responding to "Think-About-It" questions.
- Applying concepts, re-organizing relationships of concepts.
- Reading text and responding to "Think-About-It" questions.
- Perceiving general context; recognizing objectives, procedures, and concept relationships.
- Perceiving concept relationships, enlarging range of understanding, recognizing procedures.
- Responding to questions, building ownership of knowledge via verbalization.
- Increasing level of concept ownership via application and performance.
- Assessing personal learning experiences.

### Terminal Performance Objectives

- Cognitive: Reactive
- Affective: Reactive
- Psychomotor: Reactive

### Class of Learning

- Reactive
- Interactive

---

**Figure 22**

Model Instructional System for Industrial Technology
For Any One Day of the Year
(Daily Tactic)
(Buffer, Lux, & Ray, 1971, p. 31)
Figure 23

Instructional Model
(Industrial Arts Curriculum Project Staff, 1969, p. 19)
Implications have been suggested for potential curriculum development with potential methods of instruction. The development of the textbook, laboratory manual, teacher's guide, hardware and instructional aids, and achievement tests would comprise the next activity of the development phase of the curriculum project.

**Chapter Summary**

In this chapter a Rationale and Structure for Industrial Arts Subject Matter was reviewed.

Solid materials processing technology as a subsystem of knowledge was derived. Three implications for curriculum development were proposed and a plan for designing instructional materials for the technology of solid materials processing was presented.
CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

This chapter will provide a summary of the research. It contains the conclusions which are based upon the findings and suggests recommendations for further study.

Summary

Restatement of the Problem

There were two different phases of this study: (1) The development of a classification of content that might constitute a body of knowledge; and (2) the organization of the content or knowledge that may be effectively developed into learning experiences.

The purpose of this study was to develop a rationale and classification for the teaching of solid materials processing technology. A further purpose was to delineate the implications of this body of knowledge for curriculum development.

There were four important questions to be answered.

1. What is the underlying reason for studying solid materials processing technology?

The body of knowledge of solid
materials processing technology is a subsystem of knowledge of industrial technology.

2. What materials could be classified as solids?
A development of a "Classification of Solid Materials" constituted an answer to this question.

3. What are the properties that solid materials may possess?
A development of a "Classification of Properties of Solid Materials" constituted an answer to this question.

4. Can universal processes be applied to the solid materials?
The classification of processes applicable to all materials developed by the IACP can be utilized in the processing of solid materials classified in this study.

Review of the Literature

The review of the literature consisted of three main sections to aid the reader in reviewing the reported relevant literature for the study of solid materials processing technology in industrial arts education. The
first section reported information of traditional industrial arts programs and selected contributions of individuals who guided and set the stage for the contemporary innovative programs in industrial arts. The second section reported major contributions and influences related to the newer developments in conceptualizing and organizing studies of materials processing technology. The establishment of institutes devoted to the development of instructional units in "materials" demonstrated the interest in materials processing technology as a part of industrial arts curriculum content. A review of expert opinion suggested curriculum specialists were influenced by concepts of structuring. The third section reported two instructional programs which considered materials as a subsystem of industrial knowledge. There appeared to be inadequacies in their conceptualization. However, they provided an example of the need for and application of this study. The two programs lacked specific recognition of the placement of materials processing technology as a subsystem of knowledge of industrial technology.

Procedure

The analysis of material for this study was derived by the following eight procedures outlined by Sax (1968).
A. Specification of objectives

There were two different purposes to this study:

1. The classification of a body of knowledge of solid materials processing and (2) the implementation of the body of knowledge that may be effectively developed into learning experiences.

B. Development of Hypotheses

1. The knowledge of solid materials processing technology can be identified and a classification of it can be developed to provide a basis for developing instructional programs.

2. The structured body of knowledge of materials processing has implications for industrial arts curriculum workers at many levels as well as for curriculum workers in other technical curricula, such as engineering.

C. Sampling of information

The conceptualization was produced by searching literature, conferring with materials specialists, and meeting with teaching personnel. The libraries at the American Society for Metals, The Ohio State University, and the Cleveland Public Library were investigated for references. Records, reports, proceedings, journals, and syllabi were reviewed for possible leads in development of a "Proposed Classification of Solid Materials" and a "Proposed Classification of Properties of Solid Materials." There were several difficulties in collecting data for samples:
1. The printed word may not necessarily be trustworthy.

2. Documents used for the structure must be evaluated.

3. Genuine information is important.

4. Contents must be valid.

5. Proof lies with the person doing the research.

Steps were taken to avoid the difficulties mentioned:

1. Printed matter was reviewed before being used as a reference to derive a classification of solid materials and properties.

2. Documents selected to derive a classification of solid materials and properties were evaluated by staff liaison of the American Society for Metals.

3. It was important that information helpful for the derivation of the classification systems be evaluated as genuine.

4. The contents of a classification of solid materials and properties had to be valid.

5. The "Proposed Classification of Solid Materials" and the "Proposed Classifications of Properties of Solid Materials" was reviewed and evaluated by expert reviewers.

D. Determining categories

After considering various classification systems, a classification limited to solid materials was adopted.
E. Category analysis

The conceptualization of a body of knowledge of solid materials processing was developed using the principles of logic.

1. Categories should be well defined.
2. Categories should be mutually exclusive.
3. Categories should be univocal.
4. Categories must be exhaustive.

F. Quantification

The frequency with which an item appeared was not relevant in attempting a classification of solid materials and properties.

G. Standardizing the coding procedure

The members of the Career Development Committee and the Young Members Committee of the American Society for Metals who served as the expert reviewers in evaluating the classifications were notified by written communication of the purpose of the study prior to receiving the "Proposed Classification of Solid Materials" and the "Proposed Classification of the Properties of Solid Materials." The proposed classifications were also evaluated by ASM staff.

H. Reliability

To establish the reliability of the "Proposed Classification of Solid Materials" and the "Proposed classification of Properties of Solid Materials" two
committees of expert reviewers reacted to and revised them.

When all suggestions, which met the established criteria, were made by the two committees, the changes were added, revised, or deleted in the "Proposed Classifications." The revised classifications were then reviewed by staff of the American Society for Metals.

Results

A viable body of knowledge of solid materials processing technology was developed by use of the procedures which were employed in this study. The preponderance of expert opinion accepted the developed classifications.

It was established that solid materials processing technology is a subsystem of knowledge as derived by the Industrial Arts Curriculum Project. The classification of processes—forming, separating, and combining—can be applied to the solid materials derived in the study.

A matrix with three axes (solid materials, processes, and properties) was employed to illustrate the infinite possibilities for deriving subject matter for various courses of study from the delineated body of knowledge. Three proposals were made for curriculum implementation.

1. The development of "a story of processing solid materials into standard stock."
2. The development of "a story of processing solid materials used in construction and manufacturing."

3. The development of "procedures for efficient practices in processing solid materials."

Steps were outlined for the development of curriculum material that could be used in the classroom.

The development of a "Classification of Solid Materials" and a "Classification of Properties of Solid Materials" should not be considered as the final answer. The process should be ongoing to include new solid materials that are constantly being developed.

Conclusions

On the basis of conceptualizing a body of knowledge of solid materials processing with implications for curriculum development, the following conclusions are presented.

1. A "Classification of Solid Materials" provides a basis for the identification of a body of knowledge of solid materials processing technology.

2. A "Classification of Properties of Solid Materials," with mechanical and non-mechanical sub-elements, provides a basis for the identification of a body of knowledge of solid materials processing technology.
3. The classification of processes (forming, separating, and combining) and their sub-elements as developed by the IACP, are applicable to all materials and provides a basis for the identification of a body of knowledge of solid materials processing technology.

4. The structured body of knowledge of materials processing has implications for industrial arts curriculum workers at many levels as well as for curriculum workers in other technical curricula such as engineering.

**Recommendations**

The recommendations presented in this section are based upon the development of the classifications of solid materials and properties and ways which may aid the investigator in fulfilling subsequent steps related to this research.

Based upon the development of the classifications, it is recommended that the following actions be initiated:

1. Determine levels at which curriculum would be developed.
2. Obtain sources of funding to complete remaining research and development.
3. Select writing committee to complete readings in textbook.
4. Develop a textbook.
5. Develop a teacher's guide.
7. Develop a laboratory manual.
8. Develop hardware and instructional aids.
9. Develop periodic achievement tests.
10. Field test and revise system components.

The following recommendations are directed to other researchers conceptualizing bodies of knowledge for curriculum purposes.

1. Develop methods by which data for proposed classifications can be placed on computer data cards for greater facilitation of handling.

2. Classifications of materials based on economic or industrial importance should be conducted for curriculum purposes.

3. The development of a list of appropriate properties should be done under broad classes of materials to aid curriculum specialists in developing curriculum content.
4. Use the Delphi Technique to establish categories for materials based on economic, industrial, or frequency of use criteria.

5. Committees affiliated with other professional societies should be selected as expert reviewers to evaluate the classification of solid materials and properties.

6. Continuing efforts must be made to keep classifications of materials and their properties current as new materials are being developed.

7. Since results of this type of research are important to curriculum development in industrial arts, it is advisable that liaison be established between educators and representatives of the manufacturing and construction industries.

It is obvious that some of the research recommended at this time could not be conducted because of preliminary developmental work remaining to be completed, such as, designing the instructional materials for solid materials processing technology. This does not preclude curriculum development in solid materials processing technology by
industrial teachers and/or institutions.

To conclude, this study attempted to develop a body of knowledge of solid materials processing technology with implications for curriculum development. The three suggested implications may contribute to the curriculum content for industrial technology.
June 1, 1971

It is generally agreed by educators that the first step in curriculum development is that of conceptualizing subject matter. The purpose of my dissertation study is to develop a structure for the technology of solid materials processing as a basis for curriculum development in this subject matter. Two basic questions must be answered: (1) what are the materials that may be classified as solids, and (2) what are the properties that solid materials may possess?

A classification of solid materials and properties has been tentatively developed. Please react to and evaluate the classification of Solid Materials and the Properties of Solid Materials outlines that are enclosed. Individuals of the Young Members Committee and the Career Development Committee of the American Society for Metals are being asked to respond.

Since a curriculum for the study of solid materials processing will be developed to follow courses called Construction and Manufacturing, recent developments of the Industrial Arts Curriculum Project of The Ohio State University, a reprint describing those basic programs is included for your inspection.

Your cooperation in assisting with this study, which will aid in curriculum development in the technology of solid materials processing, is greatly appreciated.

Please return the Classification of Solid Materials, Properties of Solid Materials, both Reaction Forms and the Personal Data Form in the stamped, addressed envelope by June 14, 1971. Please place your initials on the following blank if you wish to receive an abstract of this study.

Sincerely yours,

Lorin V. Waitkus

Enc.
CLASSIFICATION OUTLINE I

Proposed Classification of Solid Materials

1.0 Metals

1.1 Ferrous

1.1.1 Steel
   1.1.1.1 Low carbon
   1.1.1.2 Medium carbon
   1.1.1.3 High carbon

1.1.2 Stainless steel
   1.1.2.1 Ferritic
   1.1.2.2 Austenitic
   1.1.2.3 Martensitic

1.1.3 Cast iron
   1.1.3.1 Gray
   1.1.3.2 White
   1.1.3.3 Ductile or nodular
   1.1.3.4 Malleable

1.1.4 Alloy Steel
   1.1.4.01 Manganese steels
   1.1.4.02 Nickel-chromium steels
   1.1.4.03 Molybdenum steels
   1.1.4.04 Chromium-molybdenum steels
   1.1.4.05 Nickel-chromium-molybdenum steels
   1.1.4.06 Nickel-molybdenum steels
   1.1.4.07 Chromium steels
   1.1.4.08 Chromium-vanadium steels
   1.1.4.09 Nickel-chromium-molybdenum-Triple-alloy steels
   1.1.4.10 Silicon-manganese steels
   1.1.4.11 Boron steels

1.2 Non-ferrous

1.2.1 Light metals and alloys
   1.2.1.01 Lithium
   1.2.1.02 Beryllium
   1.2.1.03 Sodium
   1.2.1.04 Magnesium
   1.2.1.05 Potassium
   1.2.1.06 Calcium
   1.2.1.07 Rubidium
   1.2.1.08 Strontium
   1.2.1.09 Barium
   1.2.1.10 Aluminum
1.2.2 Heavy metals and alloys
1.2.2.01 Scandium
1.2.2.02 Titanium
1.2.2.03 Vanadium
1.2.2.04 Chromium
1.2.2.05 Manganese
1.2.2.06 Cobalt
1.2.2.07 Nickel
1.2.2.08 Copper
1.2.2.09 Yttrium
1.2.2.10 Zirconium
1.2.2.11 Technetium
1.2.2.12 Hafnium
1.2.2.13 Rhenium
1.2.2.14 Radium

1.2.3 White metals and alloys
1.2.3.01 Zinc
1.2.3.02 Germanium
1.2.3.03 Cadmium
1.2.3.04 Indium
1.2.3.05 Tin
1.2.3.06 Antimony
1.2.3.07 Thallium
1.2.3.08 Lead
1.2.3.09 Bismuth
1.2.3.10 Polonium

1.2.4 Precious metals and alloys
1.2.4.1 Ruthenium
1.2.4.2 Rhodium
1.2.4.3 Palladium
1.2.4.4 Silver
1.2.4.5 Osmium
1.2.4.6 Iridium
1.2.4.7 Platinum
1.2.4.8 Gold

1.2.5 Refractory metals and alloys
1.2.5.1 Niobium
1.2.5.2 Molybdenum
1.2.5.3 Tantalum
1.2.5.4 Tungsten

1.2.6 Rare earth
1.2.6.1 Lanthanide series
1.2.6.2 Actinide series
1.2.7 Metalloids
1.2.7.1 Boron
1.2.7.2 Silicon
1.2.7.3 Arsenic
1.2.7.4 Tellurium
1.2.7.5 Astatine

2.0 Non-metals

2.1 Pure elements

2.1.1 Iodine
2.1.2 Carbon
2.1.3 Phosphorus
2.1.4 Sulfur
2.1.5 Selenium

2.2 Ceramics

2.2.1 Dielectrics
2.2.1.1 Glass
2.2.1.1.1 Silica
2.2.1.1.2 Crystalline silica
2.2.1.1.3 Soda silica

2.2.1.2 Clay
2.2.1.2.01 Kaoline
2.2.1.2.02 Ball
2.2.1.2.03 Fire
2.2.1.2.04 Flint
2.2.1.2.05 Pottery
2.2.1.2.06 Shale
2.2.1.2.07 Vitrifying
2.2.1.2.08 Brick
2.2.1.2.09 Slip
2.2.1.2.10 Talc
2.2.1.2.11 Pyrophyllite
2.2.1.2.12 Block talc
2.2.1.2.13 Feldspar
2.2.1.2.14 wollastonite
2.2.1.2.15 Sillimanite

2.2.1.3 Refractory raw materials
2.2.1.3.1 Alumina
2.2.1.3.2 Magnesia
2.2.1.3.3 Dolomite
2.2.1.3.4 Chrome
2.2.1.3.5 Asbestos
2.2.2 Ferroelectrics

2.2.2.1 Transducers
   2.2.2.1.1 Barium titanate
   2.2.2.1.2 Lead titanate

2.2.2.2 Ceramic semi-conductors

2.2.3 Magnetics

2.2.3.1 Ferrites
2.2.3.2 Spinels

2.3 Plastics

2.3.1 Thermoplastics

2.3.1.1 Cellulose derivatives
   2.3.1.1.1 Regenerated cellulose
   2.3.1.1.2 Cellulose esters
   2.3.1.1.3 Cellulose ethers

2.3.1.2 Ethenic polymers
   2.3.1.2.01 Polyethylene
   2.3.1.2.02 Polypropylene
   2.3.1.2.03 Polysobutylene
   2.3.1.2.04 Fluorocarbon polymers
   2.3.1.2.05 Polyvinyl acetate and its derivatives
      2.3.1.2.5.1 Polyvinyl alcohol
      2.3.1.2.5.2 Acetals
   2.3.1.2.06 Vinyl chloride polymers and copolymers
   2.3.1.2.07 Polyvinylidene chloride
   2.3.1.2.08 Polystyrene
   2.3.1.2.09 Acrylic polymers
   2.3.1.2.10 Coumarone-indene polymers
   2.3.1.2.11 Polyvinyl ethers
   2.3.1.2.12 Polyvinyl ketones
   2.3.1.2.13 Polyvinyl amines
   2.3.1.2.14 Divinyl polymers

2.3.2 Thermosets

2.3.2.1 Phenolic resins
   2.3.2.1.1 Phenol-formaldehyde
   2.3.2.1.2 Phenol-furfural
   2.3.2.1.3 Resorcinol-formaldehyde

2.3.2.2 Amino resins
   2.3.2.2.1 Urea-formaldehyde
   2.3.2.2.2 Melamine-formaldehyde
2.3.2.3 Polyesters
2.3.2.4 Polyurethanes
2.3.2.5 Polyamides
2.3.2.6 Epoxides
2.3.2.7 Polyethers

2.3.3 Rubbers

2.3.3.1 Polyisoprene
2.3.3.2 Polybutadiene
2.3.3.3 Polychloroprene
2.3.3.4 Butadiene copolymers
   2.3.3.4.1 SBR
   2.3.3.4.2 Nitrile rubbers
2.3.3.5 Isobutylene-isoprene copolymers
2.3.3.6 Polysulfide rubbers
2.3.3.7 Chlorosulfonated polyethylene
2.3.3.8 Polyurethane rubbers
2.3.3.9 Silicone rubbers
2.3.3.10 Fluorine rubbers

2.4 Natural Organics

2.4.1 Plants
   2.4.1.1 Food
      2.4.1.1.1 Grains and cereals
      2.4.1.1.2 Legumes
      2.4.1.1.3 Vegetables
      2.4.1.1.4 Fruits
      2.4.1.1.5 Nuts
      2.4.1.1.6 Seeds
   2.4.1.2 Fiber
      2.4.1.2.1 Cellulose
      2.4.1.2.2 Ligno-cellulose
   2.4.1.3 Derivatives
      2.4.1.3.1 Resins
      2.4.1.3.2 Rosin
      2.4.1.3.3 Lignin

2.4.2 Animals
   2.4.2.1 Food
      2.4.2.1.1 Meat
      2.4.2.1.2 Poultry
      2.4.2.1.3 Fish
      2.4.2.1.3.1 Fin back
      2.4.2.1.3.2 Shell back
      2.4.2.1.4 Dairy
      2.4.2.1.5 Eggs
2.4.2.2 Fiber
   2.4.2.2.1 Hide
   2.4.2.2.2 Fur
   2.4.2.2.3 Protein
2.4.2.3 Derivatives

3.0 Composites
3.1 Coated
3.2 Dispersed
3.3 Laminated
3.4 Agglomerated
3.5 Bonded
3.6 Fiber-reinforced
3.7 Powder compacted
3.8 Diffused
CLASSIFICATION OUTLINE II
Proposed Classification of Properties of Solid Materials

1.0 Non-mechanical

1.1 Physical
   1.1.01 Water absorption
   1.1.02 Dimensions
   1.1.03 Density
   1.1.04 Porosity
   1.1.05 Crystalline type
   1.1.06 Atomic spacing
   1.1.07 Specific gravity
   1.1.08 Viscosity
   1.1.09 Weight
   1.1.10 Radioactivity resistance
   1.1.11 Damping
   1.1.12 Durable
   1.1.13 Texture
   1.1.14 Shape
   1.1.15 Moisture content

1.2 Thermal
   1.2.1 Thermal conductivity
   1.2.2 Specific heat
   1.2.3 Thermal expansion (warpage)
   1.2.4 Melting point
   1.2.5 Contraction
   1.2.6 Deflection temperature
   1.2.7 Fire resistance
   1.2.8 Heat resistance
   1.2.9 Sintering temperature

1.3 Electric and Magnetic
   1.3.1 Conductivity
   1.3.2 Magnetic permeability
   1.3.3 Dielectric strength
   1.3.4 Dielectric constant
   1.3.5 Dissipation factor
   1.3.6 Arc resistance
   1.3.7 Galvanic action

1.4 Acoustical
   1.4.1 Sound transmissivity
   1.4.2 Sound reflectance

1.5 Optical
   1.5.1 Color
   1.5.2 Light transmissivity
   1.5.3 Light reflectance
   1.5.4 Light refraction
   1.5.5 Light absorption
1.6 Chemical
  1.6.1 Corrosion resistance
    1.6.1.1 Acidity
    1.6.1.2 Alkalinity
  1.6.2 Reactive ability
  1.6.3 Adhesion
  1.6.4 Cohesion
  1.6.5 Oxidation
  1.6.6 Reduction

2.0 Mechanical

2.1 Strength
  2.1.1 Compression
  2.1.2 Tensile
  2.1.3 Shear
  2.1.4 Flexure
  2.1.5 Impact
    2.1.5.1 Toughness
    2.1.5.2 Brittleness

2.2 Ductility
  2.2.1 Elasticity
  2.2.2 Plasticity

2.3 Hardness
  2.3.1 Penetration
  2.3.2 Indentation
  2.3.3 Scratch

2.4 Malleability
  2.4.1 Elasticity
  2.4.2 Plasticity

2.5 Fatigue
  2.5.1 Notch sensitivity
  2.5.2 Cross-section
  2.5.3 Fracture toughness

2.6 Shrinkage

2.7 Creep
# Proposed Classification of Solid Materials

## Levels 1, 2 and 3

Do you agree or disagree with the following categories or classifications?

<table>
<thead>
<tr>
<th>Level</th>
<th>Category</th>
<th>Disagree</th>
<th>Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>Metals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1</td>
<td>Ferrous</td>
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<td></td>
</tr>
<tr>
<td>1.2</td>
<td>Non-ferrous</td>
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<td></td>
</tr>
<tr>
<td>2.0</td>
<td>Non-metals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.1</td>
<td>Pure elements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.2</td>
<td>Ceramics</td>
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</tr>
<tr>
<td>2.2.1</td>
<td>Dielectrics</td>
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<tr>
<td>2.2.2</td>
<td>Ferroelectrics</td>
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<td></td>
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<tr>
<td>2.2.3</td>
<td>Magnetics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.3</td>
<td>Plastics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.3.1</td>
<td>Thermoplastics</td>
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<tr>
<td>2.3.2</td>
<td>Thermosets</td>
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<tr>
<td>2.3.3</td>
<td>Rubbers</td>
<td></td>
<td></td>
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<tr>
<td>2.4</td>
<td>Natural Organics</td>
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<td>2.4.1</td>
<td>Plants</td>
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<tr>
<td>2.4.2</td>
<td>Animals</td>
<td></td>
<td></td>
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<tr>
<td>3.0</td>
<td>Composites</td>
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<tr>
<td>3.1</td>
<td>Coated</td>
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<tr>
<td>3.2</td>
<td>Dispersed</td>
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<td>3.3</td>
<td>Laminated</td>
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<td>3.4</td>
<td>Agglomerated</td>
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<tr>
<td>3.5</td>
<td>Bonded</td>
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<td></td>
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<tr>
<td>3.6</td>
<td>Fiber-reinforced</td>
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<td></td>
</tr>
<tr>
<td>3.7</td>
<td>Powder compacted</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.8</td>
<td>Diffused</td>
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<td></td>
</tr>
</tbody>
</table>

Name
Levels 1, 2 and 3 (continued)

If you disagreed, what alternate titles or categories would you suggest? Use more than three categories if you wish, placing others on the reverse side.

1.0
  1.1
  1.2
  others

2.0
  2.1
  2.2
    2.2.1
    2.2.2
    2.2.3
    others
  2.3
    2.3.1
    2.3.2
    2.3.3
    others
  2.4
    2.4.1
    2.4.2
    others

3.0
  3.1
  3.2
  3.3
  3.4
  3.5
  3.6
  3.7
  3.8
  others
What alternate terms or components would you suggest for levels 4, 5 and 6?

<table>
<thead>
<tr>
<th>Number</th>
<th>Given Term</th>
<th>Alternate Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>(example)</td>
<td>Glass</td>
<td>Crystal</td>
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<tr>
<td>2.2.1.1</td>
<td>Alumina</td>
<td>Corundum</td>
</tr>
<tr>
<td>(example)</td>
<td>Acetal</td>
<td>Vinyl</td>
</tr>
</tbody>
</table>
Do you agree or disagree with the following categories or classifications?

<table>
<thead>
<tr>
<th>Category</th>
<th>Disagree</th>
<th>Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 Non-mechanical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1 Physical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.2 Thermal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.3 Electric and Magnetic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.4 Acoustical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5 Optical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.6 Chemical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.0 Mechanical</td>
<td></td>
<td></td>
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<tr>
<td>2.1 Strength</td>
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<td></td>
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<tr>
<td>2.2 Ductility</td>
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<td></td>
</tr>
<tr>
<td>2.3 Hardness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.4 Malleability</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.5 Fatigue</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.6 Shrinkage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.7 Creep</td>
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<td></td>
</tr>
</tbody>
</table>

Name
Levels 1 and 2 (continued)

If you disagreed, what alternate titles or categories would you suggest? Use more than two categories if you wish, placing others on the reverse side.

1.0

1.1
1.2
1.3
1.4
1.5
1.6
others

2.0

2.1
2.2
2.3
2.4
2.5
2.6
2.7
others
What alternate terms or components would you suggest for levels 3 and 4?

<table>
<thead>
<tr>
<th>Number</th>
<th>Given Term</th>
<th>Alternate Term</th>
</tr>
</thead>
<tbody>
<tr>
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</table>
APPENDIX  F

160
<table>
<thead>
<tr>
<th>Name</th>
<th>Title</th>
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<tbody>
<tr>
<td>Firm</td>
<td>Chief Product</td>
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<tr>
<td>Address</td>
<td></td>
</tr>
<tr>
<td>City</td>
<td>State</td>
</tr>
</tbody>
</table>

Optional:
**Major industrial contributions or innovations:**

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

**Major publications:**

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________


On June 1, 1971 a request was made for your cooperation to react to and evaluate a classification of solid materials and properties as part of my dissertation study. The purpose of this study being to develop a structure for the technology of solid materials processing as a basis for curriculum development.

Since the reaction forms have not been received from you, I am enclosing a second set of materials in case you would want to respond.

Your cooperation in assisting with this study, which will aid in curriculum development in the technology of solid materials processing, is greatly appreciated.

Please return the Classification of Solid Materials, the Properties of Solid Materials, both Reaction Forms and the Personal Data Form in the stamped, addressed envelope by July 9, 1971. Please place your initials on the following blank if you wish to receive an abstract of this study.

Sincerely yours,

Enc.

Lorin V. Waitkus
APPENDIX H
CAREER DEVELOPMENT COMMITTEE

Purpose: The Career Development Committee is to work to increase the number and competence of persons studying and teaching the science, engineering, and technology of metals and related materials.

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Research Center  
26201 Northwestern Highway  
Southfield, Michigan 48075
APPENDIX I
Purpose: The following are the purposes of the committee:

First, to expose young members to different aspects of metallurgy, thereby, to enhance their professional development;

Second, to create a sense of identification with opportunity for participation of young members in society activities;

Third, to provide avenues of communication and forum for discussion of different viewpoints of common problems;

Fourth, to help to create an American Society for Metals that is alert to the needs of our society.

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Teaching Assistant
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Materials Sciences Lab.
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Vic Thevenow
Allison Division
General Motors Corporation
Indianapolis, Indiana 46206

Seth R. Thomas
Manager, Metallurgy &
   Quality Control
Rodney Metals
1357 East Rodney French Blvd.
New Bedford, Massachusetts
PRELIMINARY CLASSIFICATION OF SOLID MATERIALS

1.0 Metals

1.1 Ferrous

1.1.1 Steel
   1.1.1.1 Low carbon
   1.1.1.2 Medium carbon
   1.1.1.3 High carbon

1.1.2 Stainless steel
   1.1.2.1 Ferritic
   1.1.2.2 Austenitic
   1.1.2.3 Martensitic

1.1.3 Cast iron
   1.1.3.1 Gray
   1.1.3.2 White
   1.1.3.3 Ductile or nodular
   1.1.3.4 Malleable

1.2 Non-ferrous

1.2.1 Light metals and alloys
   1.2.1.1 Lithium
   1.2.1.2 Beryllium
   1.2.1.3 Sodium
   1.2.1.4 Magnesium
   1.2.1.5 Potassium
   1.2.1.6 Calcium
   1.2.1.7 Rubidium
   1.2.1.8 Strontium
   1.2.1.9 Barium
   1.2.1.10 Radium

1.2.2 Heavy metals and alloys
   1.2.2.1 Scandium
   1.2.2.2 Titanium
   1.2.2.3 Vanadium
   1.2.2.4 Chromium
   1.2.2.5 Manganese
   1.2.2.6 Cobalt
   1.2.2.7 Nickel
   1.2.2.8 Copper
1.2.2.9 Yttrium
1.2.2.10 Zirconium
1.2.2.11 Technetium
1.2.2.12 Hafnium
1.2.2.13 Rhenium

1.2.3 White metals and alloys
1.2.3.1 Aluminum
1.2.3.2 Zinc
1.2.3.3 Germanium
1.2.3.4 Cadmium
1.2.3.5 Indium
1.2.3.6 Tin
1.2.3.7 Antimony
1.2.3.8 Thallium
1.2.3.9 Lead
1.2.3.10 Bismuth
1.2.3.11 Polonium

1.2.4 Precious metals and alloys
1.2.4.1 Ruthenium
1.2.4.2 Rhodium
1.2.4.3 Palladium
1.2.4.4 Silver
1.2.4.5 Osmium
1.2.4.6 Iridium
1.2.4.7 Platinum
1.2.4.8 Gold

1.2.5 Refractory metals and alloys
1.2.5.1 Niobium
1.2.5.2 Tantalum
1.2.5.3 Molybdenum
1.2.5.4 Tungsten

1.2.6 Rare earth
1.2.6.1 Lanthanide series
1.2.6.2 Actinide series

1.2.7 Metalloids
1.2.7.1 Boron
1.2.7.2 Silicon
1.2.7.3 Arsenic
1.2.7.4 Tellurium
1.2.7.5 Astatine
2.0 Non-metals

2.1 Pure elements
2.1.1 Iodine
2.1.2 Carbon
2.1.3 Phosphorus
2.1.4 Sulfur
2.1.5 Selenium

2.2 Ceramics
2.2.1 Dielectrics
2.2.1.1 Glass
2.2.1.1.1 Silica
2.2.1.1.2 Crystalline silica
2.2.1.1.3 Soda silica

2.2.1.2 Clay
2.2.1.2.1 Kaolin
2.2.1.2.2 Ball
2.2.1.2.3 Fire
2.2.1.2.4 Flint
2.2.1.2.5 Pottery
2.2.1.2.6 Shale
2.2.1.2.7 Vitrifying
2.2.1.2.8 Brick
2.2.1.2.9 Slip
2.2.1.2.10 Talc
2.2.1.2.11 Pyrophyllite
2.2.1.2.12 Block talc
2.2.1.2.13 Feldspar
2.2.1.2.14 Wollastonite
2.2.1.2.15 Sillimanite
(adapted from Kingery, 1967, pp. 23-27)

2.2.1.3 Refractory raw materials
2.2.1.3.1 Alumina
2.2.1.3.2 Magnesia
2.2.1.3.3 Dolomite
2.2.1.3.4 Chrome
2.2.1.3.5 Asbestos

2.2.2 Ferroelectrics
2.2.2.1 Transducers
2.2.2.1.1 Barium titanate
2.2.2.1.2 Lead titanate

2.2.2.2 Ceramic semi-conductors

2.2.3 Magnetics
2.2.3.1 Ferrites
2.2.3.2 Spinels
2.3 Plastics

2.3.1 Thermoplastics

2.3.1.1 Cellulose derivatives
  2.3.1.1.1 Regenerated cellulose
  2.3.1.1.2 Cellulose esters
  2.3.1.1.3 Cellulose ethers

2.3.1.2 Ethenic polymers
  2.3.1.2.1 Polyethylene
  2.3.1.2.2 Polypropylene
  2.3.1.2.3 Polyisobutylene
  2.3.1.2.4 Fluorocarbon polymers
  2.3.1.2.5 Polyvinyl acetate and its derivatives
    2.3.1.2.5.1 Polyvinyl alcohol
    2.3.1.2.5.2 Acetals
  2.3.1.2.6 Vinyl chloride polymers and copolymers
  2.3.1.2.7 Polyvinylidene chloride
  2.3.1.2.8 Polystyrene
  2.3.1.2.9 Acrylic polymers
  2.3.1.2.10 Coumarone-indene polymers
  2.3.1.2.11 Polyvinyl ethers
  2.3.1.2.12 Polyvinyl ketones
  2.3.1.2.13 Polyvinyl amines
  2.3.1.2.14 Divinyl polymers

2.3.2 Thermosets

2.3.2.1 Phenolic resins
  2.3.2.1.1 Phenol-formaldehyde
  2.3.2.1.2 Phenol-furfural
  2.3.2.1.3 Resorcinol-formaldehyde

2.3.2.2 Amino resins
  2.3.2.2.1 Urea-formaldehyde
  2.3.2.2.2 Melamine-formaldehyde

2.3.2.3 Polymesters
  2.3.2.4 Polyurethanes
  2.3.2.5 Polyamides
  2.3.2.6 Epoxides
  2.3.2.7 Polyethers

2.3.3 Rubbers

2.3.3.1 Polysoprene
  2.3.3.2 Polybutadiene
  2.3.3.3 Polychloroprene

2.3.3.4 Butadiene copolymers
  2.3.3.4.1 SBR
  2.3.3.4.2 Nitrile rubbers
2.3.3.5 Isobutylene-isoprene copolymers
2.3.3.6 Polysulfide rubbers
2.3.3.7 Chlorosulfonated polyethylene
2.3.3.8 Polyurethane rubbers
2.3.3.9 Silicone rubbers
2.3.3.10 Fluorine rubbers
(adapted from Winding & Hiatt, 1961, pp. 17-18)

2.4 Natural Organics

2.4.1 Plants
2.4.1.1 Food
2.4.1.1.1 Grains and cereals
2.4.1.1.2 Legumes
2.4.1.1.3 Vegetables
2.4.1.1.4 Fruits
2.4.1.1.5 Nuts
2.4.1.1.6 Seeds
2.4.1.2 Fiber
2.4.1.2.1 Cellulose
2.4.1.2.2 Ligno-cellulose
2.4.1.3 Derivatives
2.4.1.3.1 Resins
2.4.1.3.2 Rosin
2.4.1.3.3 Lignin

2.4.2 Animals
2.4.2.1 Food
2.4.2.1.1 Meat
2.4.2.1.2 Poultry
2.4.2.1.3 Fish
2.4.2.1.3.1 Fin back
2.4.2.1.3.2 Shell back
2.4.2.1.4 Dairy
2.4.2.1.5 Eggs
2.4.2.2 Fiber
2.4.2.2.1 Hide
2.4.2.2.2 Fur
2.4.2.2.3 Protein
2.4.2.3 Derivatives

3.0 Composites

3.1 Coated

3.2 Dispersed
3.3 Laminated
3.4 Agglomerated
3.5 Bonded
3.6 Fiber-reinforced
3.7 Powder compacted
3.8 Diffused
APPENDIX K
1.0 Non-mechanical

1.1 Physical
1.1.1 Absorption
1.1.2 Dimensions
1.1.3 Density
1.1.4 Porosity
1.1.5 Crystalline type
1.1.6 Atomic spacing
1.1.7 Specific gravity
1.1.8 Viscosity
1.1.9 Weight
1.1.10 Radioactivity resistance
1.1.11 Damping
1.1.12 Durable
1.1.13 Texture
1.1.14 Shape
1.1.15 Moisture content

1.2 Thermal
1.2.1 Thermal conductivity
1.2.2 Specific heat
1.2.3 Thermal expansion (warpage)
1.2.4 Melting point
1.2.5 Contraction
1.2.6 Deflection temperature
1.2.7 Fire resistance
1.2.8 Heat resistance
1.2.9 Sintering temperature

1.3 Electric and Magnetic
1.3.1 Conductivity
1.3.2 Magnetic permeability
1.3.3 Dielectric strength
1.3.4 Dielectric constant
1.3.5 Dissipation factor
1.3.6 Arc resistance
1.3.7 Galvanic action

1.4 Acoustical
1.4.1 Sound transmissivity
1.4.2 Sound reflectance
1.5 Optical
  1.5.1 Color
  1.5.2 Light transmissivity
  1.5.3 Light reflectance
  1.5.4 Light refraction
  1.5.5 Light absorption

1.6 Chemical
  1.6.1 Corrosion resistance
    1.6.1.1 Acidity
    1.6.1.2 Alkalinity
  1.6.2 Reactive ability
  1.6.3 Adhesion
  1.6.4 Cohesion
  1.6.5 Oxidation
  1.6.6 Reduction

2.0 Mechanical

2.1 Strength
  2.1.1 Compression
  2.1.2 Tensile
  2.1.3 Shear
  2.1.4 Flexure
  2.1.5 Impact
    2.1.5.1 Toughness
    2.1.5.2 Brittleness

2.2 Ductility
  2.2.1 Elasticity
  2.2.2 Plasticity

2.3 Hardness
  2.3.1 Penetration
  2.3.2 Indentation
  2.3.3 Scratch

2.4 Malleability
  2.4.1 Elasticity
  2.4.2 Plasticity

2.5 Fatigue
  2.5.1 Notch sensitivity
  2.5.2 Cross-section
  2.5.3 Fracture toughness

2.6 Shrinkage

2.7 Creep
II. INDUSTRIAL PRODUCTION TECHNOLOGY

1. Pre-processing

1.1 Receiving

1.2 Unpackaging

1.3 Handling*
   1.3.1 Pumping and Compressing
   1.3.2 Elevating
   1.3.3 Carrying
   1.3.4 Filling
   1.3.5 Evacuating
   1.3.6 Attaching
   1.3.7 Operating
   1.3.8 Skidding

1.4 Storing*

1.5 Protecting

2. Processing

2.1 Separating
   2.1.1 Classifying
      2.1.1.1 Screening
         2.1.1.1.1 Grizzly Screening
         2.1.1.1.2 Rotary Screening
         2.1.1.1.3 Shaking Screening
         2.1.1.1.4 Vibrating Screening
         2.1.1.1.5 Oscillating Screening
      2.1.1.2 Floating
         2.1.1.2.1 Subaerating Floating
         2.1.1.2.2 Pneumatic Floating
         2.1.1.2.3 Vacuum Floating
         2.1.1.2.4 Pressure Floating
      2.1.1.3 Sedimenting
         2.1.1.3.1 Batch Thickening
         2.1.1.3.2 Continuous Thickening
         2.1.1.3.3 Single Compartment Thickening
         2.1.1.3.4 Tray Thickening

* Handling and Storing practices, while listed here under Pre-Processing, are utilized throughout the production cycle. Thus, Carrying, Filling, and Elevating for example, will also occur between and within operations in the Processing category.
2.1.1.4 Filtering - Clarifying
  2.1.1.4.1 Cake Filtering
    2.1.1.4.1.1 Hydrostatic Head Filtering
    2.1.1.4.1.2 Pressure Filtering
    2.1.1.4.1.3 Vacuum Filtering
  2.1.1.4.2 Clarifying
    2.1.1.4.2.1 Disk and Plate Press Filtering
    2.1.1.4.2.2 Pre-coat Pressure Filtering
    2.1.1.4.2.3 Cartridge Clarifying

2.1.1.5 Magnetizing
  2.1.1.5.1 Tramp-Iron Magnetic Separating
    2.1.1.5.1.1 Magnetic Head Pulleys
    2.1.1.5.1.2 Suspended Magnets
    2.1.1.5.1.3 Magnetic Drums
    2.1.1.5.1.4 Plate Magnets
    2.1.1.5.1.5 Grate Magnets
  2.1.1.5.2 Concentration and Purification
    2.1.1.5.2.1 Wet Magnetic Separating
    2.1.1.5.2.2 Dry Magnetic Separating

2.1.1.6 Distilling
  2.1.1.6.1 Destructive Distilling
  2.1.1.6.2 Batch Distilling
  2.1.1.6.3 Extractive Distilling
  2.1.1.6.4 Rectifying
  2.1.1.6.5 Dephlegmatizing
  2.1.1.6.6 Flash Distilling
  2.1.1.6.7 Simple Distilling
  2.1.1.6.8 Refluxing
  2.1.1.6.9 Fractional Distilling
  2.1.1.6.10 Azeotropic Distilling
  2.1.1.6.11 Vacuum Distilling
  2.1.1.6.12 Molecular Distilling

2.1.1.7 Evaporating
  2.1.1.7.1 Forced Circulation Evaporating
  2.1.1.7.2 Short-Tube Vertical Evaporating
  2.1.1.7.3 Long-Tube Vertical Evaporating
  2.1.1.7.4 Horizontal Tube Evaporating
  2.1.1.7.5 Agitated Film Evaporating
  2.1.1.7.6 Grainer Evaporating
  2.1.1.7.7 Submerged Combustion Evaporating
  2.1.1.7.8 Disk or Cascade Evaporating
  2.1.1.7.9 Flash Evaporating
2.1.1.8 Centrifuging
- 2.1.1.8.1 Ultracentrifuge
- 2.1.1.8.2 Tubular Bowl Centrifuge
- 2.1.1.8.3 Hydrocyclone Centrifuge

2.1.1.9 Drying
- 2.1.1.9.1 Direct Drying
  - 2.1.1.9.1.1 Direct Continuous Drying
  - 2.1.1.9.1.2 Direct Batch Drying
- 2.1.1.9.2 Indirect Drying
  - 2.1.1.9.2.1 Indirect Continuous Drying
  - 2.1.1.9.2.2 Indirect Batch Drying
- 2.1.1.9.3 Radiant Heat Drying
- 2.1.1.9.4 Dielectric Heat Drying

2.1.1.10 Adsorbing
- 2.1.1.10.1 Gas (or Vapor) on Solid Adsorption
- 2.1.1.10.2 Gas (or Vapor) on Liquid Adsorption
- 2.1.1.10.3 Liquid on Liquid Adsorption
- 2.1.1.10.4 Solid on Solid Adsorption

2.1.1.11 Absorbing
- 2.1.1.11.1 Plate Tower Absorbing
- 2.1.1.12.2 Sieve Tray Absorbing
- 2.1.1.13.3 Spray Tower Absorbing
- 2.1.1.14.4 Cyclone Scrubber Absorbing
- 2.1.1.15.5 Wetted-wall Column Absorbing

2.1.1.12 Crushing
- 2.1.1.12.1 Primary Crushing
  - 2.1.1.12.1.1 Jaw Type Crushing
  - 2.1.1.12.1.2 Gyratory Crushing
  - 2.1.1.12.1.3 Cone Crushing
- 2.1.1.12.2 Secondary Crushing
  - 2.1.1.12.2.1 Hammer Crushing
  - 2.1.1.12.2.2 Roll Crushing
    - 2.1.1.12.2.2.1 Smooth Roll Crushing
    - 2.1.1.12.2.2.2 Corrugated or Toothed-Roll Crushing

2.1.1.13 Milling
- 2.1.1.13.1 Tumbling Milling
  - 2.1.1.13.1.1 Ball Milling
  - 2.1.1.13.1.2 Pebble Milling
  - 2.1.1.13.1.3 Rod Milling
  - 2.1.1.13.1.4 Tube Milling
2.1.1.13.2 Ring Roller Milling
2.1.1.13.2.1 Bowl Milling
2.1.1.13.3 Hammer Milling
2.1.1.13.3.1 Disintegrated Hammer Milling
2.1.1.13.3.2 Vertical Hammer Milling
2.1.1.13.3.3 Impact Hammer Milling
2.1.1.13.4 Disk Attrition Milling
2.1.1.13.5 Pin-Type Milling
2.1.1.13.6 Buhrstone Milling
2.1.1.13.7 Dispersion & Colloid Milling
2.1.1.13.7.1 Sand Milling
2.1.1.13.8 Jet Milling
2.1.1.13.9 Flash Pulverization
2.1.1.13.10 Roller Milling (for paint grinding & flour milling)

2.1.1.14 Leaching
2.1.1.14.1 Percolation Leaching
2.1.1.14.1.1 Open Tank or Vat Leaching
2.1.1.14.1.2 Diffusion Battery Leaching
2.1.1.14.1.3 Rake Classifying
2.1.1.14.1.4 Bucket-Elevator Contactors
2.1.1.14.1.5 Screw-Conveyor Contactors
2.1.1.14.1.6 Horizontal Disk Contactors
2.1.1.14.2 Dispersed-Solid Leaching
2.1.1.14.2.1 Agitated Vessels
2.1.1.14.2.1.1 Simple Agitators
2.1.1.14.2.1.2 Pachuca Tanks
2.1.1.14.2.2 Gravity Thickeners
2.1.1.14.2.3 Continuous Centrifuges

2.1.1.15 Stripping
2.1.1.15.1 Pressure Reduction Stripping
2.1.1.15.2 Heat Stripping
2.1.1.15.3 Inert Gas Stripping

2.1.1.16 Electrostatic Separating
2.1.1.16.1 Contact Electrification
2.1.1.16.2 Conductive Induction
2.1.1.16.3 Ion Bombardment

2.1.2 Material Removing
2.1.2.1 Turning
2.1.2.1.1 Lathe Turning
2.1.2.1.1.1 Engine Lathe Turning
2.1.2.1.1.2 Bench Lathe Turning
2.1.2.1.1.3 Toolroom Lathe Turning
2.1.2.1.1.4 Speed Lathe Turning
2.1.2.1.1.5 Duplicating Lathe Turning
2.1.2.1.1.6 Gap Bed Lathe Turning
2.1.2.1.1.7 Turret Lathe Turning
2.1.2.1.1.7.1 Vertical Turret Lathe
2.1.2.1.1.7.2 Horizontal Turret Lathe

2.1.2.1.2 Screw Machine Turning
2.1.2.1.2.1 Single Spindle Screw Machine
2.1.2.1.2.2 Multiple Spindle Screw Machine

2.1.2.1.3 Chucking Machine Turning
2.1.2.1.3.1 Horizontal Chucking Machine
2.1.2.1.3.1.1 Single Spindle
2.1.2.1.3.1.2 Multiple Spindle
2.1.2.1.3.2 Vertical Chucking Machine
2.1.2.1.3.2.1 Single Spindle
2.1.2.1.3.2.2 Multiple Spindle

2.1.2.2 Shaping
2.1.2.2.1 Horizontal Shaping
2.1.2.2.1.1 Plain Shaper
2.1.2.2.1.2 Universal Shaper
2.1.2.2.1.3 Draw Cut Shaper
2.1.2.2.1.4 Travelling Head Shaper
2.1.2.2.1.5 Double Head Shaper
2.1.2.2.2 Vertical Shaping

2.1.2.3 Planing
2.1.2.3.1 Double Housing Planing
2.1.2.3.2 Open Side Planing
2.1.2.3.3 Plate Planing

2.1.2.4 Drilling
2.1.2.4.1 Standard Upright Drilling
2.1.2.4.2 Bench Drilling
2.1.2.4.3 Sensitive Drilling
2.1.2.4.4 Multiple Spindle Drilling
2.1.2.4.5 Gank Drilling
2.1.2.4.6 Turret Drilling
2.1.2.4.7 Radial Drilling
2.1.2.4.8 Deep Hole Drilling
2.1.2.4.9 Gun Drilling
2.1.2.4.10 Trepanning

2.1.2.5 Boring
2.1.2.5.1 Horizontal Boring
   2.1.2.5.1.1 Table-Type Hor. Boring
   2.1.2.5.1.2 Floor-Type Hor. Boring
2.1.2.5.2 Vertical Boring
2.1.2.5.3 Jig Boring

2.1.2.6 Milling
2.1.2.6.1 Knee and Column Milling
   2.1.2.6.1.1 Plain Milling
      2.1.2.6.1.1.1 Plain Horizontal Milling
      2.1.2.6.1.1.2 Plain Vertical Milling
   2.1.2.6.1.2 Universal Milling
2.1.2.6.2 Ram Type Milling
2.1.2.6.3 Bed-Type Milling
2.1.2.6.4 Profiling-Type Milling
2.1.2.6.5 Planer-Type Milling
2.1.2.6.6 Thread Milling
2.1.2.6.7 Hand Milling
2.1.2.6.8 Skin Milling

2.1.2.7 Broaching
2.1.2.7.1 Push Broaching
2.1.2.7.2 Pull Broaching
2.1.2.7.3 Surface Broaching
2.1.2.7.4 Horizontal Continuous Surface Broaching

2.1.2.8 Sawing
2.1.2.8.1 Hand Sawing
2.1.2.8.2 Band Sawing
   2.1.2.8.2.1 Toothed Band Sawing
   2.1.2.8.2.2 Friction Band Sawing
2.1.2.8.3 Circular Sawing

2.1.2.9 Abrading
2.1.2.9.1 Grinding
   2.1.2.9.1.1 Precision Grinding
      2.1.2.9.1.1.1 Cylindrical Center Type
      2.1.2.9.1.1.1.1 Plain Center Type
      2.1.2.9.1.1.1.2 Universal Center Type
2.1.2.9.1.1.2 Centerless Grinding
  2.1.2.9.1.1.2.1 Thru-Feed Centerless
  2.1.2.9.1.1.2.2 In-Feed Centerless
  2.1.2.9.1.1.2.3 End-Feed Centerless
2.1.2.9.1.1.3 Chucking Grinding
2.1.2.9.1.1.4 Internal Grinding
  2.1.2.9.1.1.4.1 Plain Internal
  2.1.2.9.1.1.4.2 Universal Internal
  2.1.2.9.1.1.4.3 Centerless Internal
  2.1.2.9.1.1.4.4 Planetary Internal
2.1.2.9.1.1.5 Disk Grinding
2.1.2.9.1.1.6 Thread Grinding
2.1.2.9.1.1.7 Cam Grinding
2.1.2.9.1.1.8 Crankshaft Grinding
2.1.2.9.1.1.9 Ultrasonic Grinding
2.1.2.9.1.1.10 Electro-Chemical Grinding
2.1.2.9.1.1.11 Surface Grinding
  2.1.2.9.1.1.11.1 Spindle Surface Grinding
    2.1.2.9.1.1.11.1.1 Reciprocating Table
  2.1.2.9.1.1.11.2 Rotary Table
  2.1.2.9.1.1.11.2.2 Vertical Spindle Surface Grinding
    2.1.2.9.1.1.11.2.2.1 Reciprocating Table
  2.1.2.9.1.1.11.2.2.2 Rotary Table
2.1.2.9.1.1.2 Non-Precision Grinding
  2.1.2.9.1.1.2.1 Belt Grinding
  2.1.2.9.1.1.2.2 Bench-Floor Stand Grinding
  2.1.2.9.1.1.2.3 Flexible Shaft Grinding
  2.1.2.9.1.1.2.4 Electro-Chemical Grinding
  2.1.2.9.1.1.2.5 Abrasive Cut-Off
2.1.2.9.2 Finishing
   2.1.2.9.2.1 Precision Finishing
      2.1.2.9.2.1.1 Abrasive Belt Finishing
      2.1.2.9.2.1.2 Honing
      2.1.2.9.2.1.3 Lapping
      2.1.2.9.2.1.4 Hand Scraping
      2.1.2.9.2.1.5 Superfinishing
   2.1.2.9.2.2 Non-Precision Finishing
      2.1.2.9.2.2.1 Abrasive Belt Finishing
      2.1.2.9.2.2.2 Blasting
      2.1.2.9.2.2.3 Brushing
      2.1.2.9.2.2.4 Buffing
      2.1.2.9.2.2.5 Polishing
      2.1.2.9.2.2.6 Scaling
      2.1.2.9.2.2.7 Spallling
      2.1.2.9.2.2.8 Tumbling
      2.1.2.9.2.2.9 Ultrasonic Cleaning
   2.1.2.10 Shearing
      2.1.2.10.1 Blanking
      2.1.2.10.2 Punching or Piercing
      2.1.2.10.3 Slotting
      2.1.2.10.4 Perforating
      2.1.2.10.5 Notching
      2.1.2.10.6 Slitting
      2.1.2.10.7 Lanceing
      2.1.2.10.8 Nibbling
   2.1.2.11 Etching
      2.1.2.11.1 Photo-Etching
      2.1.2.11.2 Chemical Milling
   2.1.2.12 Burning
      2.1.2.12.1 Laser Burning
      2.1.2.12.2 Electrical Discharge Cutting
      2.1.2.12.3 Electric Arc Cutting
      2.1.2.12.4 Gas Cutting
         2.1.2.12.4.1 Oxy-Acetylene Cutting
         2.1.2.12.4.2 Powder Cutting
      2.1.2.12.5 Solar Energy Cutting
   2.1.2.13 Clearing
      2.1.2.13.1 Blasting
      2.1.2.13.2 Chopping
      2.1.2.13.3 Digging
      2.1.2.13.4 Grubbing
      2.1.2.13.5 Scraping
      2.1.2.13.6 Igniting
2.2 Combining

2.2.1 Mixing

2.2.1.1 Beating

2.2.1.1.1 Agitator Beating

2.2.1.1.1.1 Paddle

2.2.1.1.1.1.1 Flat

2.2.1.1.1.1.2 Pitched

2.2.1.1.1.2 Gate

2.2.1.1.1.3 Anchor

2.2.1.1.1.4 Double Action

2.2.1.1.2 Turbine Imbeller Beating

2.2.1.1.2.1 Blade

2.2.1.1.2.2 Disc

2.2.1.1.2.3 Radial

2.2.1.1.2.4 Cone

2.2.1.2 Blending

2.2.1.2.1 Miscible Fluid Blending

2.2.1.2.2 Immiscible Liquid Blending

2.2.1.2.3 Emulsification Blending

2.2.1.2.4 Solid Suspension Blending

2.2.1.2.5 Agitation Blending

2.2.1.2.5.1 Gases

2.2.1.2.5.2 Liquids

2.2.1.2.5.3 Heat Transfer

2.2.1.3 Kneading

2.2.1.3.1 Batching Kneading

2.2.1.3.1.1 Internal

2.2.1.3.1.2 Open Trough

2.2.1.3.2 Continuous Kneading

2.2.1.4 Masticating

2.2.1.5 Impregnating

2.2.2 Coating

2.2.2.1 Spraying (and Vaporizing)

2.2.2.1.1 Atomizing Liquids

2.2.2.1.1.1 Air

2.2.2.1.1.2 Mechanical Pressure

2.2.2.1.1.3 Electrostatically

2.2.2.1.1.3.1 Nozzle-grid

2.2.2.1.1.3.2 Centrifugal Principle

2.2.2.1.2 Metal Spraying

2.2.2.1.2.1 Low-Temp. Melting Metals (venturi action)

2.2.2.1.2.1.1 Lead-tin solders

2.2.2.1.2.2 Medium-Temp. Melting Metals (Schooping gun)

2.2.2.1.2.2.1 Copper

2.2.2.1.2.2.2 Steel
2.2.2.1.2.3 High-Temp. Melting
   Metals (Plasma Arc Torch)
   2.2.2.1.2.3.1 Tungsten
   2.2.2.1.2.3.2 Molybdenum
   2.2.2.1.2.3.3 Refractory oxides
   2.2.2.1.2.3.4 Nitrides
   2.2.2.1.2.3.5 Carbides
2.2.2.1.3 Metal-Vapor Plating
   2.2.2.1.3.1 Vacuum Chamber Methods
      2.2.2.1.3.1.1 Evaporation
      2.2.2.1.3.1.2 Sublimation
   2.2.2.1.3.2 Atmospheric Heating
   2.2.2.1.3.3 Pyrolysis
   2.2.2.1.3.4 Sputtering
2.2.2.2 Brushing
2.2.2.3 Rolling
2.2.2.4 Dipping
   2.2.2.4.1 Hot Dipping
   2.2.2.4.2 Galvanizing
   2.2.2.4.3 Tin "Plating"
   2.2.2.4.4 Terne Coating
2.2.2.5 Printing
   2.2.2.5.1 Relief Printing
   2.2.2.5.2 Intaglio Printing
   2.2.2.5.3 Lithographic Printing
   2.2.2.5.4 Rotogravure Printing
   2.2.2.5.5 Photo-Gelatine Printing
   2.2.2.5.6 Photo-Copy Printing
   2.2.2.5.7 Silk Screen Printing
   2.2.2.5.8 Memo Printing
   2.2.2.5.9 Spirit Printing
   2.2.2.5.10 Transfer Printing
      2.2.2.5.9.1 Decal
2.2.2.6 Dyeing
   2.2.2.6.1 Electrolyte Dyeing
   2.2.2.6.2 Level Dyeing
   2.2.2.6.3 Diazotizing Dyeing
   2.2.2.6.4 Developing Dyeing
   2.2.2.6.5 Pigment Dyeing
   2.2.2.6.6 Dope or Spin Dyeing
2.2.2.7 Calendar Coating
2.2.2.8 Electrodeposition
   2.2.2.8.1 Electroplating
      2.2.2.8.1.1 Aqueous Solutions
      2.2.2.8.1.2 Salt Baths
      2.2.2.8.1.3 Organic Electrolytes
2.2.2.9 Oxide Coating
  2.2.2.9.1 Anodizing
2.2.2.10 Enamelling
  2.2.2.10.1 Vitreous (fired and fused, e.g., porcelain)
  2.2.2.10.2 Non-Vitreous (paints)
2.2.2.11 Spreading
  2.2.2.11.1 Seeding
  2.2.2.11.2 Fertilizing
  2.2.2.11.3 Chemical Treating
2.2.2.12 Sodding

2.2.3 Assembling
  2.2.3.1 Positioning
    2.2.3.1.1 Locating
    2.2.3.1.2 Orienting
  2.2.3.2 Fastening
    2.2.3.2.1 Winding
    2.2.3.2.2 Spinning
    2.2.3.2.3 Laminating
    2.2.3.2.4 Felting
    2.2.3.2.5 Warping
    2.2.3.2.6 Braiding
    2.2.3.2.7 Weaving
    2.2.3.2.8 Welding
    2.2.3.2.9 Brazing and Soldering
    2.2.3.2.10 Pinning
    2.2.3.2.11 Sewing
    2.2.3.2.12 Seaming and Curling
    2.2.3.2.13 Shrinking
    2.2.3.2.14 Pressing
    2.2.3.2.15 Bonding
    2.2.3.2.16 Clipping
    2.2.3.2.17 Tying

2.3 Forming
  2.3.1 Working
    2.3.1.1 Peening
      2.3.1.1.1 Shot Peening (finishing process)
      2.3.1.1.2 Press Peening
      2.3.1.1.3 Impact Peening
    2.3.1.2 Rolling
      2.3.1.2.1 Continuous Rolling (Milling)
      2.3.1.2.2 Ingot or Hot Rolling (Bloom Rolling)
      (Sendzimir Rolling)
    2.3.1.2.3 Cold Rolling
2.3.1.2.4 Pierce Rolling
2.3.1.2.5 Tube or Strip Rolling
2.3.1.2.6 Cold Powder Spin Rolling
2.3.1.2.7 Compacting
2.3.1.3 Drawing
2.3.1.3.1 Cold Drawing
2.3.1.3.2 Tube Drawing
2.3.1.3.3 Silver Drawing
2.3.1.3.4 Shell Drawing
2.3.1.4 Pressing
2.3.1.4.1 Cold Pressing
2.3.1.4.2 Hot Pressing
2.3.1.4.3 Finish Pressing (textile)
2.3.1.5 Forging
2.3.1.5.1 Hammer Forging
2.3.1.5.2 Drop Forging
2.3.1.5.3 Impact Forging
2.3.1.5.4 Press Forging
2.3.1.5.5 Upset Forging
2.3.1.5.6 Roll Forging
2.3.1.5.7 Swag Forging
2.3.1.5.8 Cold Head Forging
2.3.1.6 Stamping
2.3.1.6.1 Rupture Stamping
2.3.1.6.1.1 Blanking
2.3.1.6.1.2 Piercing
2.3.1.6.1.3 Cutting Off
2.3.1.6.1.4 Lancing
2.3.1.6.2 Non-Rupture Stamping
2.3.1.6.2.1 Drawing
2.3.1.6.2.2 Bending
2.3.1.6.2.3 Embossing
2.3.1.7 Bending
2.3.1.7.1 Die Bending
2.3.1.7.2 Roller Bending
2.3.1.7.3 Press Bending
2.3.1.7.4 Wiper Bending
2.3.1.7.5 Wrap Form Bending
2.3.1.7.6 Spin Bending
2.3.1.7.7 Squeeze Bending
2.3.1.7.8 Press Brake Bending
2.3.1.8 Extruding
2.3.1.8.1 Hot Extruding
2.3.1.8.2 Cold Extruding
2.3.1.8.2.1 Backward
2.3.1.8.2.2 Forward
2.3.1.8.3 Thick Mud Extruding
2.3.1.8.4 Slot-Die Extruding
2.3.1.8.5 Inflated Tube Extruding

2.3.1.9 Metal Spinning
  2.3.1.9.1 Curl Metal Spinning
  2.3.1.9.2 Smooth Metal Spinning
  2.3.1.9.3 Shape Metal Spinning
  2.3.1.9.4 Neck Metal Spinning
  2.3.1.9.5 Bulge Metal Spinning
  2.3.1.9.6 Burnish Metal Spinning
  2.3.1.9.7 Bead Metal Spinning

2.3.1.10 Molding (plastics)
  2.3.1.10.1 Compression (cold-hot)
  2.3.1.10.2 Transfer
  2.3.1.10.3 Injection
  2.3.1.10.4 Lamination
  2.3.1.10.5 Extrusion

2.3.1.11 Vacuum Forming (plastics)
  2.3.1.11.1 Cavity Type Mold
  2.3.1.11.2 Force Above Sheet
  2.3.1.11.3 Force Below Sheet

2.3.1.12 Pounding
  2.3.1.12.1 Hammering
  2.3.1.12.2 Tamping

2.3.2 Thermal Conditioning

2.3.2.1 Curing
  2.3.2.1.1 Preserving (salting, smoking, drying)
  2.3.2.1.2 Setting (vulcanizing, etc.)

2.3.2.2 Crystallizing
  2.3.2.2.1 Supersaturation
  2.3.2.2.2 Seeding (nucleation)
  2.3.2.2.3 Evaporation
  2.3.2.2.4 Cooling

2.3.2.3 Casting
  2.3.2.3.1 Sand Casting
    2.3.2.3.1.1 Green Molds
    2.3.2.3.1.2 Dry-Sand Molds
    2.3.2.3.1.3 Shell Molding
  2.3.2.3.2 Permanent-Mold Casting (metal molds)
  2.3.2.3.3 Die Casting
    2.3.2.3.3.1 Piston
    2.3.2.3.3.2 Cold-Chamber Machine
  2.3.2.3.4 Investment Casting (wax)
  2.3.2.3.5 Plaster Mold Casting
  2.3.2.3.6 Centrifugal Casting
2.3.2.4 Vacuum Depositing (See metal-vapor plating)

2.3.2.5 Heat Treating
   2.3.2.5.1 Non-ferrous Metals and Alloys
      2.3.2.5.1.1 Annealing
      2.3.2.5.1.2 Stress Relieving
      2.3.2.5.1.3 Heating for Homogenization
      2.3.2.5.1.4 Hardening

   2.3.2.5.2 Steels
      2.3.2.5.2.1 Annealing
      2.3.2.5.2.2 Normalizing
      2.3.2.5.2.3 Hardening
      2.3.2.5.2.4 Tempering

   2.3.2.5.3 Glass Products
      2.3.2.5.3.1 Annealing
      2.3.2.5.3.2 Tempering

2.3.2.6 Melting
   2.3.2.6.1 Metallurgical Furnaces
      2.3.2.6.1.1 Fuel Fired
         2.3.2.6.1.1.1 Crucible
         2.3.2.6.1.1.2 Metal Pot
         2.3.2.6.1.1.3 Reverberatory
         2.3.2.6.1.1.4 Open Hearth
         2.3.2.6.1.1.5 Cupola
      2.3.2.6.1.2 Electric
         2.3.2.6.1.2.1 Arc Type
         2.3.2.6.1.2.2 Induction Type

2.3.2.7 Freezing (see heat transfer)
   2.3.2.7.1 Evaporation Processes (many kinds)
   2.3.2.7.2 Conduction (contact-momentum)
   2.3.2.7.3 Convection (fluids)
   2.3.2.7.4 Radiation

2.3.2.8 Chilling

2.3.3 Combing

2.3.4 Winding

2.3.5 Knitting

2.3.6 Displacing
   2.3.6.1 Bulldozing
   2.3.6.2 Disassembling
2.3.6.3 Grading
2.3.6.4 Plowing
2.3.6.5 Ripping
2.3.6.6 Scarifying
2.3.6.7 Wrecking

3. Post-Processing

3.1 Altering
3.2 Installing
3.3 Maintaining
3.4 Repairing
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