# A STUDY TO DEVELOP A CURRICULUM IN INDUSTRIAL DESTRUCTIVE TESTING PROCEDURES FOR FERROUS AND NON-FERROUS METALS AT THE UNIVERSITY LEVEL

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Geary, Michael R., A Study to Develop a Curriculum in Industrial Destructive Testing Procedures for Ferrous and Non-Ferrous Metals at the University Level. Master of Science (Industrial Arts), May, 1971, 101 pp., 2 tables, 1 illustration, bibliography, 33 titles.

The problem of this study was to develop a curriculum based on present destructive testing procedures used in industry dealing with the mechanical properties of ferrous and non-ferrous metals, and to organize the curriculum at the university level.

The data were gathered by examination of current literature in the field, a collection of sample curricula from institutions of higher learning, and through the use of a check list mailed to various industrial firms engaged in metals testing.

Chapter I of the study includes an introduction, statement of the problem, background and significance, limitations, definitions of terms, related studies, procedure, and the organization of study.

Chapter II presents a discussion of the properties and characteristics of both ferrous and non-ferrous metals along with a brief history of the metals industry.

Methods and types of metal testing, definitions, and the development of metal testing in industry are presented in Chapter III.

A study of present metal testing curricula at the college and university level is presented in Chapter IV. It includes the types of courses available at the participating institutions as well as the organization of course work. The areas emphasized in the sample course work are also covered in this chapter.

In accordance with data gathered by use of the instrument, Chapter V includes the course organization, areas to be emphasized, and the various laboratory test procedures.

Chapter VI presents the summary, findings, conclusions, and recommendations of the study.

The following constitute a few of the findings of the study. The majority of the participating industrial firms believed an educational gap exists in the area of destructive testing. The majority of the firms considered destructive testing to be very important. The majority of the firms consider a background in destructive testing to be very important in relation to the hiring of new personnel. Other findings were made concerning the sample curricula, and to the reaction of the check list by the participating industrial firms.

It was concluded, among other things, that colleges are not placing enough importance on destructive metal testing to meet the personnel needs of industry, and a curriculum devoted to the presentation of destructive metallurgical investigative techniques and mechanical properties of metal could be valuable to the present industrial arts program.

Various recommendations were made concerning the proposed curriculum. It was recommended that the curriculum should be continuously modernized to stay abreast with new trends as they occur in industry. An inquiry into laboratory facility requirements should be made concerning the proposed curriculum. It was further recommended that consideration be given to the proposed curriculum for implementation into the present programs of various departments of industrial arts at the university level.

# A STUDY TO DEVELOP A CURRICULUM IN INDUSTRIAL DESTRUCTIVE TESTING PROCEDURES FOR FERROUS AND NON-FERROUS METALS AT THE UNIVERSITY LEVEL

THESIS

Presented to the Graduate Council of the
North Texas State University in Partial
Fulfillment of the Requirements

For the Degree of

MASTER OF SCIENCE

By

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Denton, Texas
May, 1971

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# CHAPTER I

## INTRODUCTION

The field of material testing is rapidly becoming a separate entity in the context of modern industry. More specifically, the area of metals testing has grown to be staggeringly complex and involved. With the development of specially made steel and other custom-made metals for use in specific jobs, the importance of metal testing is at an all time high. Many different industries make use of metal testing in some form or other. The steelmaking industry tests each batch they produce to insure top quality on their standard steels. Testing is also used to develop new steels with improved qualities and characteristics. The industries associated with the space effort run extensive tests on metal to determine its suitability for every task imaginable. Many other industries also make use of metal testing to some degree.

In the main, the field of industrial arts exists for the purpose of studying industry. Industrial arts categorizes the various industrial processes and procedures into certain basic areas and then groups related processes and procedures into these areas. These include such areas as electricity and electronics, crafts, woods, metals, drafting, printing, photography, and plastics. Within these areas are grouped the processes and procedures used to work with these materials or subjects. To keep up with the dynamic American industrial complex, the field of industrial arts should experience a growth paralleling that of industry in the form of relative curricula to stay abreast with current industrial developments. This is basic to the survival of industrial arts. There is, therefore, a present and growing need in the field of industrial arts for the development of a metal testing curriculum at the university and college level.

## Statement of the Problem

The problem of this study was to develop a curriculum based on present destructive metal testing procedures used in industry dealing with the mechanical properties of ferrous and non-ferrous metals and to organize the curriculum at the university level. There were certain questions for which answers were sought. They are as follows:

1. What are the properties and characteristics of ferrous and non-ferrous metals?

2. How has metal testing developed and what are the methods used?

3. What are the various types of metal tests used in industry?

4. What are some industrial metal testing procedures?

5. What are the types of courses available today at the university and college level, and what are the apparent areas of emphasis?

6. How is the course work organized?

## Background and Significance of Study

Iron and steel have made many products possible. Without a widely available material capable of being easily formed and treated to obtain the special properties necessary, such common items as the automobile would still be a curiosity. Iron has been used by man for thousands of years. Today it is such a common material that we take its existence for granted. The early Egyptians called iron <u>ba-en-pet</u>, the metal from heaven, because of the iron meteors which fell to earth from the sky. Likewise, the Assyrians and Babylonians used the term <u>an-bar</u> or <u>parzillu</u>, which meant the metal of heaven, and the Chaldeans and Hebrews spoke of <u>barsa</u>, <u>barsal</u> or <u>barzel</u>, meaning the same thing (10, p. 6).

The historical importance of iron can be clearly established. It is believed that prehistoric man had a few iron implements which he had shaped from meteors. However, this is only theory, for anything made of iron which was used by prehistoric man would have turned to rust thousands of years ago. The use of iron by man has been traced back for many centuries by historians.

> The use of iron in Egypt can be traced back 3500 to 4000 B.C.. However, it did not come into general use for another 2000 years. At one time iron was so rare that it was almost as costly as gold. In India, iron may have been used about 2000 B.C. and some historians think that the Hindoos were the first people to learn how to smelt iron from the ore. They may even have supplied the tools used to carve the hieroglyphics on the Egyptian temples, tombs and obelisks (10, p. 6).

It is not strange that iron can be traced back so far because iron is one of the most common elements in nature. About one-twentieth of the earth's crust is composed of iron, and it is the fourth most abundant of all the elements. Meteorites are composed almost entirely of iron, and it is also present in all natural waters such as lakes, rivers, springs, and the oceans. Iron can also be found in the bodies of all plants and animals. The body of a man contains from a quarter to a half ounce of iron which is very important to the hemoglobin of the blood (10, p. 7).

Steel is the most valuable form of iron and can be thought of as an alloy of iron and carbon. Carbon content has a great deal to do with the mechanical properties of steel. Steels are the strongest and most versatile of construction materials, as they may be made so hard that they scratch glass or so soft they can be scratched with a needle. Steels can operate over a wide temperature range and can be easily formed, cut, welded, or bent without destroying their inherent properties. Nature also gave steel excellent magnetic properties to make it valuable in electrical machinery.

Steel is more important than all of the gold, silver, copper, tin, and lead combined, for we could give up any other metal with less effect upon our civilization (10, pp. 14-15). The importance of steel to industrial arts is clear since it is the metal which makes modern industry possible. It is vital to the very existence of mankind, and it is certainly worthy of receiving a special place in the industrial arts curriculum.

The field of industrial arts is regarded by some people to be neither static nor complacent. By virtue of its definition, it is dynamic and constantly seeking self-improvement to enrich its course offerings. Curriculum offerings in industrial arts should reflect contemporary industry and its role in our technological society. Instructional materials must be available which are not only interesting and stimulating but which also relate to current industrial materials and processes (9, p. 30). Further investigation reveals that industrial arts embodies two important principles. These principles hold that industrial arts is part of general education and that industry is the source of its content (2, p. 17). The principle which concerns this study most directly is that which points out the source of content. Therefore, one main idea stands out at this point which is very important to this study. Industrial arts is the study of industrial processes and procedures, and industry is the source of its curricula content. Also, industrial arts must reflect and relate to contemporary industrial practices; therefore, as industry undergoes change so must industrial arts.

There is much current research going on today in industrial arts. This research concerns itself with many problems important to the profession. Householder and Suess stated:

> Among the most important areas, recent curriculum studies have been based upon sound analytical endeavors to identify, classify, and organize content and experience for industrial arts students. A principal concern of these researchers has been the development of better balanced programs. Several significant curriculum projects have developed full-fledged courses and/or programs (6, p. 4).

The study of curriculum is not new as there is a constant effort on the part of industrial arts educators to update existing curricula and to establish new programs when justified by industrial change or new technology.

The field of metal testing is a new form of technology, and its importance to modern industry cannot be overestimated. It is based upon the fact that all metals have three distinct sets of properties. These properties are classified as physical, chemical, or mechanical. The industrial arts student has a need for knowledge of at least one of these properties. The mechanical properties of metal pose a problem for the serious student of industrial arts when he attempts to design a project made of metal. The American Iron and Steel Institute reports that while physical properties may determine whether or not steel or some other metal can be used in a design, mechanical properties help determine the best type of steel for the design (3, p. 5). On a much greater scale, a similar situation applies to industry. It is constantly faced with this problem and the responsibilities are usually great. The Apollo space program depends not only upon correct design but also on the use of proper metals in construction. When a certain type metal is needed, but is not available, it is developed through the use of metal testing.

Understanding the importance that industry places upon metals testing and recognizing the need for the industrial arts student to have a working knowledge of the mechanical properties of metal, it is clear that there is a present need for a course of study dealing with metals testing in the field of industrial arts. Also, in order that this new knowledge may reach the most students, it should be taught to potential teachers of industrial arts as well as to those planning to go into industry. It should, therefore, be taught on the university and college level. In keeping with the nature of industrial arts, the course should deal with mechanical properties of ferrous and non-ferrous metals only.

## Limitations of Study

This study had certain limitations which were self-imposed in order to better define and solve the problem. These limitations are as follows:

1. This study was limited to the destructive testing of ferrous and non-ferrous metals. Also, only the major ferrous and non-ferrous metals were used in the design of the curriculum.

2. A total of five institutions of higher learning participated in the study.

3. The number of industrial firms which participated in the study was limited to seven.

4. This study concerned itself with appropriate curriculum only and dealt with the design of a course lasting one semester in duration. An appropriate curriculum was considered to be that material which was judged most important or important by the jury.

## Definition of Terms

It was necessary to define some pertinent and commonly used words in this study to clarify and understand their meanings. The definitions are as follows:

Annealing is a heat treatment operation which involves heating and controlled cooling for the purpose of decreasing hardness and increasing the ease of machining or improving the cold-working characteristics.

Curriculum pertains to a group of courses which make up a single academic program or a single course of study in a particular field.

Destructive Testing is the method of testing a material to determine its properties which cause it to be destroyed in the process and render it useless in the future.

Ferrous Metal defines any metal containing iron, which is a chemical property, such as any of the steels.

Hardenability is the property that determines the depth and distribution of hardness which is brought about by quenching.

Heat Treatment is a procedure or a combination of operations whereby certain desirable mechanical, micro-structural, or corrosion-resisting properties are obtained by the heating and cooling of steels in the solid state.

Industry pertains to the manufacture of commercially produced products which, in many cases, involves extensive use of material testing to produce these products.

Instrument refers to the means of accomplishing a purpose or task. The instrument in this study is a form of an evaluation sheet sent to each member of the jury.

Jury refers to a group of persons forming a body in order to render a verdict on some matter. The matter in this case is a proposed curriculum.

Material Testing is the testing of any raw material used by industry or any material used in the making of a finished product. The material may be anything from plastic to steel, and the tests are performed to learn their physical, chemical, or mechanical properties.

Mechanical Properties are those properties which indicate the ability of a metal to be formed, punched, bent or drawn, how long the metal will endure, or how it will react to different mechanical tests such as tensile and yield strength, fatigue strength, or hardness.

Metal Testing refers to the testing of any metal, ferrous or non-ferrous, to determine its properties.

Non-Destructive Testing is the method of material testing which does not destroy the material or product being evaluated in the process.

Non-Ferrous Metal defines any metal which does not contain iron such as brass, copper, or aluminum.

Tempering is a process of reheating quench-hardened steel to a temperature below the critical transformation range and then recooling at any desired rate.

## Related Studies

An examination of previous studies made at North Texas State University and of published abstracts of research in industrial arts elsewhere revealed that no study is directly related to the investigation at hand. However, several theses dealing with curriculum research in other areas were found. It was believed that these studies might serve as guides in the preparation for and conducting of this particular thesis.

A recent study by MyCue (8) was made in 1970 to identify concepts concerning the mechanical characteristics of materials used by industrial arts students and to develop learning experiences that provide the students with an opportunity to develop such concepts. MyCue gathered the data necessary for completion of the study by means of library research of existing material in the field. MyCue concluded that materials testing should be used in industrial arts as a medium to develop concepts concerning the mechanical properties of materials.

A study by Hicks (5) was made in 1969 to determine the need for and interest in an electricity-electronics course in the industrial arts department of Amarillo High School, Amarillo, Texas. Hicks conducted the study by constructing and submitting questionnaires to the senior students enrolled at Amarillo High School for the school year 1968-1969 and to certain selected electrical industries in and around Amarillo, Texas. Personal interviews were held and current literature in the field was studied. Among Hicks' conclusions were that very few of the senior students required a general understanding of electricity for part-time employment but that approximately one-half of the students made domestic electrical appliance repairs. A substantial majority of the business firms surveyed believed that the inclusion of an electricity-electronics course at the high school would be beneficial to their prospective employees. Over one-half of the employees hired by the firms possessed a basic working knowledge of electricity. Also, the employees were expected to be able to use several test instruments.

In 1963, Kress (7) conducted a study into the need for a curriculum in construction engineering at San Jose City College, San Jose, California. Kress concluded, among other things, that employers in the construction industry were very interested in the study and they gave a great deal of assistance in answering questions and offering suggestions for developing a curriculum in construction engineering. He also concluded that the contractors felt that an adequate understanding of construction by young people entering the building trades is of primary importance. The contractors also felt that technical education is the next best thing to on-the-job training as a method to obtain adequate understanding of construction.

A study by Aldrich (1) was made in 1961 to determine a course of study in machine shop technology for a two-year technical institute. Aldrich concluded that a course of study must be carefully constructed and well developed. It must also be flexible so that it may be adapted easily to the varied needs and abilities of the more advanced student. Also, revisions will be necessary each year to keep abreast of the rapidly changing technology.

In 1960, Teel (11) made a study concerned with the development of a curriculum for industrial electricity and electronics. Teel conducted his study by means of personal interviews with representatives of various industries in Iowa and Illinois. Among Teel's conclusions were that all industries indicated that they could, on the average, absorb one technician a year and a preference for male technicians was indicated. The industries also indicated that they would hire a young technician with no previous work experience. Teel concluded that there was no set starting salary and that opportunity for advancement was limited.

## Procedure of Study

In the statement of the problem, several questions considered vital to the completion of the research to the point of actual development of the curriculum were listed. Most of the questions were answered through the use of library research. A form letter, requesting a synopsis of their metal testing curricula, was sent to certain selected colleges and universities to determine the nature and organization of their course work. These schools were selected after a review of college bulletins. At this point in the development of the curriculum, an instrument was developed which contained a list of processes, procedures, laboratory work, metals tests, and areas emphasized concerning metal testing. These areas emphasized were selected from synopses of existing course work and from current literature in the field. The instrument was sent to members of a selected jury. The jury members were selected from industries which have a vital interest in and daily concern with metal testing. The addresses of the firms were obtained from advertisements in technical publications. In all cases the instruments were sent to the main office of the industries concerned with a request that they forward it to the head of the testing department. The jury members were asked to judge what they considered to be very important, important, and not important from the instrument list. When the results were received and the data treated, the curriculum was developed according to the opinions of the participating industrial firms.

## Organization of Study

Chapter I of the study includes an introduction, statement of the problem, background and significance of the study, limitations of the study, definitions of terms, related studies, procedure of study, and organization of study.

Chapter II is concerned with a coverage of the properties and characteristics of both ferrous and non-ferrous metals. A brief history of the metals industry is included.

Chapter III is devoted to a study of industral testing procedures. This chapter includes methods and types of metal testing, definitions, and the development of metal testing in industry.

Chapter IV consists of a study of present metal testing curricula at the college and university level. It includes the types of courses available at the participating institutions as well as the organization of course work. The areas emphasized in the sample course work are also covered in this chapter.

Chapter V is devoted to the actual development of the curriculum in accordance with data gathered by use of the instrument. It includes the course organization, areas to be emphasized, and the various laboratory test procedures.

Chapter VI presents the summary, findings, and conclusions of the study. Recommendations are made in view of the findings of the study.

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CHAPTER II

# PROPERTIES AND CHARACTERISTICS OF FERROUS AND NON-FERROUS METALS

Metals are among the most common elements found in nature; yet metallurgy is considered to be one of our newest sciences. On the other hand, metallurgy is one of the oldest arts. The art of metallurgy can be traced back to Biblical times. A descendant of Cain, named Tubal Cain, was reported to be a teacher of metalworking specializing in brass and iron. A background on the subject of iron was discussed in the previous chapter. However, iron is not the only metal of which there is an early history. Gold artifacts have been unearthed in and around the ancient Mesopotamian city of Ur, which displayed remarkable craftsmanship and showed that the Mesopotamians were a cultural society. Gold and silver date back to 3500 B.C. and 2400 B.C. respectively and were utilized mainly in the production of utensils. Copper artifacts in the native form have been discovered in the Near East which date back to 4000 B.C., and ancient Egyptian copper mines have been located on the Island of Crete. Also, the Romans utilized lead pipes in their water distribution system which indicates that they were able to extract the metal from its matrix (1, p. 1).

During the Middle Ages, the art of swordmaking was at its peak. It was an art which had been passed down through each generation by certain families who jealously guarded their secret. During this period of time, metallurgy was limited in its practice and scope. The metals industry did not exist as we recognize it today (1, p. 1).

After the Middle Ages, when man began to overcome his fear of the unknown, technology in all fields made rapid advances and metallurgy began to evolve into a more exact science. It is difficult to say whether the advancement of metallurgy as a science was instrumental in the industrial revolution, or if the industrial revolution advanced the science of metallurgy. Certainly metallurgy is a building block for all industries regardless of their nature. Today the metals industry is probably the most important industry we have. Without it, it is doubtful that modern civilization could exist. As technology in the metals industries advanced, so did our knowledge of ferrous and non-ferrous metals.

## Properties and Characteristics of Ferrous Metals

As previously defined, a ferrous metal is one which contains the chemical element of iron. This study was concerned with various types and classes of steel in the discussion of ferrous metal.

Steel is an alloy of iron and carbon. In addition, there are minute percentages of other elements present. Steels may be roughly classified as straight carbon steels or alloy steels. A straight carbon steel is one which owes its particular properties chiefly to the presence of certain percentages of carbon without substantial amounts of other alloying elements. There are three groups into which straight carbon steels may be classified. These classifications are low-carbon, medium-carbon, and high-carbon steels (2, p. 400).

Carbon is of great importance to steel because it is the element which makes possible the hardening of straight carbon steel. Steel must contain at least 0.6 per cent of carbon before it can be hardened sufficiently for commercial use (3, p. 86).

Low-carbon steel is so classified because it does not contain a sufficient amount of carbon to be hardened when heated to a high temperature and quenched in air, water, or oil. The amount of carbon in low-carbon steel may vary from 0.05 to 0.20 per cent. Some types of machine steel and cold-rolled steel are of the low-carbon classification. Products made of low-carbon steel should not be designed for continuous wear. When required, a low-carbon steel may be case-hardened by a special process to develop a hard-wearing surface and a soft core (2, pp. 400-401).

Medium-carbon steel contains from 0.20 to 0.60 per cent carbon. Medium-carbon steels are widely used since they are useful for such products as crankshafts, construction beams, and automobile bodies. Production manufacturers use an extensive quantity of medium-carbon steel. Some degree of hardness may be obtained by heat treating this classification of straight carbon steel (2, p. 401).

High-carbon steels contain from 0.60 to 1.30 per cent of carbon of which tool steel is an example. It possesses characteristics which lend themselves to the various heat treatment processes. This classification of straight carbon steel is capable of obtaining a high level of hardness and is used in making many of the tools and working parts of machines or other items required to stand a great deal of wear (2, p. 401).

An alloy steel is a metal in which one or more elements, along with carbon, may be added to provide the desired physical or mechanical properties (2, p. 400). Other sources include three other classifications of steel which are high-strength low-alloy, stainless, and tool-and-die steel. However, these extra classifications are forms of alloy steels (5, p. 345).

Alloy steels contain certain alloying elements which give some particular characteristics not possessed by straight carbon steel. When a steel has to meet specific requirements, alloys can be used in combination. Steel is alloyed with other elements for many reasons. Some of the reasons are (1) to provide greater hardness, (2) to secure greater toughness or strength, (3) to enable the steel to hold its size and shape during hardening, and (4) to enable the steel to retain its hardness at elevated temperatures (2, p. 401).

Some of the different alloying elements, along with their chemical symbols, and their effects on steel are as follows:

1. Some of the effects of carbon (C) on steel have been previously explained. This element has a very great effect on steel. When the percentage of carbon in steel is increased, the strength, hardness, wear resistance, and hardenability of the steel are also increased. At the same time there is a loss of ductility. The reverse holds true when the percentage of carbon is decreased (6, p. 21).

2. Chromium (Cr) is naturally resistant to corrosion and is used as an alloying element in chrome steel as well as a plating metal. When used in steel, it increases the elastic limit, tensile strength and hardness, and decreases ductility. Chromium also increases the quality of hardenability by making it possible to harden the steel by quenching in oil rather than in water. When more than 10 per cent chromium is present, the steel can be classified as stainless steel as the additional chromium provides rust-resisting qualities (6, pp. 21-22).

3. Cobalt (Co) is usually utilized as a component of stellite and carboloy and is also used in high speed steel along with other special alloys. The addition of cobalt provides steel with the ability to maintain a sharp cutting edge while being used at extreme temperatures (6, p. 22).

4. Silicon (Si) is one of the earth's more common elements as it forms one-fourth of the earth's crust. As an alloying element, silicon is used as a deoxidizing agent to assist in making steel more sound when it is cast (6, p. 23).

5. Phosphorous (P) is usually present in iron ores and, except for very special cases, is considered an undesired impurity in alloys. Phosphorous causes brittleness in steels which is almost never desirable (6, p. 23).

6. Manganese (Mn) is extremely hard in the pure state and ranks as one of the most useful alloying elements. Manganese is present in small amounts (0.30 to 0.60 per cent) in all steel and acts as a deoxidizing agent. In other words, manganese removes oxygen which would make the steel brittle and weak. In amounts over 0.60 per cent, manganese is regarded as an alloying element. When 1.5 to 2.0 per cent manganese is added to high-carbon steel, a non-deforming, deep hardening, oil hardened alloy steel will result. The addition of other elements in conjunction with manganese produces air hardened steels. In amounts up to 15.0 per cent, manganese produces very hard, wear resistant

steels which cannot be cut or drilled by standard or conventional means but must be machined with carbide tipped tools (6, pp. 22-23).

7. Molybdenum (Mo) gives steel remarkable toughness and increases the hardenability value. It permits steel to be hardened by quenching in oil or air, rather than water. In some high speed steels, molybdenum is used in place of tungsten to induce red hardness (6, p. 23).

8. Nickel (Ni) is used extensively for plating purposes as well as an alloying element. The outstanding property of nickel in steel is its natural toughness. Nickel lowers the critical transformation temperature of steel, thus making it possible to harden steel by quenching in oil, causing less cracking, warping, and scaling of parts during heat treating. This alloying element also promotes deep hardening, improves toughness at low temperatures, and when used in combination with chromium, helps form corrosion resistant stainless steels (6, p. 23).

9. Sulphur (S) is a harmful impurity in steel because it promotes brittleness and also causes cracking at high temperatures. Getting rid of sulphur is sometimes difficult because it is found mostly in coke, which is an ingredient used in the blast furnace (6, pp. 23-24).

10. Tungsten (W) is twice as heavy as iron and has a very high melting point. When added to steel, it increases wear resistance and the ability to obtain red hardness.

Tungsten is used extensively in conjunction with chromium and molybdenum to produce high speed and hot work steels (6, p. 24).

11. Vanadium (V) causes a fine grained structure when used as an alloying element in steel. Vanadium confers toughness to steel and gives it the ability to withstand severe shocks without failure. Vanadium also increases the ability of steel to resist metal fatigue while increasing the elasticity (6, p. 24).

The basic mechanical properties of ferrous metals apply to all materials. However, the values vary for each material. All metals either do, or do not possess certain general properties or characteristics such as strength, toughness, resistance to atmospheric destruction, plasticity, weldability, castability, ductility, or malleability. Some characteristics are limited to only a few metals. The ability to be magnetized and to conduct electric current are two examples of limited characteristics (1, pp. 2-3).

This study deals primarily with the mechanical properties of metals in the organization of the proposed curriculum. Mechanical properties include stress, strain, elasticity, strength, hardness, toughness, plasticity and brittleness. These properties are explained as follows:

1. Stress is a mechanical property which is representative of a pressure which may be applied by several means. It may be a pulling, compressing, twisting, or shearing

pressure depending upon the nature of the applied load and the direction of the resultant force. The mathematical unit for stress is load per unit area and is measured in pounds per square inch (PSI). There are four different meanings of stress which are as follows:

a. Tensile stress which causes a material to elongate,

b. compressive stress which causes a material to become shorter or smaller in shape,

c. shear stress causes a material to divide into layers, and

d. a combination of the first three involving flexing or bending loads and torsional or twisting loads.

Stress is used in determining the amount of pressure or force steel or some other material can withstand prior to fracture. Stress is widely used in metals testing (1, pp. 4-5).

2. Strain pertains to per cent change in unit length which occurs to a metal specimen due to elongation or contraction. It is a measure of deformation under load. In other words, strain is used to determine to what extent a material will stretch or elongate under a predetermined load (1, p. 5).

3. Elasticity is a mechanical property which was expressed as a theory in the year 1678 by an English

experimental scientist named Robert Hooke. His theory is known as "Hook's Law" which states that the strain or deformation undergone by an elastic body is in direct proportion to the amount of force or stress acting upon it. However, this law applies only within a limited range of stresses. Beyond this range is a point known as the "elastic limit" which is the ultimate stress a body or metal specimen can withstand and still retain its original shape. The body becomes permanently deformed if loading is increased beyond this point (1, p. 5).

4. Strength, one of the most valuable properties a metal can have, can be defined as the ability of a material to resist deformation. There are four forms of strength which are as follows:

a. Tensile strength refers to the maximum load in tension a body can withstand before fracturing. It is the value used most often when referring to the strength of a material and is expressed in pounds per square inch (P.S.I.).

b. Compressive strength is indicative of the ultimate compressive load which a body will withstand prior to some amount of deformation which was predetermined. In all metals, with the exception of cast iron, tensile strength is greater than compressive strength.

c. Fatigue strength is the maximum load a material can withstand during a large number of load reversals before fracturing. Fatigue strength values are used in the design of structures which may be subject to rapidly fluctuating forces. It is influenced by several factors including micro-structure, surface condition, corrosive environment, cold work, and others.

d. Yield strength is the ultimate load at which a specimen exhibits a specified deformation. A total elongation of 0.2 per cent is used in the determination of yield strength values for many metals. Most engineering calculations for structures use yield strength values rather than tensile strength values for specifications (1, pp. 5-7).

5. Hardness is related to elastic and plastic properties of materials but is not a fundamental property by itself. Hardness can be defined as the resistance of a material to indentation. The resistance to forcible penetration is in direct proportion to the hardness value of a material. Different hardness tests are widely used because of their simplicity and because hardness is closely related to other properties such as the strengths of steels (1, p. 7).

6. Toughness is a property which cannot be directly or accurately measured. However, toughness involves both

ductility and strength and is the ability of a metal to absorb energy and maintain its original shape. The impact or shock resistance of a material is closely related to toughness (1, p. 7).

7. Plasticity is the ability of a material to be extensively deformed without failure. Plasticity, in combination with strength, are the two most beneficial properties a metal can possess. There are two forms of plasticity which are as follows:

a. Ductility is the plasticity displayed by a metal under tension loading and is measured by the amount the metal specimen can be permanently elongated. This ability permits the drawing of a metal from a larger size to a smaller size of wire. Non-ferrous metals have a greater degree of ductility than do ferrous metals.

b. Malleability is the ability of a metal to be compressed until permanent deformation occurs without rupturing the metal. The non-ferrous metals as a group exhibit greater malleability than does steel (1, pp. 7-8).

8. Brittleness is the property directly opposite to plasticity. A brittle metal fails without any warning of impending failure. Certain hard metals may exhibit little plasticity and by definition can therefore be classified as brittle. However, hardness is not a measure of plasticity.

A brittle metal may only be used safely in compression as they exhibit little shock or impact strength (1, pp. 8-10).

The eight mechanical properties are common to all engineering materials, not just to those metals discussed in this study. It is difficult to impart any particular properties or characteristics to ferrous metal as a group. As previously mentioned, steels can be made to fit almost any specification by varying the amount of carbon content, as in the case of straight carbon steels, or by the addition of one or more alloying elements, as in the case of alloy steels. All ferrous metals have their original beginning in the molten state, unlike non-ferrous metals. Steel does not take on any special characteristics until it has undergone further refinement. Therefore, as far as ferrous metals as a group are concerned, properties and characteristics of any kind are relative. However, non-ferrous metals have certain inherent properties and characteristics which provide the subject matter for the next topic of study.

## Properties and Characteristics of Non-Ferrous Metals

A non-ferrous metal is one which does not contain iron. the term "base metal" refers to a metal which is found in the earth and is not in combination with other metals. Some of the more common of these non-ferrous base metals include aluminum, magnesium, zinc, lead, chromium, tin, copper, and nickel. It was observed that some of these metals are used as alloying elements in the production of alloy steel. Non-ferrous metals are as a rule non-magnetic and resist corrosion due to a protective layer of oxide formed on their surface by the action of oxygen (6, p. 1). Since non-ferrous base metals are separate elements in nature, they have certain identifying properties and characteristics. There are non-ferrous alloys which are combinations of non-ferrous base metals. If the non-ferrous metals known to men were versatile enough, there would be no need for alloys. Sometimes, however, it is desirable to obtain more hardness, strength, toughness, ductility, or some other property to better facilitate the need at hand. It is to this end that non-ferrous alloys are necessary.

Aluminum, the wonder metal of this era, is widely used for many different purposes. Today it is taken for granted, but approximately 150 years ago aluminum cost over 500 dollars a pound and was considered more precious than gold. "When Napoleon III dined, he used an aluminum fork while his guests had to be content with gold tableware" (4, p. 322). Aluminum was known for many years to have desirable properties. Until the discovery of the electrolytic process for the reduction of aluminum from its ores, it was far too expensive for commercial use. Aluminum is light in weight and is relatively high in strength, especially in alloys. Therefore, aluminum is one of today's most widely used metals.

The weight of aluminum is one-third that of iron. It is resistant to atmospheric corrosion and is a good conductor of heat and electricity. It melts at 1220° Fahrenheit, is ductile and malleable, and can easily be cast, extruded, forged, rolled, drawn, or machined. Also, aluminum is classified as a "hot short" metal; that is, it loses its strength at high temperatures. At normal temperatures the tensile strength of aluminum is greater than that of most of the common metals except copper and iron (6, p. 2).

The base metal magnesium occurs abundantly in nature but is never found in the pure form. Magnesium is produced from an ore known as "dolomite" but can also be produced by the electrolysis process. The outstanding property of magnesium is its light weight which is two-thirds that of aluminum. In the pure state, magnesium has a low elastic limit. Therefore, where strength is required, alloys of aluminum and magnesium are used. Salt water has a very corrosive effect on magnesium, and it is non-magnetic. However, magnesium is a good conductor of electricity is ductile, malleable, and burns with a very hot and bright flame when used in flares, fireworks, bombs, and the thermit welding process. Magnesium can be cast, rolled, extruded, or welded and is used in products ranging from aircraft parts to typewriter cases (6, p. 3).

Zinc is a bluish white metallic element which comes from an ore called "sphalerite" or zinc sulfide. The metal is extracted from the ore by a process of roasting, reducing, and refining. Zinc is moderately hard and somewhat brittle and weighs slightly less than iron. At temperatures from 212 to 302 degrees Fahrenheit, zinc becomes malleable and ductile and can be rolled into sheets or drawn into fine wire. At these temperatures the metal does not become brittle again when cooled. However, if heated to 572 degrees Fahrenheit and cooled, zinc once again becomes brittle. Zinc is principally used for galvanizing iron and steel (6, pp. 3-4).

The base metal, lead, is found in many forms in nature. Lead is soft, malleable, heavy, and has a melting point around 620 degrees Fahrenheit. Lead is somewhat ductile and has very little mechanical strength. One of the outstanding characteristics of lead is its natural resistance to atmospheric corrosion and the action of some acids which make it useful in batteries and for linings in vats and tanks. Oxides of lead are used as bases for paints. The fumes of molten lead can be fatal as inhalation of the fumes can result in lead poisoning (6, p. 4).

The chief source of metallic tin is "oxide cassiterite", as tin is not often found in its free state. Tin is a soft white metal with a melting point of approximately 450 degrees Fahrenheit; it is extremely malleable, and is highly resistant to atmospheric corrosion and to the action of some acids. Tin is used for the production of tin plate, tin foil, bronze, type metal, babbitt, solder, and fusible alloys (6, p. 4).

Copper, one of the oldest metals known to man, is found in its pure state and in the form of sulfides or carbonates. There are several different types of carbonates or copper ores which require several different refining processes. In general, each process involves crushing, roasting, reducing, and electrolytic refining. Copper is soft, ductile, malleable, and melts at around 1984 degrees Fahrenheit. This metal can be easily rolled, hammered, or drawn, but these processes cause copper to become work-hardened and brittle. Heating copper from 900 to 1300 degrees Fahrenheit, then quenching in water produces an annealed state. Copper is the best conductor of heat and electricity, next to silver. A self protecting film forms when exposed to air which will resist any further corrosion. Copper has several uses including electrical work, plumbing, and the manufacture of several alloys such as brass and bronze. Copper is also used in the production of coins and jewelry (6, p. 5).

Nickel is found in the form of a sulfide, and the refining process is very complicated. Nickel is corrosion resistant, very hard, and is capable of obtaining a high polish. When alloyed with steel, it greatly increases the strength and toughness without decreasing the ductility. The major uses of nickel are as a plating agent for iron and brass and as an alloying element (6, p. 5).

Chromium is the last pure base metal to be covered in this study. Chromium comes from an ore called "chromite" or chromic iron ore. It is hard, brittle, melts at 2930 degrees Fahrenheit, and is capable of retaining a high polish at elevated temperatures or in atmospheric conditions which would corrode other metals. Chromium is used for plating purposes and as an alloying element in steel. Chromium is also used to produce a decorative effect on automobiles and on other surfaces where a high polish is desirable (6, p. 6).

Two or more non-ferrous metals which are thoroughly dissolved in each other are referred to as non-ferrous alloys. Although non-ferrous metals will not combine with each other, the ones which do combine,resist corrosion because of protective oxides formed on them by exposure to air.

Brass is an alloy of copper and zinc with properties which can be varied according to its composition. Other non-ferrous metals can be added to brass to further change or improve the mechanical properties. Brass, along with its resistance to corrosion, has good wearing qualities which makes this metal highly useful. Brass can be cast, rolled, forged, and easily machined. Some of its uses include plumbing, hardware, brazing-filler metal, and bushings (6, pp. 8-9).

Bronze is an alloy of copper, tin, lead, zinc, manganese, and others. The composition of bronze can also be varied according to the desired need. Bronze is a hard alloy which has good wearing qualities, can be made to resist high pressures at elevated temperatures, and is very tough. Bronze is used for bearings, wear plates, bushings, gears, and for such other purposes where anti-frictional properties are desired (6, p. 9).

Babbitt is a soft, white alloy of tin, copper, and antimony which melts at around 870 degrees Fahrenheit and is used mainly in bearings, where it gives good anti-frictional properties. Babbitt has a very low rate of contraction when passing from a molten to a solid state, which makes it an excellent alloy for pouring and die casting (6, pp. 9-10).

Stellite is an alloy of cobalt, chromium, and tungsten. Stellite is very hard, wear resistant, and cannot be forged or rolled but must be cast and ground to shape. Up to 1500 degrees Fahrenheit, it is as hard as hardened steel; therefore, it is especially useful for cutting tools. Stellite will grow tougher at elevated temperatures. This alloy is used in the form of tool bits, inserted teeth for milling cutters, and as a hard surfacing material (6, p. 10).

Each of the metals, characteristics, and properties, which have been discussed, play a vital role in metals testing. Different investigative techniques are performed on metals to determine their properties and characteristics. The qualities contained within metals are the unknown factors which testing reveals. For each property, there is a test to determine and evaluate that property. Mechanical destructive tests are discussed fully in the following chapter.

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## CHAPTER III

## METHODS AND TYPES OF INDUSTRIAL TESTING PROCEDURES

Industrial testing procedures encompass a very broad subject area. Types of tests refer to the classification or grouping of investigative procedures according to function, while methods refer to the nature and operational principles of the various tests.

### Definitions

As the study progressed it was found necessary to define other terms which are used frequently in this chapter. The definitions are as follows:

Brinell Hardness is a "hardness number" as determined by a Brinell hardness tester which measures the depth of penetration by a penetrator under certain load conditions. Other hardness numbers include Rockwell, Shore and Vickers.

Creep is a gradual extension under a constant stress. Creep testing is performed by a static test over a long period of time.

Crystal is a physically homogenous solid in which the constituent atoms are grouped in a three-dimensional pattern which is repetitive in nature. Crystals are the building blocks of metals and are the basis of study in physical metallurgy.

Dynamic Test is a procedure which utilizes repeated or fluctuating stresses and is used to determine fatigue failure where the test piece is subjected to a large number of stress reversals.

Etching is a process of revealing structural details by preferential attack of reagents (chemical agents) on the polished exterior surface of a metal specimen.

Grains are microstructures composed of individual crystals in a metal.

Inclusions are particles of non-metallic substances which are mechanically entrapped or formed during solidification, or by subsequent reaction within the solid metal.

Microstructure is the structure of metals including grain formations and crystals as revealed by examination of polished and etched metal samples under a microscope.

Normalizing is a heat treatment process usually applied to steel castings and forgings to improve their structures and to relieve stresses which were induced by hot-working or forging the metal.

Permanent Set is the permanent deformation of a metal specimen induced by a mechanical destructive test.

Reduction of Area refers to the difference between the original cross-sectional area of a metal specimen and that of the smallest area at the point of rupture in a tensile test. It is stated as a percentage of the original area.

Soaking is holding steel at an elevated temperature for the purpose of obtaining uniformity of temperature throughout a metal specimen.

Development of Metal Testing in Industry

Metal testing has developed through an early process of trial and error. Industry did not reach its present level of refinement until just a few years ago. The rapid advance of technology in the last two decades not only gave birth to modern metal testing procedures but also made testing imperative. Many of the plans of today's engineers could not be utilized were it not for the availability of materials capable of carrying out those plans. Also, if the available materials do not possess the desired properties, materials which do can be developed through the use of metal testing. Many of today's so-called "exotic" metals and wonder materials have been developed through testing procedures. Material testing, in all of today's metals related industries, plays a vital role in research and development. However, this was not always so. On the subject of the development of modern industrial materials, Patton stated:

> The rapid increase in the number and variety of industrial materials is explained in part by the increasing demands made upon these materials. A hundred years ago, metals were required to have only the properties of reasonable tensile strength, reasonable ductility, and sufficient softness for such machining operations as punching and drilling. Nowadays, if a new metal is offered to the market,

> a wider range of requirements is imposed, including such qualities as weldability, machinability, corrosion resistance, controlled grain size, close tolerance on dimensions, fatigue resistance, hot strength, suitability for low temperature operation, plasticity, vibrational damping capacity, suitable electrical and magnetic characteristics, low neutron absorption for nuclear work, low vapor pressure for aerospace applications, impact and wear resistance, and many more (10, p. 4).

Metal testing has come a long way from the old days when the only tests available were primitive forms of the file test or the ultimate success or failure of a part.

The testing and inspection of parts has become increasingly important to modern industry. Greater equipment loads and operating speeds are making it imperative that fatigue cracks and other flaws in parts be detected before they can result in possible trouble involving equipment failure, resultant expense, delay, and injury to personnel. In many industries, the testing of parts and materials is commonly known as "quality control." Quality control is divided into several categories including destructive testing and non-destructive testing which have been previously defined (5, p. 438). Every industry which deals with the production of materials, development of a product, or assembly of a product on a mass-production basis will probably have a quality control department within the industry. However, there are now many independent testing facilities available which serve the testing needs of many smaller industries. Materials testing not only plays an integral role in many of today's industries but is developing into a separate service industry of its own.

## Types of Metal Tests

There are several types of metal tests. In fact, there are often several separate tests for each mechanical property. One source divides metal tests into three groups which are as follows: (1) Tests that are designed to simulate conditions of service, (2) destructive tests which have been designed to allow a study of the behaviour of materials under controlled conditions, which are not necessarily related to service conditions, and (3) nondestructive tests. The first of these tests is usually expensive, slow, and generally requires elaborate equipment. The third grouping does not concern this study as previously pointed out. It is the second group with which this study is concerned. These tests deal with the determination of the eight mechanical properties discussed previously. They have one distinct disadvantage in that they are destructive and, with the exception of some hardness tests, cannot be performed as a routine test on components going into service (9, pp. 99-100).

Another source classifies types of tests somewhat differently. According to Nutt, the tests that are in most common use today for determining properties of materials are as follows:

(1) structural-stability tests which include tensile, impact (Charpy and Izod), hardness (Brinell, Rockwell, Vickers, and Shore), ductility in rupture, and metallographic examinations; (2) surface-stability tests which include corrosion, metallographic, and impact tests; (3) load-carrying ability tests which include tests for tensile, creep, rupture, creep-rupture, and relaxation; (4) fatigue tests; (5) impact tests; (6) thermal expansion tests; (7) hot workability tests; and (8) hot hardness tests (8, pp. 284-285). Nutt further stated:

> Tests made on materials are, for the most part, made for the purposes of establishing reproducibility, so they cannot be considered as being fundamental. The main purpose of these tests is to determine accurately that the material in question meets some specification which may be empirically related to a certain application. Very few laboratory tests have been designed that will reproduce actual conditions in service. As an example, all laboratory tests for evaluating types of strength (tensile, yield, creep, rupture time, relaxation) are based on uniaxial tensile stresses, whereas in service, very seldom are stresses all in a single direction. It should also be understood that all tests and their results are statistically distributed. In other words, there is no such thing as a true tensile strength, a true creep strength, or an exact rupture strength; instead, there is a range of values one may expect to find in making duplicate tests. This is why the so-called factor of safety is introduced according to which the reported strength values obtained are divided by a realistic number, such as four or five, for purposes of design calculations in order to be on the safe side (8, p. 284).

There are various ways of classifying types of tests. There are a limited number of tests which perform only certain specified functions. Therefore, it does not really matter how they are classified so long as one understands their principles of operation and how they are used.

## Methods of Testing Metal

There are perhaps more tests for determining the hardness of a metal than for any other property. These range from the very simple to the rather complicated. The two simpliest methods for determining hardness are the scratch test and the file test. The scratch hardness test is a method of measuring relative hardness by determining whether or not one material will scratch another. One scratch hardness scale in use today is the "Mohs Scale" which rates very soft powder with a hardness of 1 and diamond, which will scratch all other materials, with a hardness of 10 (1, pp. 21-22). In the case of the file test, it is possible to make a rough estimate of the hardness of steel by using the arris of a file. The flat surface of the file should not be used because the teeth might be ruined. Table I shows how to approximate the hardness property of a metal with a file test.

TABLE I

DATA FOR ESTIMATING HARDNESS OF STEEL
WITH A FILE (7, p. 460)

| Rockwell Hardness Number | Action of File on Steel |
|---|---|
| 20. . . . . . . . . . . . . . . . . . . | File removes metal easily with slight pressure. |
| 30. . . . . . . . . . . . . . . . . . . | File starts to resist cutting metal. |
| 40. . . . . . . . . . . . . . . . . . . | File cuts metal with difficulty. |
| 50. . . . . . . . . . . . . . . . . . . | File barely cuts metal with great difficulty. |
| 57. . . . . . . . . . . . . . . . . . . | File glides over metal without cutting. |

One testing instrument measures hardness by resistance to pressure in what is referred to as an indentation test. These tests are the most commonly used in engineering because they are simple to perform. In these tests, hardness is referred to as the resistance to plastic deformation by an indentor. This involves forcing an indentor into the surface of the metal specimen under test and then basing the hardness value either upon the surface area of the impression or upon the depth to which the indentor enters the material. The Brinell Hardness Testing Machine, the Firth Brown Hardometer, and the Vickers Hardness Testing Machine all produce hardness values based upon surface area of the impression.

In the Brinell system and in the Firth Brown Hardometer, a hardened steel ball is used as the indentor. The Vickers system uses a diamond indentor which gives a better appraisal of the hardness of high-hardness metals because steel balls tend to deform under great pressure. The

Rockwell Hardness Testing Machine establishes hardness values based upon the depth of penetration using a steel ball or a diamond cone (6, pp. 57-58). A diamond indentor which makes an impression in the shape of a parallelogram, having one diagonal about seven times as long as the other, is called a "Knoop" indentor. The Knoop indentor is used in the Tukon Micro Hardness Testing Machine, which is similar to the Vickers, but does not make as deep an impression. The Tukon system is used in the testing of very thin materials. It can also be used in determining the hardness of small diameter wires and non-metallic inclusions. The Tukon performs well on brittle materials such as glass and minerals that would crack under the pressure of other testing machines (8, pp. 316-317).

Another form of hardness testing instrument measures the height of rebound of a diamond-tipped weight which is allowed to fall on a metal specimen from a height of ten inches. The most common example of this type is the Shore Scleroscope Hardness Testing Machine. Since hard metals have a higher resiliency due to a lack of plasticity, the weight will rebound to a higher distance than on softer metals. The scleroscope is used primarily because of its portability (8, pp. 315-316). The Monotron is another useful hardness testing machine which measures the load in kilograms required to penetrate the material under test. The Monotron utilizes the depth of impression instead of the pressure as the constant value in the test. Because each specimen is subjected to the same amount of work hardening, irregardless of the initial hardness of the material, a wider range of materials can be tested with the Montron without making any change in the penetrator or the methods of the test (1, pp. 25-26).

The latest form of a hardness testing device is ultrasonic and is called the "Sonodur". It has appeared on the market very recently and its official name is the Ultrasonic Microhardness Tester. This machine is almost completely electronic which makes its readings very exact. On its method of operation, Allen stated:

> This device, which is an indentation type microhardness tester with an electronic readout, employs the use of a diamond tipped magnetostrictive rod which is electrically excited to its resonant frequency. As the vibrating rod is brought into pressure contact with the surface of the material to be treated, the tip penetration is a function of hardness. The resonant frequency of the rod increases with penetration and the frequency change is displayed on the readout meter in terms of hardness. Thus a shift in frequency of the vibrating rod is a linear function of hardness (1, p. 26).

The Sondur will more than likely gain a position of increased importance among hardness testers in the future.

The hardness values associated with each form of hardness tester are read from a corresponding scale. The values may be easily converted into another scale by use of a conversion chart.

The toughness of a metal is tested by impact. The most common impact testing instrument is a pendulum type device which uses the "notched bar" principle of impact testing. The behavior of metals under impact loads, or shock, may often be entirely different from their reaction to loads slowly applied. There are two recognized tests in which notched specimens are fractured by a swinging pendulum. These two tests are called the Izod and the Charpy. The British Izod Machine holds the test specimen vertically at the base and the top half is broken off by a heavy pendulum. The amount of energy absorbed in so doing is calculated from the lessening of the normal arc of the pendulum after the snapping of the test piece (2, p. 378). The American made Charpy calculates its values on the same principle. It holds the test piece by its ends in a horizontal position. The specimens differ in that the Izod machine uses a cantilever-type while the Charpy uses a beam-type test piece. The Izod utilizes a "V" notch cut off center on the specimen; whereas, the Charpy uses a keyhole type notch cut directly in the middle of the test specimen. The energy required to fracture the specimens in both tests is measured in foot-pounds.

The most versatile of all testing machines is a tensile testing machine, of which there are several suitable makes. They are used to obtain information about static mechanical properties including ductility, tensile strength, proportional limit, modulus of elasticity, elastic limit, resilience, yield point, yield strength, and breaking strength. The tensile test is well standardized and may be either mechanically or hydraulically operated. All tensile testers consist of three main components which include a device for straining the specimen, a device to indicate the load applied to the specimen, and a gauge called an "extensometer." The extensometer measures strain over that part of the metal specimen in which strain is essentially uniform (1, p. 30). Extensometers are highly sensitive as they must be extremely accurate when measuring extension or elongation. The main types must depend either upon a micrometer screw measurement, an optical method, or direct reading upon a dial gauge (4, p. 139).

Specimens used in the tensile test are machined to a standard size which is usually round or flat. The specimen gauge length is marked with prick punch marks and cross-sectional area of the reduced section is then measured. If a stress-strain diagram is to be plotted, an extensometer is attached to the specimen after the specimen has been secured in the grips of the machine. A heavy load is applied to seat the specimen in the grips and the extensometer is set at zero. As the load is increased, both the load and the elongation of the specimen is recorded (1, pp. 30-31). A stress-strain diagram may then be plotted from the data. Figure 1 indicates a typical stress-strain diagram.

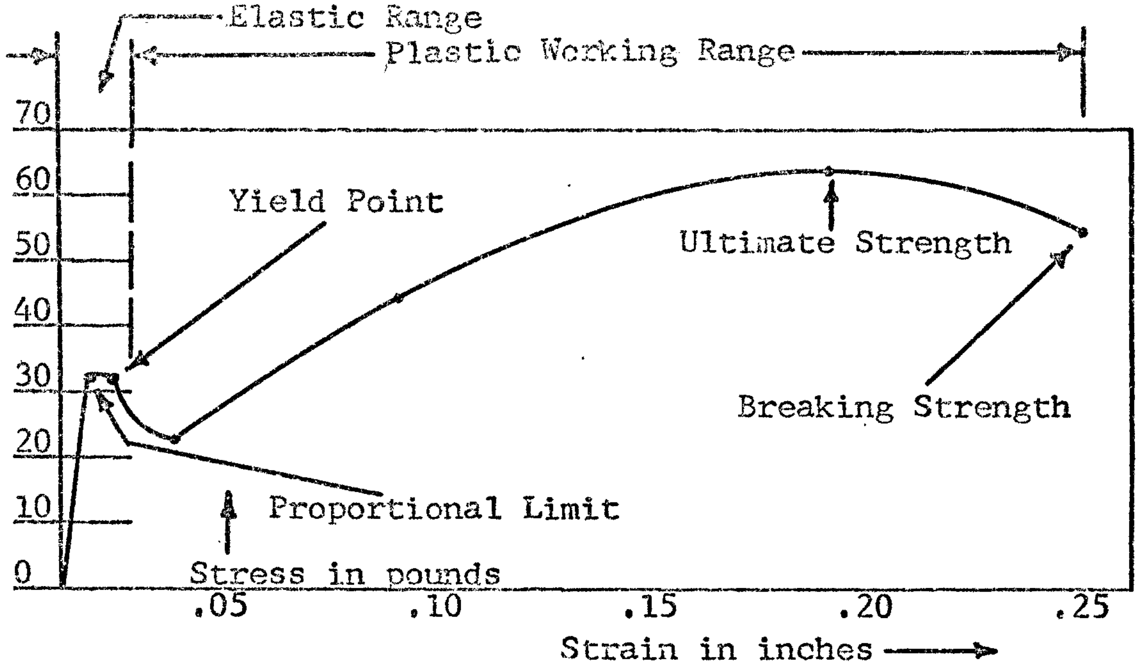


Fig. 1 -- Typical Stress-Strain Diagram for Low-carbon Steel (1, p. 32).

The straight line of the curve (portion from 0 to 32 pounds) shows the elastic properties of the material under test. The proportional limit is the point at which Hooke's Law no longer applies. The elastic limit is esentially the same as the proportional limit. The stress-strain ratio or slope of the initial straight portion within the elastic region of the curve is known as "Young's Modulus" or the "Modulus of Elasticity", which is a measure of stiffness and is the ability of a metal to resist deflection. The area under the curve leading up to the elastic limit is referred to as the "Modulus of Resiliency." This is a measure of the ability of a metal to quickly return to its original shape after the occurrence of deformation. As the strain induced on a metal specimen continues beyond the yield point, a corresponding increase in stress occurs up to a maximum value. This is the highest point on the curve and is known as the "Ultimate Tensile Strength." If the specimen is strained beyond the ultimate strength point, it will fracture. The stress at which this occurs is known as the breaking, fracture, or rupture strength (1, pp. 31-35).

Another test to determine strains uniformly distributed in the compression test. This test is not widely used because of the difficulty in obtaining accurate results on ductile material. The compression test is affected by compression instability and by friction restraint between the ends of the test piece and the faces of the compression machine. The results of this test are important in the design of structural members subjected to compressive rather than tensile stresses (4, p. 154). Twisting stresses can be determined and evaluated through use of a torsion tester. This testing device can determine the ultimate torsional strength of a metal specimen from which torque-twist curves can be plotted which are similar to stress-strain curves in a tensile test. The test pieces are placed in a machine which twists the specimen until it breaks (4, pp. 154-155). The torsion test is useful for testing parts such as axles, shafts, twist drills, and couplings. It is also useful for the testing of brittle materials.

There are several types of tests for determining the ductility of metals. A bend test is a simple test of ductility that does not require special equipment or a specially shaped test specimen. The metal under test is bent with the aid of a former and must, after bending through a specified angle, be unbroken and free from cracks on the outside surface which are visible to the unaided eye. Bend tests for sheet metal can be classified into a single bend and reverse bend tests. Basically, in the single bend test, the specimen is bent through a certain angle one time. In the reverse bend test, a specimen is bent through a specified angle in one direction then rebent to the same angle in the reverse direction. The cupping test is another ductility test that is used on metal that is to be pressed into shape. The Erichson Test is a common cupping test in which the metal, in sheet form, is pressed into a die by a screw-operated punch. The operation continues until fracture occurs and the depth of the cup at the point of fracture is called the "Erichson Value." This test is not regarded as being as discriminating as tensile and bend tests and is not yet recommended by all testing organizations as a test for specification purposes (6, pp. 60-61).

The effects of fatigue on a metal can be disastrous if not anticipated prior to failure. The start of a crack due to fatigue is not always easy to identify. Cellitti and Carter stated:

> Failure by fatigue is a continuous fracturing process which starts at the weakest point and progresses at a rate dependent upon material bulk properties, conditions of applied stress, and material quality. Also of considerable import are plastic and elastic strains associated with loading conditions (3, p. 226).

When a specimen is broken in a tensile tester, a certain stress is required to cause that fracture. However, that same specimen would fail under a much smaller stress if subjected to a cyclic or fluctuating load. Allen's statement follows:

> Metals consist of minute crystals with planes of slip oriented in many directions. Sufficient stress will cause slipping to occur on planes within the individual crystalline planes. At first this slipping may not cause harm, but continued repeated slipping causes minute cracks to form and spread until the cross section of a member is so reduced that it will no longer support the applied load (1, pp. 38-39).

All such physical failures in metal are known as "fatigue failures." The "fatigue limit" or "endurance limit" is the maximum stress a metal will withstand prior to fracture for a specified number of stress cycles and is more important in the design of parts than tensile or yield strength. The three most common fatigue tests are the rotating-beam, vibrating-beam, and the tension-compression test. All fatigue testing machines include (1) a driving mechanism, which may be mechanical, hydraulic, or magnetic for applying repeated cycles of stress to a metal specimen, (2) a gauge for measurement of the maximum and minimum stresses applied during a cycle, (3) a device for counting the number of cycles of stress applied, and (4) a means of terminating the test automatically when the specimen fractures (1, p. 39). The Wöhler Reverse Bend Fatigue Tester is regarded as a very common machine in which a specimen is held in a chuck and rotated. A load is applied at the free end of the specimen and the rotation produces a reversal of bending (6, pp. 63-64).

Constant stress applied over a long period of time may gradually deform and fracture a material. This gradual extension is called "creep" and temperature has a significant effect upon it. Non-ferrous metals will creep at room temperature, but steels will not start to creep until a temperature of 500 degrees Centigrade is reached. Materials to be creep-tested are machined to a standard size and tested in simple tension under constant load at elevated temperatures (6, p. 61). The results of the test are in the form of four diagrams involving stress, strain, time, and temperature which relate to how a certain material will perform at a certain expected temperature when varying amounts of stress are applied to it. This information is of considerable value in engineering design.

Hardenability testing, not to be confused with hardness testing, is of significant importance in the steel industry. It was brought to the attention of steel manufacturers that different lots of steel, which have the same chemical analysis and which are produced by the same process, would sometimes display different hardening characteristics. This is of great concern to steel manufacturers. Therefore, experimental tests were developed to help in evaluating steels in terms of their hardenability, which is the relative ability of a steel to be hardened by quenching. Two common tests in use today are the Jominy End Quench Test and the Hardness Traverse or Hardness Penetration Test. Both involve heating, quenching, and then comparing results of data. From these tests, one solid principle has surfaced. This principle states that all points on any steel part will be of equal hardness provided that they are cooled at the same rate (1, pp. 43-50).

Other forms of destructive tests include corrosion testing, grain size testing, spark testing, macroscopic, and microscopic testing. Corrosion testing involves introducing a specimen to various atmospheric conditions, liquids, chemicals, or gases to determine how a metal will react under these different influences. Grain size tests are made to determine the grain sizes of different metals. Grain size is known to effect certain properties of the metals. These tests usually involve carborization, polishing, etching, and microscopic examination. Another method is to harden, quench, and then fracture by impact to observe internal grain structure. Both forms are widely used. Spark testing is a simple method of classifying steels according to their chemical composition by visual study of the sparks formed when the steel is held against a high speed grinding wheel. It has been noted that each grade of steel has its own particular characteristic spark pattern, which is easily identified. An experienced observer can classify steels very close to their actual chemical composition (1, pp. 50-56). Microscopic examination is carried out with the aid of a low-power magnifying glass and with the use of etching chemicals or reagents. Many flaws can be discovered by this rather simple form of examination including cracks, porosity, basic unsoundness, inclusions, segregates, and flow-lines. Therefore, certain determinations about metal can be made involving minute structural flaws without the aid of a microscope. With the use of a microscope, however, it is possible to observe specimens in greater detail than it is with a handglass. The microscope is of such value, it is now a basic instrument in all metallurgical laboratories (8, pp. 295-303).

The types and methods of tests discussed in this chapter were of the utmost importance in the development of the curriculum. These tests are included in most of the metal laboratories concerned with mechanical destructive testing.

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## CHAPTER IV

# STUDY OF METAL TESTING CURRICULA AT THE UNIVERSITY AND COLLEGE LEVEL

It was realized at the beginning of the study that curricula dealing with the mechanical properties of materials and metals testing is available at certain institutions throughout the country. To develop a curriculum in this area, it was necessary to understand the nature and organization of related course work offered at other institutions. Bulletins of various universities, senior colleges, junior colleges, and vocational institutions were studied to determine which had curricula dealing with metals testing, mechanical properties of materials, or both. A letter requesting information concerning their course work was drafted and mailed to various schools which had related curricula in the aforementioned areas. Results were received from two out-of-state universities, one Texas senior college, one Texas junior college, and one Texas vocational institution. The participating institutions are listed in Appendix E.

### Types of Courses Available at Certain Selected Institutions

After a study of the curricula synopses of the participating schools, it was possible to classify their course work into four types, which are as follows:

1. An engineering technology course geared to the mechanical or technical engineer in content and level of difficulty. This type of course stresses mathematics and analysis of data as well as experiments dealing with the mechanical properties of metal.

2. A materials science course designed to meet the needs of industrial arts or industrial education students and industrial engineers. This type of course deals with a study of various industrial materials and their properties and characteristics.

3. A welding technology course on the senior college level designed for the welding or metallurgical engineering student and a welding technology course on the junior college level geared to produce welding technicians for industry. In these types of courses are included the testing of welded joints and test plates. A discussion of metallurgical investigative techniques, mechanical and physical properties, and basic structure of matter was included at the junior college level.

4. An elementary metallurgy and metallography course offered at the junior college level for the technical vocational student. This type of course is generalized in nature as it covers many different areas of metallurgy.

There are probably other types of courses available dealing with the field of metals testing or mechanical properties of materials located at certain other schools, but the above were the only types which this study examined.

## Areas Emphasized

The areas emphasized are those major subject areas which were stressed in the course outline or syllabus of any of the participating schools. Many of these areas are duplicated in each syllabus; hence all areas emphasized as indicated by each syllabus are combined. This was done to avoid duplication of major subject areas and to provide a more meaningful presentation of data.

There was a wide variety of areas emphasized touching upon many facets of the metallurgical field. The areas emphasized as indicated by the participating schools are as follows:

1. The reduction and refining of iron
2. The alloy system
3. Heat treatments of steel
4. Fundamental shaping of metals
5. Alloying elements in steel
6. Non-ferrous alloys
7. Metallurgical investigative techniques
8. Structure of metallics
9. Physical and mechanical properties
10. Surface treatments of steel
11. Non-ferrous metallurgy
12. Metallurgical applications for the welding technician

13. Discussion and laboratory work dealing with types of bonding and cutting

14. The subjection of welded test plates to the tensile, bend impact, and hardness mechanical tests

15. The subjection of welded joints to various metallographical tests including microscopic examination and microstructure photography

16. The study of commonly used metals in industry

17. Extractive metallurgy

18. Properties of common ferrous and non-ferrous metals

19. The industrial applications of common ferrous and non-ferrous metals

20. Tool and high strength alloy steels

21. A technical study of various industrial materials including both solids and liquids

22. Report writing

23. The stress-strain curve and the determination of the mechanical properties of materials

24. Carbon steels

25. Analysis of plane stress problems

26. Mohr's circle analysis in plane stress problems

27. Generalized Hooke's Law

28. Photoelasticity

Each of the above major subject areas is given priority coverage in the curriculum of one or more of the participating schools. Those areas which fit the needs of the industrial arts student were given careful consideration for inclusion in the curriculum proposed by this study. The appropriate areas were included in a check list sent to industrial firms which is discussed in the following chapter.

## Organization of Course Work

The organization of course work, in most cases, followed the apparent areas emphasized as previously described. Each area of emphasis was taught as a section, and all the sections combined made up the course of study. This method of course organization was utilized by three of the participating institutions. These three schools together submitted a syllabus for four courses which constitute a majority of the samples received. As the organization of these courses follows the areas of emphasis, some of which have no direct relationship to this study, only those areas dealing with metals testing and mechanical properties are covered. The following is a synopsis of the course organization of the above three schools.

1. This is a synopsis of an engineering materials course and is a presentation of experiments performed in the laboratory. The experiments are as follows:

    a. Tension experiment
    b. Compression experiment
    c. Torsion experiment
    d. Hardness tests of metal
    e. Creep experiment

f. Fatigue experiment
g. Impact experiment
h. Stress concentration experiment of aluminum plate
i. Flexure of beam experiment
j. Combined loading experiment
k. Column buckling experiment
l. Photoelasticity (4).

The lecture portion of the above course consisted largely of mathematical analysis.

2. The following is a synopsis of a materials science course dealing with industrial materials. Only that part of the course dealing with metals is presented.

a. Materials for a technical civilization
b. Science of materials including matter, structure of molecules, and forces of attraction
c. The arrangement of atoms and molecules in crystal, molecular, and non-crystalline materials
d. Elastic and inelastic behavior
e. Structure of metals including the liquid state, crystal and grain development, microscopic and macroscopic structures, and imperfection
f. Comparative physical and mechanical property values involving specific gravity or density, tensile and compressive strengths, thermal expansion and conduction, electrical conductivity and resistivity, effects due to alloying and heat treatment. Also included in this topic are elastic, yield, plastic, elongation, hardness, and impact strength values
g. Ferrous and non-ferrous metals including American Society of Testing Materials (ASTM) numbering systems, American Iron and Steel Institute (AISI) alloys, and precious metals
h. Heat treatment problems
i. Powered metallurgy
j. Corrosion and corrosion phenomena
k. Designing for corrosion protection (3).

3. Presented here are two separate courses from a technical institute. Both are basic metallurgy curricula emphasizing welding technology. The first to be presented is

the more elementary of the two courses. Again, only that part of the course involving metals testing or mechanical properties is presented.

a. Hardness tests
b. Tensile tests
c. Impact tests
d. Guided bend tests
e. Microscopic examinations (2).

The second course is more advanced in nature, and the laboratory work presented here is more complete in its coverage.

a. Preparation and examination of metal samples with metallograph
b. Observation and recording of hardness, tensile strength, ductility, and microstructure of iron both cold-worked and recrystallized
c. Observe heat treated steel, stainless, aluminum, and copper.
d. Analyze steels using carbon analyzer
e. Produce welded joints by various methods and compare properties (2).

Unlike the programs of the above three schools, the remaining two organized their course work under specific topics. The major areas emphasized listed by these schools comprised broad subject areas. Their organization combines class room discussion and laboratory experiments and demonstrations. The following is a synopsis of the entire course organizations of the remaining two schools.

1. The following is a synopsis of an elementary metallurgy and metallography course offered at a local junior college. All subject matter is listed.

a. The structure of metals
b. Slip, plastic deformation, and recrystallization
c. Alloys and constitutional diagrams
d. Structures of iron and steel in the solid state
e. Iron ore and production of pig iron
f. Chemistry involved in the metallurgy of iron and steel
g. Cast iron and wrought iron
h. Steel
i. Steel production processes
j. Ingot practice
k. Working, shaping, and joining of iron and steel
l. Principles involved in the heat treatment of steel
m. Annealing, hardening, and tempering of steel
n. Surface hardening of steel
o. Alloy steels
p. Corrosion or rusting
q. Copper and copper alloys
r. Aluminum and aluminum alloys
s. Magnesium and magnesium alloys
t. Zinc
u. Control and testing
v. Foundry practice
w. Forming and finishing
x. Ultrahigh-purity metals (5).

2. Presented here is the course organization of a welding methods course. Illustrated slides are used throughout the course as instructional aids. Although metals testing was listed as a major area of emphasis, it is not listed under course organization. However, one week is devoted in the laboratory to the testing of one inch welded test plates. The course is organized as follows:

a. Introduction
b. Types of steel and their manufacture
c. Welding methods and processes
d. Review (1).

The data obtained from the participating institutions were useful in the organization of a check list which was mailed to various industrial firms. The check list was used as a means to develop the curriculum proposed by this study and is discussed in the following chapter.

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## CHAPTER V

## DEVELOPING A CURRICULUM IN INDUSTRIAL TESTING PROCEDURES

Many people working in industry have a need for a background in destructive testing as well as a knowledge of the mechanical properties of metals and other materials. These people include not only engineers but also designers, welders, machinists, fabricators, assemblymen, and others who deal with metals or metal products. Many industrial arts students go into industry fitting into a variety of jobs from management to production. It has been determined in the previous chapter that course work involving a certain amount of metal testing and mechanical properties does exist in various schools. Therefore, a precedent has been established for the development and inclusion of a curriculum involving industrial destructive testing procedures and the mechanical properties of metals in existing industrial arts programs.

To develop the curriculum, it was necessary to construct an instrument in the form of a check list, and to mail it to various industrial plants and testing firms. These firms are listed in Appendix F. The check list consisted of possible areas of importance to the proposed curriculum. The results of the tabulated data, obtained from the returned check lists, indicated which subject areas industry believed most important for inclusion in the curriculum. The participating firms also expressed their opinions on destructive testing in general. A large majority of the firms indicated they believed an educational gap exists in the area of destructive testing. Fifty-seven point two per cent expressed the opinion that colleges were placing no importance on destructive testing, while 85.8 per cent of the firms considered this form of testing to be very important. Therefore, it was the opinion of the majority of the firms that the needs of industry are not being met by colleges in this area of instruction. Also, 71.5 per cent of the firms indicated that they believed the long range value of destructive testing for their particular company will remain very important, and 42.9 per cent of them believed that the long range value will be very important for industry as a whole. Further, 57.2 per cent of the firms indicated destructive testing to be very important in relation to non-destructive testing and that this relationship probably will not change in the future. Seventy-one point five per cent of the firms considered a background in destructive testing to be very important when hiring new personnel.

Table II presents the levels of importance of major subject areas as indicated by the participating firms.

TABLE II

LEVELS OF IMPORTANCE OF THE MAJOR SUBJECT AREAS OF THE PROPOSED CURRICULUM AS INDICATED BY INDUSTRIAL FIRMS

| Major Subject Areas | Levels of Importance | | | |
|---|---|---|---|---|
| | Very Important | Important | Not Important | No Response |
| History of Metallurgy | 14.3% | 14.3% | 57.2% | 14.3% |
| Extractive Metallurgy | 0.0% | 28.6% | 57.2% | 14.3% |
| The Basic Structure of Matter | 71.5% | 28.6% | 0.0% | 0.0% |
| Hot and Cold Metalworking | 42.9% | 42.9% | 0.0% | 14.3% |
| Basic Mechanical Properties | 100 % | 0.0% | 0.0% | 0.0% |
| Chemical and Physical Properties | 42.9% | 57.2% | 0.0% | 0.0% |
| Properties of Non-Ferrous Metals | 28.6% | 71.5% | 0.0% | 0.0% |
| Production of Non-Ferrous Metals | 14.3% | 57.2% | 28.6% | 0.0% |
| Carbon and Alloy Steels | 28.6% | 71.5% | 0.0% | 0.0% |
| Alloys and Alloying Elements | 42.9% | 57.2% | 0.0% | 0.0% |
| Heat Treatment of Steels | 42.9% | 57.2% | 0.0% | 0.0% |
| Surface Treatment for Steels | 14.3% | 85.8% | 0.0% | 0.0% |
| Production of Ferrous Metal | 14.3% | 42.9% | 42.9% | 0.0% |
| Testing Procedures and Techniques | 57.2% | 42.9% | 0.0% | 0.0% |

The above table provides the data which could be used to develop the curriculum. The data emphasizes those areas which industry most often indicated as being very important or important.

The remainder of the instrument was concerned with specific metals, properties, and investigative procedures. Those items which industry considered valuable were included in the course development, and the items industry considered unimportant were omitted.

## Purpose of the Course

The purpose of the course is to familiarize the industrial arts student with various metallurgical destructive testing techniques and mechanical properties of commonly used metals. The objectives were selected on the basis of their application to the study of destructive testing procedures for ferrous and non-ferrous metals. They are as follows:

1. To develop an understanding of the basic structure of matter.

2. To acquaint the industrial arts student with the use of the microscope for purposes of metallographic examination as well as in specimen selection and preparation.

3. To develop an awareness and understanding of the mechanical properties of metals and to learn to compare and distinguish these from certain physical and chemical properties.

4. To develop an understanding of the relationship of mechanical properties to design criteria in the field of industrial arts.

5. To acquaint the student with the use and operation of various mechanical testing instruments and investigative procedures.

6. To familiarize the student with the properties and characteristics of commonly used ferrous and non-ferrous metals and to develop an appreciation of these metals.

7. To develop an understanding of the various heat treatments for steel and to be aware of the varying degrees of hardenability.

## Areas Emphasized

The data obtained from the instrument indicate which subject areas industry believes most important for inclusion in the curriculum. The areas so indicated should receive priority coverage in the course. The basic mechanical properties of metals are of the utmost importance and should receive extensive coverage in both classroom discussion and laboratory demonstrations. The methods of evaluation and determination of the mechanical properties in the form of destructive tests should be the main concern of the laboratory portion of the course. The dominant learning activity in the laboratory should be experiments conducted by the students either individually or in groups following exact procedure as set forth by a laboratory manual or by the instructor. Other subject areas receiving emphasis in the curriculum are as follows:

1. The basic structure of matter
2. Properties of non-ferrous metals
3. Carbon and alloy steels
4. Alloys and alloying elements
5. Heat and surface treatments for steels
6. Hot and cold metalworking

Each of the above subject areas was considered either very important or important by the participating industrial firms.

The metallurgical investigative techniques covered by the course should include common mechanical destructive testing machines and procedures, corrosion tests, hardenability quench tests, macroscopic and microscopic observations. The student should be introduced to the various mathematical formulae, curves, graphs and charts associated with the evaluation of the various mechanical properties.

## Course Organization

Since the proposed curriculum is a laboratory course, there should be two mediums of instruction which are lecture and laboratory experiments and demonstrations. The course organization is concerned with major subject or topic areas to be covered in lecture. These major areas of instruction include:

1. Introduction to the course, which includes (a) course objectives and (b) a historical background of metallurgy from an art to a science.

2. The basic structure of matter, which involves (a) atomic structure, (b) crystallization, (c) the space lattice, (d) crystals and grain structure, (e) slip and plastic deformation, and (f) recrystallization and grain growth.

3. The basic properties of metal, which are divided into three topics. The first of these is elastic and in-elastic behavior, which included (a) elastic action, (b) plastic action, (c) creep, (d) stress, (e) strain, (f) stress-strain curve, (g) hardness, and (h) strength. The second topic is comparative physical and mechanical property values, which involves discussion of (a) specific gravity or density, (b) the relationship of yield values to the stress-strain curve, (c) elongation, (d) tensile and compressive strengths, (e) rupture and fatigue strengths, (f) thermal expansion, (g) thermal conductivity, (h) impact strength, and (i) toughness. The third topic under basic properties is a discussion of various commonly used non-ferrous base metals and alloys, including (a) aluminum, (b) magnesium, (c) copper, (d) nickel, (e) chromium, (f) bronze, (g) brass, and (h) stellite.

4. Carbon and alloy steels which are also divided into three topics. The first topic considered is the

classification of straight carbon steels, which includes (a) low-carbon, (b) medium-carbon, and (c) high-carbon steels and their uses. A coverage of alloy steels is the second topic, and this includes (a) alloying elements and their effects on steel, and (b) high-speed and special alloy steels. The third topic is a coverage of various surface treatments for steel, which includes (a) pack, gas and liquid carburdizing, (b) cyaniding, (c) nitriding, (d) hot dip coatings, (e) sprayed coatings, and (f) clad coatings.

5. The effects of corrosion and various heat treatments on steel which are divided into two topics. The first topic consists of a discussion of various corrosive chemicals and atmospheric conditions which have an adverse effect on metal. The second topic deals with different heat treatments, which include (a) annealing, (b) normalizing, (c) tempering, (d) case hardening, (e) residual stresses and the relief of same, (f) hardenability evaluation, and (g) effects of elevated temperature on various metals.

6. A discussion of hot and cold metalworking, which includes (a) various hot metalworking techniques, and (b) various cold metalworking techniques.

7. The relationship of mechanical testing and properties to design criteria, which should be stressed throughout the course.

The above major subject areas should be presented in the lecture portion of the course. A working knowledge of the above areas should be necessary for the completion of the laboratory assignments.

Laboratory Procedures and Tests

The laboratory portion of the course is most important for it is here that the student should receive experience in testing and be able to put lecture theory into actual practice. The following areas of instruction in the laboratory are

1. Instruction on the uses and operation of the microscope and low-power handglass for metallographic examinations.

2. Instruction on the use of various etching reagents, and specimen selection and preparation, or purchase.

3. Laboratory demonstrations of the basic properties of metals.

4. Macroscopic and microscopic observation of the grain structure of each metal covered in the curriculum.

5. Instruction on the various metallurgical investigative techniques. Destructive tests include (a) the Charpy and Izod impact testers, (b) the Rockwell, Brinell, Vickers, Tukon Micro and Shore hardness testers, (c) the fatigue tests, (f) the tensile test, (g) the compression test, and (h) the torsion test.

6. Student experiments involving all tests, procedures and observations covered by the curriculum. Correct scientific procedure should be followed in every report, and the experiments should continue throughout the semester.

7. Laboratory demonstrations on corrosion tests, hardenability quench tests, and heat treatments.

The above procedures and tests should be covered in the laboratory portion of the course. Specimens of each metal considered in the curriculum should be obtained by the students for test purposes. Steel samples should be tested after undergoing each heat treatment to evaluate property change. The laboratory experiments should include every test available in the laboratory if possible, as well as all investigative procedures and macroscopic and microscopic observations covered by the curriculum. The time allotted to each area, both in lecture and laboratory, is left up to the discretion of the instructor or in accordance with existing policies. A description of the proposed course in outline form is located in Appendix D.

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# CHAPTER VI

## SUMMARY, FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

### Summary

The problem of this study was to develop a curriculum in industrial destructive testing procedures for ferrous and non-ferrous metals and to organize the curriculum at the university level. Primarily, the curriculum deals with the mechanical properties of metals and their determination and evaluation by means of certain metallurgical investigative techniques.

The mechanical properties and inherent characteristics of certain ferrous and non-ferrous metals were discussed, and a brief historical background of the metals industry and metals testing in industry was given. Types of destructive tests and metallurgical investigations performed in industry were discussed along with their methods of operation.

To provide an insight into the actual development of the curriculum, sample curricula from other institutions of higher learning were studied. Bulletins listing course work offered at various universities, senior colleges, junior colleges, and vocational technical institutions were examined to determine which have course offerings dealing entirely or in part with metals or materials or materials testing, mechanical properties of materials, metallography, or elementary metallurgy. Those institutions which had course work in any of the above areas were contacted by means of a letter and were asked for certain information concerning their curriculum. The information requested consisted of course outlines, materials distributed to students, or a syllabus of the course. The data received from these institutions were studied to determine the types of courses available, the areas emphasized, and the organization of their course work.

A check list was also utilized in obtaining data for the development of the curriculum. It contained listings of possible subject areas of emphasis, various investigative procedures and tests, and questions seeking general information concerning destructive testing. The subject areas included in the check list were obtained from the study of existing curricula and from current literature in the field. The check list was mailed to eleven industrial firms and testing organizations located throughout the country, and they were asked to indicate their opinion as to the level of importance of each item listed by the check list. In keeping with the definition of industrial arts, those items industry indicated to be very important or important most often were given primary consideration in the development of the curriculum.

A curriculum involving industrial destructive testing procedures for ferrous and non-ferrous metals was developed. The proposed curriculum consists of major subject areas, sub-topics, demonstrations, metallurgical investigative procedures, and mechanical tests which should be included in the course work. The curriculum is divided into classroom discussion and laboratory work and is designed to fit into an existing industrial arts program at the university or senior college level.

## Findings

From this study, the following findings are presented.

1. The types of metal tests were classified according to varying criteria and their limitations were usually specified to the evaluation of only one mechanical property.

2. Of the sample course work received from participating institutions, there were four basic types which included (a) an engineering course, (b) a materials science course, (c) an elementary metallurgy course, and (d) a welding technology course.

3. The areas emphasized, as listed by each course, usually depended upon the type and nature of the course. There were, however, certain areas which were emphasized in each course.

4. The sample curricula were largely organized according to major areas which were emphasized by the course.

5. The majority of the industrial firms participating in the study believed that an education gap exists in the area of destructive testing.

6. The majority of the firms considered destructive testing to be very important.

7. The majority of the firms expressed the opinion that destructive testing will remain very important in the future as far as their particular companies are concerned and will remain important for industry as a whole.

8. The majority of the firms considered a background in destructive testing to be very important in relation to the hiring of new personnel.

9. The firms considered the most important areas of instruction to be as follows: (a) the basic structure of matter, (b) hot and cold metalworking, (c) basic mechanical properties, (d) physical and chemical properties, (e) the properties of non-ferrous metals, (f) carbon and alloy steels, (g) alloys and alloying elements, (h) heat and surface treatments for steel, and (i) metallurgical investigative techniques.

10. The firms considered aluminum, magnesium, copper, nickel, bronze, and brass to be the most important non-ferrous base metals and alloys for study in the proposed curriculum.

11. The firms considered the Brinell, Vickers, Rockwell, and Tukon Micro to be the most important hardness tests.

12. The firms considered the tensile test to be very important in the evaluation of stress, strain, elasticity, and strength.

13. The firms considered microscopic examinations to be very important to the curriculum.

## Conclusions

The following conclusions were derived from a study of the findings.

1. Metallurgy has been in the past, and will continue to be in the future, very important to the civilization of mankind. This might infer that metallurgy is vital to the advancement of modern technology.

2. The classification of metal tests may vary, but the methods of testing metal through the use of destructive testing devices will remain essentially the same in the foreseeable future.

3. Varying degrees of emphasis were placed on metals testing at the different institutions of higher learning which participated in the study. This is probably due to varying philosophies as to the importance of metals testing.

4. Course work at various institutions was organized essentially the same which was a division into sub-topics of

all the major areas emphasized by the curriculum. This probably occurred to increase the ease of presentation and uniformity of organization.

5. At the present time, colleges are not placing enough importance on destructive metal testing to meet the personnel needs of industry. Perhaps this is due to a recent increase in industrial personnel needs in the field of material testing.

6. A curriculum which devotes a heavy concentration of effort to the presentation of destructive metallurgical investigative techniques and to the mechanical properties of metal would appear to be an ultimate program.

## Recommendations

The following recommendations are based on the findings and conclusions.

1. The major areas emphasized and sub-topics listed by the proposed curriculum should be retained if the course objectives set forth in the preceding chapter are to be accomplished.

2. Concerning the student experiments, a notebook should be kept on the observations, findings, and conclusions of each experiment. This is due to the possible quantity of material which will be collected during the semester by each student and could represent an organizational aid.

3. If time permits, other metals such as titanium, which have a vital importance to industry, should be included in the curriculum.

4. A textbook and laboratory manual should be adopted for use in the curriculum.

5. The curriculum should stress relationship of tests and mechanical properties to design criteria in industrial arts.

6. The curriculum should be continuously modernized and up-dated to keep abreast with new trends as they occur in industry.

7. A study should be made dealing with the development of a curriculum in non-destructive testing procedures and metallographic investigative techniques.

8. An inquiry into laboratory facility requirements should be made concerning the curriculum proposed by this study.

9. Consideration should be given to the proposed curriculum for implementation into the present programs of various departments of industrial arts at university level.

10. If the departments are not in a position to implement the program at the present time, major aspects of the curriculum might be introduced in existing metal-working courses.

APPENDIX A

January 23, 1971

Dear Sir:

I am a graduate student in industrial arts at North Texas State University, and am currently engaged in research dealing with curriculum development in mechanical destructive testing procedures for ferrous and non-ferrous metals. In order to conduct the study, it is necessary to collect materials from certain select colleges and universities which offer course work in this area.

I should like to request from you printed or mimeographed materials such as a course outline or a syllabus concerning your curriculum on metals testing. Enclosed is a card on which you may indicate (1) the availability of materials, (2) anonymity, and (3) materials and postage charges, if any. Should the materials be readily available and you wish to forward them without delay, it would certainly be appreciated.

May I thank you in advance for your speedy cooperation and assistance, and I trust that I may hear from you soon.

Sincerely yours,

Michael R. Geary
Graduate Student

Sponsor:

Jerry C. McCain, Professor
Metals Division
North Texas State University

MRG/dm

Enclosure: Card

APPENDIX B

February 11, 1971

Dear Sir:

I am a graduate student in industrial arts at North Texas State University, and am currently engaged in research dealing with curriculum development in mechanical destructive testing procedures for ferrous and non-ferrous metals. In order to complete the study, it is necessary to send out a checklist to certain select industrial concerns who deal with metal testing. The purpose of the checklist is to determine what subject areas will receive priority coverage in the curriculum.

Enclosed is a copy of the checklist which has been designed to consume as little of your time as possible, and yet provide the information necessary for the study. If you have suggestions concerning items listed on the checklist, please feel free to add or delete information where you deem appropriate.

Also enclosed is an envelope for your convenience in returning the checklist to me. You can be assured of complete anonymity as your answers will be presented in tabular form. Thank you very much for your participation in this study.

Sincerely,

Michael R. Geary
Graduate Student

MRG/dm

Enclosures

APPENDIX C

# A DEVELOPMENT OF CURRICULUM IN INDUSTRIAL TESTING PROCEDURES FOR FERROUS AND NON-FERROUS METALS

The information obtained from this instrument will be used to develop a curriculum dealing with industrial destructive testing procedures. The curriculum will consist of one three hour course, and will be added to the existing industrial arts program at North Texas State University. Your help in making this study possible is greatly appreciated. In order to make this check list as simple as possible, all of the questions can be answered with a check mark in the appropriate column. Please feel free to make any additional comments.

| Questions concerning subject matter, areas of emphasis, and general information involving the proposed curriculum. Additional space is provided for comments. | Levels of Importance | | |
|---|---|---|---|
| | Very Important | Important | Not Important |
| **General Information** | | | |
| 1. What is your opinion of a course in destructive testing for mechanical properties being offered at a four-year university to students working toward a non-engineering degree ? | | | |
| 2. In your opinion, and to the best of your knowledge, how mjch importance are colleges placing on destructive testing at the present time ? | | | |
| 3. How does your company feel about destructive testing? | | | |
| 4. In your opinion, what will be the long-range importance of destructive testing for your company? | | | |
| 5. What is your opinion of the long-range importance for industry as a whole for destructive testing ? | | | |

| Questions Continued | Levels of Importance V.I. | I. | N.I. |
|---|---|---|---|
| 6. In your opinion, how will destructive testing rate in relation to non-destructive testing in the future? | | | |
| 7. How does your company evaluate a background in destructive testing in relation to the hiring of new personnel? | | | |
| 8. Concerning the curriculum, please indicate how you feel each of the following major subject areas should rate for inclusion in the course: | | | |
| a. History of metallurgy. . . . . . . | | | |
| b. Extractive metallurgy. . . . . . . | | | |
| c. The basic structure of matter. . | | | |
| d. Hot and cold metalworking. . . . | | | |
| e. Basic mechanical properties. . . | | | |
| f. Physical and chemical properties | | | |
| g. Properties of non-ferrous metals | | | |
| h. Production of non-ferrous metals | | | |
| i. Carbon and alloy steels. . . . . | | | |
| j. Alloys and alloying elements . . | | | |
| k. Heat treatment of steels . . . . | | | |
| l. Surface treatments for steels. . | | | |
| m. Production of ferrous metal. . . | | | |
| n. Metallurgical investigative techniques . . . . . . . . . . . . | | | |
| o. Other (please specify): | | | |
| ________ | | | |
| ________ | | | |
| 9. What is your consideration of the following non-ferrous base metals and non-ferrous alloys for inclusion in the curriculum: | | | |
| a. Aluminum . . . . . . . . . . . . . . | | | |
| b. Magnesium. . . . . . . . . . . . . . | | | |
| c. Zinc . . . . . . . . . . . . . . . . | | | |
| d. Lead . . . . . . . . . . . . . . . . | | | |
| e. Tin. . . . . . . . . . . . . . . . . | | | |

| Questions Continued | Levels of Importance V.I. | I | N.I. |
|---|---|---|---|
| f. Copper. . . . . . . . . . . . . . . | | | |
| g. Nickel. . . . . . . . . . . . . . . | | | |
| h. Chromium. . . . . . . . . . . . . . | | | |
| i. Bronze. . . . . . . . . . . . . . . | | | |
| j. Brass . . . . . . . . . . . . . . . | | | |
| k. Babbitt . . . . . . . . . . . . . . | | | |
| l. Stellite. . . . . . . . . . . . . . | | | |
| m. Other (please specify): . . . . . . | | | |
| ______________ | | | |
| General Mechanical Properties | | | |
| 1. Concerning the properties of stress, strain, and elasticity, what is your opinion of the value of each of the following in relation to the curriculum: | | | |
| a. Tensile stress. . . . . . . . . . . | | | |
| b. Compressive stress. . . . . . . . . | | | |
| c. Shear stress. . . . . . . . . . . . | | | |
| d. Torsional and flexive stress. . . . | | | |
| e. Strain. . . . . . . . . . . . . . . | | | |
| f. Elasticity. . . . . . . . . . . . . | | | |
| g. Hooke's Law . . . . . . . . . . . . | | | |
| h. Young's Modulus . . . . . . . . . . | | | |
| i. Elastic limit . . . . . . . . . . . | | | |
| j. Proportional limit. . . . . . . . . | | | |
| k. Yield point . . . . . . . . . . . . | | | |
| l. Breaking point. . . . . . . . . . . | | | |
| m. Other (please specify): | | | |
| ______________ | | | |
| 2. Concerning the property of strength, how would you rate each of the following in relation to the curriculum: | | | |
| a. Tensile strength. . . . . . . . . . | | | |
| b. Compressive strength. . . . . . . . | | | |
| c. Fatigue strength. . . . . . . . . . | | | |
| d. Yield strength. . . . . . . . . . . | | | |
| e. Ultimate strength . . . . . . . . . | | | |
| f. Other (please specify): . . . . . . | | | |
| ______________ | | | |

| Questions continued | Levels of Importance | | |
|---|---|---|---|
| | V.I. | I | N.I. |
| 3. In your opinion, how much importance should the property of hardness be given in the curriculum ? | | | |
| 4. What is your opinion of the importance of toughness in relation to the curriculum ? | | | |
| 5. Concerning the property of plasticity, how would you rate the following in relation to the curriculum: | | | |
| a. Ductility . . . . . . . . . . . . . | | | |
| b. Malleability . . . . . . . . . . . | | | |
| c. Brittleness. . . . . . . . . . . . | | | |
| d. Other (please specify): | | | |
| Destructive Investigative Procedures | | | |
| 1. Concerning the evaluation of hardness, how would you rate each of the following tests: | | | |
| a. Scratch hardness test. . . . . . . | | | |
| b. File hardness test . . . . . . . . | | | |
| c. Brinell hardness test. . . . . . . | | | |
| d. Firth Brown Hardometer . . . . . . | | | |
| e. Vickers hardness test. . . . . . . | | | |
| f. Rockwell hardness test . . . . . . | | | |
| g. Tukon Micro hardness test. . . . | | | |
| h. Shore Scleroscope hardness test. | | | |
| i. Monotron . . . . . . . . . . . . . | | | |
| j. Ultrasonic Hardness Tester (Sonodur). . . . . . . . . . . . . | | | |
| k. Other (please specify): | | | |
| 2. Concerning the evaluation of toughness, what is your opinion of the following tests: | | | |
| a. Izod Impact Test . . . . . . . . . | | | |
| b. Charpy Impact Test . . . . . . . . | | | |
| c. Other (please specify): | | | |

| Questions Continued | Levels of Importance V.I. | I. | N.I. |
|---|---|---|---|
| 3. Concerning the evaluation of stress, strain, elasticity, and strength, what is your opinion of the following tests: | | | |
| a. Tensile test. . . . . . . . . . . . | | | |
| b. Compression test. . . . . . . . . . | | | |
| c. Torsion test. . . . . . . . . . . . | | | |
| d. Tension-Compression Fatigue . . | | | |
| e. Vibrating-Beam Fatigue test . . | | | |
| f. Rotating-Beam Fatigue test. . . | | | |
| g. Other (please specify): ________ | | | |
| ________ | | | |
| 4. Concerning the evaluation of plasticity, how would you rate the following tests: | | | |
| a. Bend test . . . . . . . . . . . . . | | | |
| b. Cupping test. . . . . . . . . . . . | | | |
| c. Other (please specify): ________ | | | |
| ________ | | | |
| 5. What is your opinion of each of the following miscellaneous tests and examinations for inclusion in the curriculum: | | | |
| a. Creep test. . . . . . . . . . . . | | | |
| b. Hardenability tests . . . . . . . | | | |
| c. Corrosion tests . . . . . . . . . | | | |
| d. Spark test. . . . . . . . . . . . | | | |
| e. Macroscopic examinations. . . . | | | |
| f. Microscopic examinations. . . . | | | |
| 6. Are there any properties, testing procedures, or subject matter which I have excluded that you feel would be of value to the course? | | | |

________________________________________

________________________________________

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## APPENDIX D

# PROPOSED SYLLABUS FOR A CURRICULUM IN INDUSTRIAL DESTRUCTIVE TESTING PROCEDURES FOR FERROUS AND NON-FERROUS METALS

### Lecture Subject Areas and Topics

A. Introduction
   1. Course objectives
   2. Historical background of metallurgy from an art to a science

B. Basic structure of matter
   1. Atomic structure
   2. Crystallization
   3. The space lattice
   4. Crystals and grain structure
   5. Slip and plastic deformation
   6. Recrystallization and grain growth

C. Basic properties of metal
   1. Elastic and inelastic behavior
      a. Elastic action
      b. Plastic action
      c. Creep
      d. Stress
      e. Strain
      f. Stress-strain curve
      g. Hardness
      h. Strength
   2. Comparative physical and mechanical property values
      a. Specific gravity or density
      b. The relationship of yield values to the stress-strain curve
      c. Elongation
      d. Tensile and compressive strengths
      e. Rupture and fatigue strengths
      f. Thermal expansion
      g. Thermal conductivity
      h. Impact strength
      i. Toughness

   3. Non-ferrous base metals and alloys
      a. Aluminum
      b. Magnesium
      c. Copper
      d. Nickel

e. Chromium
f. Bronze
g. Brass
h. Stellite

D. Carbon and alloy steels
  1. Classification of straight carbon steels and their uses
     a. Low-carbon steel
     b. Medium-carbon steel
     c. High-carbon steel
  2. Alloy steels
     a. Alloying elements and their effects on steel
     b. Tool and stainless steel
  3. Surface treatments for steel
     a. Pack, gas, and liquid carburizing
     b. Cyaniding
     c. Nitriding
     d. Hot dip coatings
     e. Sprayed coatings
     f. Clad coatings

E. Effects of corrosion and various heat treatments on steel
  1. Corrosive chemicals and atmospheric conditions adversely effective to steel
  2. Heat treatments
     a. Annealing
     b. Normalizing
     c. Tempering
     d. Case hardening
     e. Residual stresses and their relief
     f. Hardenability evaluation
     g. Effects of elevated temperature

F. Hot and cold metalworking
  1. Hot metalworking techniques
  2. Cold metalworking techniques

G. Relationship of mechanical testing and properties to design criteria

Laboratory Procedures and Tests

A. Instruction on the uses and operation of the microscope and low-power handglass for metallographic examinations

B. Instruction on the uses of various etching reagents and specimen selection and preparation

C. Demonstrations concerning the properties of metals.

D. Macroscopic and microscopic examination of the grain structure of each metal considered by the curriculum.

E. Metallurgical destructive investigative techniques

1. Charpy and Izod Impact testers
2. Rockwell, Brinell, Vickers, Tukon Micro, and Shore Hardness testers
3. Bend and cupping tests
4. Creep test
5. Fatigue tests
6. Tensile test
7. Compression test
8. Torsion test

F. Student experiments involving tests, procedures, and observations.

G. Demonstrations of corrosion tests, hardenability quench tests, and heat treatments.

## APPENDIX E

## LIST OF PARTICIPATING INSTITUTIONS OF HIGHER LEARNING

1. School of Technology
   Southern Illinois University
   Champaign, Illinois

2. Department of Engineering and Technology
   Le Tourneau College
   Longview, Texas

3. Technical Vocational Department
   Cooke County Junior College
   Gainesville, Texas

4. Department of Welding Technology
   Texas State Technical Institute
   Waco, Texas

5. Industrial Studies Department
   San Jose State College
   San Jose, California

## APPENDIX F

## LIST OF PARTICIPATING INDUSTRIAL FIRMS

1. Charles C. Kawin Company
   Metallurgical Laboratories
   Broadview, Illinois

2. Delsen Corporation
   Glendale, California

3. Factory Standards Laboratory, Incorporated
   Chicago, Illinois

4. Hauser Research and Engineering Company
   Boulder, Colorado

5. Plas-Tech Equipment Corporation
   Natick, Massachusetts

6. SPS Laboratories
   Jenkintown, Pennsylvania

7. Texas Instruments, Incorporated
   Materials Analysis and Characterization
   Dallas, Texas

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