SCHOOL OF MATERIALS AND MINERAL RESOURCES ENGINEERING

UNIVERSITI SAINS MALAYSIA

STUDY ON THE RELATIONSHIP BETWEEN TENSILE AND HARDNESS PROPERTIES ON SEVERAL METALLIC MATERIALS

by

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DECLARATION

I hereby declare that I have conducted, completed the research work and written the dissertation entitled **"Study On The Relationship Between Tensile And Hardness Properties On Several Metallic Materials'**. I also declared that it has not been previously submitted for the award for any degree or diploma or other similar title of this for any other examining body or University.

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Date :

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LIST OF SYMBOLS

Zn	zinc
Cu	copper
Sn	tin
Mn	manganese
Pb	lead
Ni	nickel
Al	aluminium
Fe	iron
^{o}C	degree celcius
σ_{uts}	ultimate tensile stress
σ_{y}	yield stress
H_{v}	Vickers hardness
P	Pressure
υ	Poisson ratio
c	constraint factor
H	Hardness
S	uniaxial flow strength
σ_{t}	true stress

K	strength coefficient
n	strain hardening exponent
ε	true strain
R^2	R-square
m	gradient

LIST OF ABBREVIATIONS

FCC	Face Centered Cubic
XRF	X-ray Fluorescence
UTS	Ultimate Tensile Strength
YS	Yield Strength
ASTM	American Standard Testing Measurement
MU	Measurement Uncertainty

KAJIAN TERHADAP HUBUNGAN ANTARA CIRI-CIRI KEKUATAN DAN KEKERASAN TERHADAP BEBERAPA JENIS BAHAN LOGAM

ABSTRAK

Kajian ini dilakukan untuk menentukan hubungan antara ciri-ciri kekuatan dan kekerasan terhadap beberapa bahan logam seperti aluminium, kuprum dan keluli galvanik. Antara objektif utama dalam kajian ini adalah untuk menentukan hubungan antara ciri-ciri kekuatan dan kekerasan terhadap beberapa bahan logam dengan bantuan analisis mikrostruktur dan analisis regresi. Analisis regresi digunakan untuk mentafsir data yang ada dan ketidakpastian pengukuran juga dijalankan dia dalam kajian ini untuk menentukan pengesahan terhadap data-data daripada ujian kekuatan. Mesin INSTRON 5695 dan Vickers telah digunakan di dalam kajian ini untuk menentukan hubungan antara kekuatan dan kekerasan bahan yang diuji. Perisian iSolution di dalam optik mikroskop juga digunakan untuk menganalisis microstruktur terhadap ketiga-tiga bahan tersebut.. Hasil kajian dapat menunjukkan nilai sebenar hubungan antara kekuatan dan kekerasan di mana aluminium mempunyai julat di antara 2.94 - 2.95, kuprum adalah 2.76 - 2.76 dan keluli galvanik adalah 2.78 - 3.13. Di samping itu, hasil pengiraan ketidakpastian pengukuran menunjukkan nilai kekuatan yield dan kekuatan maksimum untuk aluminium adalah 2.69 dan 2.75, 7.60 dan 7.80 untuk kuprum dan 17.05 dan 17.13 adalah keluli galvanik. Berdasarkan kajian yang telah dilakukan, aluminium mempunyai mikrostruktur yang kecil berbanding kuprum dan keluli galvanik. Walau bagaimanapun, kekuatan aluminium adalah rendah berbanding kekuatan keluli galvanik dan kuprum.

STUDY ON THE RELATIONSHIP BETWEEN TENSILE AND HARDNESS PROPERTIES ON SEVERAL METALLIC MATERIALS

ABSTRACT

In this work, the tensile and hardness properties were investigated on the several metallic materials such as aluminium, copper and galvanize steel. The main objective in this research is to study the relationship between the tensile and hardness properties on several metallic materials with the help of microstructures observation and regression analysis for interpretation of the data. Besides, the measurement uncertainty also conducted to determine the validation of the data. INSTRON 5965 and Vickers hardness machine were used to determine the correlation between the hardness and strength of the materials. Besides, iSolution software with the optical microscope also was used in observing the microstructure. It was found that the actual correlation between hardness and strength for aluminium, copper and galvanize steel are in the range 2.94 - 2.95 for aluminium, 2.76 - 2.77 for copper and lastly 2.78 – 3.13 for galvanize steel. However, the measurement uncertainty help to validate the correlation between hardness and strength. From the measurement uncertainty calculation, the value for yield strength and ultimate tensile strength for copper, aluminium and galvanize steel are 2.69 and 2.75; 7.60 and 7.80; 17.05 and 17.13 respectively. Aluminium had the fine grain compared to galvanized steel. However, the strength of aluminium is lower than galvanize steel and copper.

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Nowadays, the metallic materials are used widely in various industry and application. Metallic materials with functional properties such as lightweight, high strength, good electrical conductor and good corrosion resistance has attracted the attention of the industries in the application of the aerospace, electrical, building, railways and automotive. The common metallic materials that used are steel, copper, aluminium and galvanize steel. These materials have their own properties that make it widely used in many application.

In some application, the materials that used require to undergo the tensile test to identify the tensile strength and other properties of the materials. Although, the tensile test can give a reliable result, but it have its own consequences such as time consuming for the test and lead to destructive of the part. Hence, the semi-destructive testing is the alternative way to study the tensile properties such as yield stress and tensile stress. Hardness test can be used because in non-destructive or semi-destructive. It only leave a small indentation on the materials (Tiryakioğlu *et al.*, 2015). Thus, the hardness and tensile are correlated with each other based on previous research (Zhang, Li and Zhang, 2011). It help to identify the properties of materials.

The advantages of the tensile and hardness relationship are it allows the rapid mechanical evaluation by using inexpensive and fast hardness test instead of the tensile test. Then, some of the high application materials such as in aerospace industry is produce in small scale. Hence it is not suitable to perform the tensile test and only the hardness test is a good choice. After that, the properties of the materials especially the tensile properties can be analyse by using hardness test for the complex structure because it is non-destructive test (Zhang, Li and Zhang, 2011).

1.2 PROBLEM STATEMENT

Metallic materials are the most common materials that used in many industries such as automotive, building and construction, railways, electrical and aerospace. It has several advantages that made in the best materials such as high strength, good electric conductivity, good corrosion resistance and lightweight. Most of the metallic materials are use in the large part and also used in high technology application such as in the aerospace industry. Hence, due to these conditions, it makes the problem for the metal in identify a few properties such as tensile properties. As we know, the tensile properties is a destructive testing which can totally damage the parts (Callister and Rethwisch, 2007).

There some researches on the correlation between hardness and tensile properties. From the research, it stated that the hardness is approximately 3 times of yield strength and ultimate tensile strength at certain condition (Zhang, Li and Zhang, 2011). Although, the researchers had done the correlation between hardness and tensile properties, but they are not study the reliability of the actual data for this correlation with materials properties. Hence, this research will further study on the reliability of the actual data of the correlation between tensile and hardness properties. From this research, it will give the advantages such as the prediction of the materials properties can be done and saving the cost for sample preparation.

1.3 RESEARCH OBJECTIVES

The objectives of the research are:

1) To investigate the relationship of the tensile and hardness properties on the several metallic materials that used
2) To observe the microstructure of several metallic materials and correlate with hardness
3) To determine the correlation between tensile and hardness properties by using regression analysis

1.4 THESIS STRUCTURE

There are five chapter provided in this thesis which includes:

1) Chapter 1: A brief overview about research background, problem statement, research objectives, scope of works and thesis structure
2) Chapter 2: Literature Review. Its cover the explanation about the tensile hardness relationship and others aspects in this research
3) Chapter 3: Methodology of research work and the equipment that used
4) Chapter 4: Experimental result and discussion about the research
5) Chapter 5: Conclusion from the research that have done and the suggestion of the future work

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

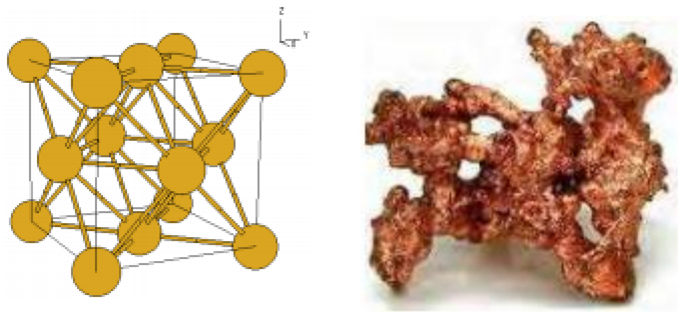
The metallic materials are highly demanded these day due to its properties that can be used in many applications. The metallic materials can be divided into two group which are ferrous materials and non-ferrous materials. Iron based materials is known as the ferrous materials while the others materials known as no-ferrous materials (Mridha, 2016). The example of ferrous material is galvanized steel and non-ferrous materials are aluminium and copper.

The metallic materials that used in various industry required certain properties to make sure it can work properly. Hence, the tensile properties become the major concern before used the materials. the tensile properties that become recently used to analyses the materials are modulus of elasticity, yield strength, ultimate tensile strength and ductility. However, the tensile test have its own consequences which are time consuming and cause the destruction to the part (Tiryakioğlu *et al.*, 2015). Thus, the study on the relationship between hardness and tensile properties become the crucial factors to overcome the problem that cause by the tensile test.

2.2 METALLIC MATERIALS

2.2.1 COPPER

Copper is the metal that malleable, easy for machining and good conductivity that made it as the favourite metal of manufacturer and engineers. Copper is the non-polymorphous metal with face centered cubic lattice (FCC). It has the range yellow, gold and red in colours and when polished it will develop a bright metallic lustre. Copper and copper alloys have an excellent electrical and thermal conductivity, generally nnmagnetic, have good formability and strength and also have outstanding resistance to corrosion and fatigue. Pure copper commonly used in electrical wire and cable, electrical contacts and various part that required the electric current to pass through it (Amruthaluri, 2007).



(a) (b)

Figure 2.1 (a) The FCC lattice for copper (b) Natural copper (Konečná and Fintová, 2012)

Table 2.1 shows the general properties of copper while Table 2.2 shows the mechanical properties of copper.

Table 2.1 General properties of copper (Matweb.com, 2018)

Properties	**Values**
Atomic Number	29
Atomic Weight	63.546
Atomic Diameter	2.551×10^{-10} m
Melting Point	1356 K
Boiling Point	2868 K
Density at 293 K	8.94×10^{3} kg/m^{3}
Electronic Structure	$3d^{10}$ 4s
Valence States	2, 1
Fermi Energy	7.0 eV
Fermi Surface	Spherical, necks at [111]
Hall Coefficient	-5.12×10^{-11} m^{3}/(A.S)
Magnetic State	Diamagnetic
Heat of Fusion	134 J/g
Heat of Vaporization	3630 J/g
Heat of Sublimation at 1299 K	3730 J/g

Table 2.2 Mechanical properties of copper (Matweb.com, 2018)

Properties	Metric
Hardness, Vickers	50
Ultimate Tensile Strength	210 MPa
Yield Strength	33.3 MPa
Elongation at break	60%
Modulus of Elasticity	110 GPa
Bulk Modulus	140 GPa
Poisons Ratio	0.343
Shear Modulus	46.0 GPa

Besides, for copper alloys it extensively used in other application such as automotive radiators, heat exchangers, home heating systems, solar collector, and others application that requiring a rapid heat conduction across metal section. Examples of copper alloys are brasses, bronzes and copper nickel.

There are a few types of copper alloys that used in nowadays application. High copper alloys contain small amount of alloying elements such as beryllium, chromium, zirconium, tin, silver, iron and sulphur. These alloying element that added into the predominant element are modify the properties of copper. The properties that may changes are creep resistance, strength, machinability and weldability. After that, brass is one of the copper alloys that commonly used. Brass are the copper that contain about 35% of the zinc as the alloying elements (Callister and Rethwisch, 2007). It also have a few alloying element such as lead and iron that enhance the machinability and strength properties of brass. Brass are commonly in wrought form. The common application of the brass are in radiator cores and tank, electrical terminal, plug and lamp fittings, cartridge cases and plumber hardware . Then, bronzes also one of the copper alloys that used for spring and fixtures, bearing, bushes, architectural fitting and features. Bronze is the copper that contain tin as the alloying element. besides tin, there are a few element that may added at least one which are phosphorus, silicon, manganese, aluminium and nickel. These alloying element improved the strength and corrosion resistance of the copper (Callister and Rethwisch, 2007).

After that, nickel also act as the alloying element in the copper and formed the copper nickel alloy. Addition of nickel help copper in the application with the seawater. It is because the outstanding of corrosion resistance in water. Example of application that used copper nickel are sheathing for boat hulls, heat exchangers, condenser and pumps and piping systems in seawater (Amruthaluri, 2007).

Coins, keys and camera parts that are used in our daily life are made up from the nickel silver. Nickel silver is the one of the copper alloys. It contain 55% - 65% of nickel and zinc. Even though it named as the silver, but it not contain any composition of silver. It call the nickel silver because its appearance which similar to pure silver (Amruthaluri, 2007).

Besides, the copper alloys are divided into two categories which are cast and wrought. The cast copper alloys is the nature of casting process which it means that most of copper alloys have greater range of alloying elements that wrought copper alloys. Wrought copper alloys are produce by using various production methods such as rolling, extrusion, drawing and stamping. These methods may be followed by a few processes such as cold working, annealing hardening and stress relieved to enhance its desire properties. Table 2.3 and Table 2.4 shows the summary of cast and wrought copper alloys.

Table 2.3 Summary of cast copper alloys (Austral Wright Metals - Ferrous, 2018)

Class Name	Composition	Application
Coppers	>99% copper	Electrical and thermal conductor
High-copper alloys	>94% copper	High strength electrical conductors including spot welding electrodes
Red brasses	Cu – Zn – Sn – (Pb) (75% - 89% Cu)	Valves, pump part, plumbing hardware
Yellow brasses	Cu – Zn – Sn – (Pb) (57% - 74% Cu)	Fittings, trim, builders hardware
Manganese bronzes	Cu – Zn – Mn – Fe – (Pb)	Gears, bearings, bushing, marine fittings
Silicon bronzes, silicon brasses	Cu – Zn – Si	Gears, bearing, bushing, marine fittings
Tin bronzes	Cu – Sn – Zn – (Pb)	Gears, bushing, bearings, pump parts
Nickel-tin bronzes	Cu – Ni – Sn – Zn – (Pb)	Wear parts, low speed bearings
Aluminium bronzes	Cu – Al – Fe – Ni	Gears, bearing, bushing, pump parts, pickling equipment, non-sparking tools
Copper – nickels	Cu – Ni – Fe	Valves, pump that resistant to seawater
Nickel silver	Cu – Ni – Zn – (Pb) – Sn	Builders hardware, valve, pumps
Miscellaneous alloys	-	Various application

Table 2.4 summary of wrought copper alloys (Austral Wright Metals - Ferrous, 2018)

Class name	Composition	Applications
Copper	>99% copper	Electrical conductors and connectors, water supply, heat exchangers, tanks, chemical equipment
High-copper alloys	>96% copper	Electrical conductors and connectors, springs, fasteners
Brasses	Cu – Zn	Deep drawn containers, tanks, heat exchangers, architectural panel, coins
Leaded brasses	Cu – Zn – Pb	Cylinders, builders hardware, wear plates, fasteners
Tin brasses	Cu – Zn – Sn – (Pb)	Electrical switches, springs, terminals, fasteners
Other copper-zinc alloys	-	Valve systems
Phosphor bronzes	Cu – Sn – P	Fastners, springs, chemical hardware, wear plates
Leaded phosphor bronzes	Cu – Sn – Pb – P	Bearings, bushings, gears, valves
Aluminium bronzes	Cu – Al – Ni – Fe – Si – Sn	Heat exchangers, pump parts, machine parts, structural members
Silicon bronzes	Cu – Si – Sn	Fasteners, springs, electrical connectors
Copper nickels	Cu – Ni – Fe	Condensers, heat exchangers, brake lines, salt water pipes

Nickel silvers	Cu – Ni – Zn	Silver plate (EPNS), nameplates, hollow ware

2.2.2 ALUMINIUM

Aluminium is a lightweight, strong and flexible metal. Due to its unique properties, it was widely used nowadays in from a production of light bulb until jet aircraft. The corrosion resistance properties of aluminum to the atmosphere are also desired at various application. Aluminium oxide thin film that form on the surface of the aluminum can protect it from corrosion. Besides, alumnium can be produce in many form which are bulk, sheet, film or powder form that is alumina powder (Callister and Rethwisch, 2007). Table 2.5 shows the physical proeprties of the aluminum.

Table 2.5 General physical properties of aluminium (Matweb.com, 2018)

Properties	**Values**
Density (kg/m^3)	2700
Modulus of elasticity (10^3 MPa)	69
Melting Point (ºC)	660
Specific heat (J/kg. ºC)	940
Electrical conductivity (% IAºCS)	62
Thermal Conductivity (W/m. ºC)	222
Coefficient of linear expansion (10^{-6} C^{-1})	23.6

Table 2.6 Mechanical properties of aluminium (Asm.matweb.com, 2018)

Properties	Metric
Hardness, Brinell	95
Hardness, Knoop	120
Hardness, Rockwell A	40
Hardness, Rockwell B	60
Hardness, Vickers	107
Ultimate Tesnile Strength	310 MPa
Tensile Yield Strength	276 MPa
Elongation at Break	12%
Modulus of Elasticity	68.9 GPa

Aluminium is the most abundnce metal in the earth. Aluminium can form either in pure or alloys. Aluminium alloys are alloys in which the aluminium is dominance. Aluminium alloys form when the alloying elements were added into the predominant metal to improve its properties. Sometimes, the alloying elements aslo added to lowered the properties. It depends on the purpose and application of aluminium alloys. The alloying elements that commonly add into the aluminum alloys group are magnesium, copper, manganese, tin, zinc and silicon (Callister and Rethwisch, 2007). Aluminium can be classified into two type which are wrought alloys and casting alloys. These two type of aluminium alloys are subdivide into two categories which are heat treatable and non-heat treatable. The wrought product of aluminium is mostly used in many application because it has lower melting point compare to cast product. It's more cost effective products. Besides, the wrought aluminium alloys have higher tensile strength compare to the cast aluminium alloys. Hence, wrought aluminium alloys are more used in application of daily life products.

Aluminium alloys is a unique materials because it have it own designation system. The designation system of alumnium alloys help in order to classify the type of aluminium alloys based on their group either wrought aluminium alloys or cast aluminium alloys. Then, each group of aluminium alloys are subdivided based on the series of aluminium alloys. The party that responsible for this designation system is Aluminium Association Inc. which it responsible in registration and classification of aluminium alloys. Over 400 wrought aluminium alloys and 200 casting and ingots of aluminium alloys are registered with this accosiation.

The classification of wrought aluminium alloys and cast aluminium alloys are based on the numbering system. It also known as the series system. The series system are determined based on the primanry alloying element that is added into predominant aluminium. Wrought aluminium alloys and cast aluminium alloys have different styles of numbering system. For the wrought aluminium alloys, it have 4 digits systems to classify it (Davis, 2001). Table 2.7 shows the wrought aluminium alloys designation system.

Table 2.7 The wrought aluminium alloys designation system (Alcotec.com, 2018)

Alloy Group	**Principal Alloying Element**
1xxx	Unalloyed aluminium (purity of 99.00% or greater)
2xxx	Copper
3xxx	Manganese
4xxx	Silicon
5xxx	Magnesium
6xxx	Magnesium and silicon
7xxx	Zinc
8xxx	Other element

For the cast aluminium alloys, the numbering system are quite different from the wrought aluminium alloys which is it have 3 digits and 1 decimal place. Table 2.8 shows the cast aluminium alloys designation system.

Table 2.8 The cast aluminium alloys designation system (Alcotec.com, 2018)

Alloy Series	**Principal Alloying Element**
1xx.x	99.00% minimum Aluminium
2xx.x	Copper
3xx.x	Silicon, Copper and/or Magnesium
4xx.x	Silicon
5xx.x	Magnesium
6xx.x	Unused Series
7xx.x	Zinc
8xx.x	Tin
9xx.x	Other elements

2.2.3 GALVANIZED STEEL

Steel is the common metal that used in our daily life. It is because, it used to construct a building and structure. Hence, make it versatile metal that used to manufacture a large range of products. Even though, steel is very popular metal among manufacturers, it still have its own weakness which is corrosion. Steel is easily to corrode when its surface was exposed to the water or moisture and form rust. Rust can damage the surface of steel and cause a failure to the parts.

The solution for the problem of steel is coat the steel with another type of metal such as zinc. The process of coated the steel with zinc is known as the galvanising process or hot dip galvanising. This process helps to protect the surface of steel from contact with water or moisture. The process of galvanising of steel is done by passing the steel through the molten bath of zinc. Temperature of zinc that used in this process usually about 460ºC. In this process, the zinc will make a bond with the steel by forming the iron-zinc alloy phase. The zinc that coated on the surface of steel also can form zinc oxide that help to prevent the corrosion (Coni *et al.*, 2009). Table 2.9 and 2.10 shows the general properties of steel and zinc.

Table 2.9 The properties of steel and zinc (Matweb.com, 2018)

Properties	**Value**	
	Steel	**Zinc**
Density (kg/m^3)	7850	7200
Melting point (ºC)	1510	419
Thermal conductivity (W/mºC)	50.2	113
Coefficient of linear expansion at 20 C(μm/m/ºC)	11.1	33.0

Table 2.10 Mechanical properties of steel and zinc (Matweb.com, 2018)

Properties	**Metric**	
	Steel	Zinc
Hardness, Brinell	121	-
Hardness, Knoop	140	-
Hardness, Vickers	126	30
Ultimate Tensile Strength	420 MPa	37.0 MPa
Yield Strength	350 MPa	-
Elongation at Break	15%	-
Modulus of Elasticity	200 GPa	96.5 GPa
Bulk Modulus	140 GPa	-
Poisson Ratio	0.25	-

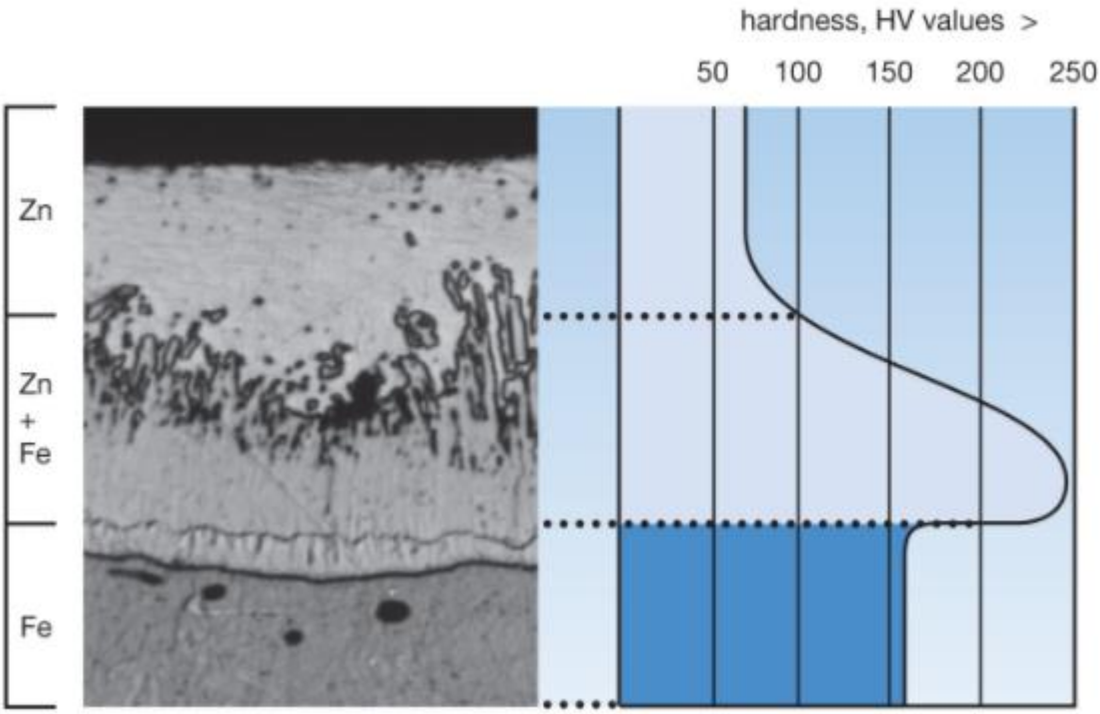


Figure 2.2 Microsection of hot dip galvanized coating showing variation in hardness through the coating (Galvanizers Association, 2018)

Galvanize steel is a unique materials that make it ideal to use in interior and exterior application because its properties. Galvanize steel have a good corrosion resistance because the zinc that coat on the surface compare to the uncoated steel. Besides, it has a good appearance which increases the aesthetic value. The coated steel with zinc form the matte-grey appearance and has a smooth surface. Then, the galvanize steel have the formability properties due to it resistant to cracking and loss of adhesion when it form into products. After that, the galvanize steel also have durability properties which is it not require the special handling to protect it during transport or use. It is durable and resistant to scratches from abrasion (AZoM.com, 2018).

2.3 MECHANICAL TESTING AND ITS PROPERTIES

2.3.1 TENSILE PROPERTIES

Tensile is a one of the mechanical properties that can be measured on the materials. A tensile properties show when the materials react after the load was applied on it. Load or force is applied in a tension. The tensile test is basic mechanical test that performs on the materials in controlled manner which the load was applied and elongation of the materials at a certain distance was measured significantly. From the tensile test, there a few information of the materials that can be interpreted which are modulus of elasticity, elastic limit, elongation, proportional limit, reduction in area, tensile strength, yield point, yield strength and others. This information help the manufacturers or engineers to design the products.

The result form the tensile test will give the load versus elongation curve. Hence, it will converted into stress versus strain curve (ASM International, 2004). The shape of the load versus elongation curve is same as the shape of stress-strain curve. It is because the engineering strain and engineering stress are obtained by dividing the load with the elongation. The stress-strain curve is related to the stress that applied and resulting the strain of the materials. Each of the materials have its own unique stress-strain curve.

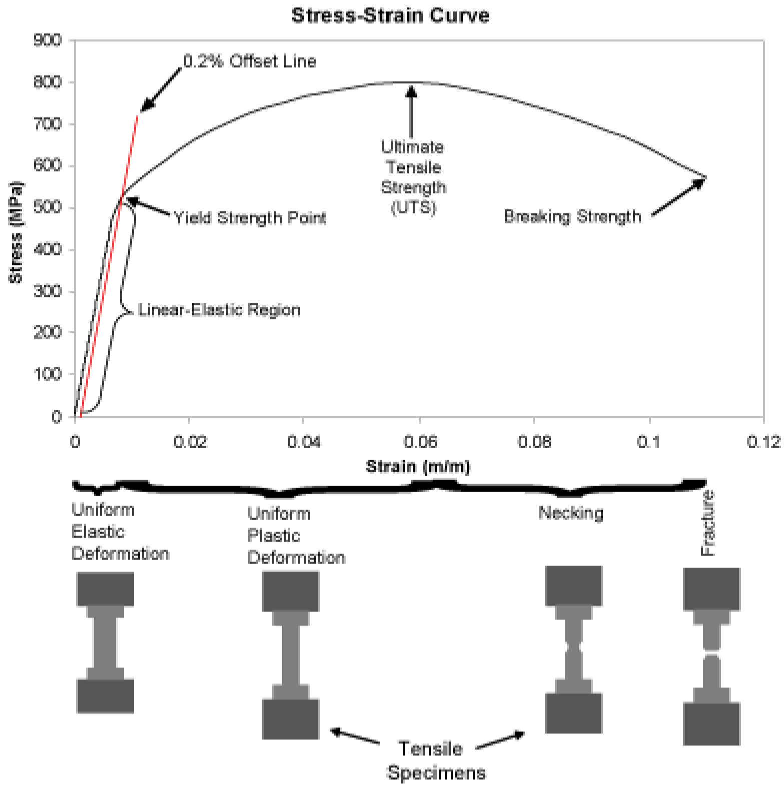


Figure 2.3 Typical engineering stress-strain curve

The first part of the stress-strain curve shows that the stress and strain increase with a linear relationship. It is indicated that there are no plastic deformation that occurs to the materials and the materials will return to its original shape as the stress is reduce. At this linear part, the line are obeyed the Hooke's Law where the ratio of stress to strain is constant.

2.3.1.1 MODULUS OF ELASTICITY

Modulus of elasticity is a slope of the line in a region where the stress is proportionally to the strain. It also known as the Young's modulus. Modulus of elasticity (E) is defines as the properties of materials that undergoes stress, its deform and return to original shape as the stress is reduced. This properties help to identify the stiffness of the materials in designing the products. The value of the modulus of elasticity is calculated by dividing the stress with the strain of materials. Since the strain is unitless, hence the unit for the modulus of elasticity is same as the stress.

From the atomic scale study, the elasticity of the materials are shown by small changes in the interatomic spacing. The bonding between the atom also stretching during the elasticity of the materials. Hence, the modulus of elasticity is measured by the resistance of atoms to separate with adjacent atoms. It is known as the interatomic bonding forces (Callister and Rethwisch, 2007).

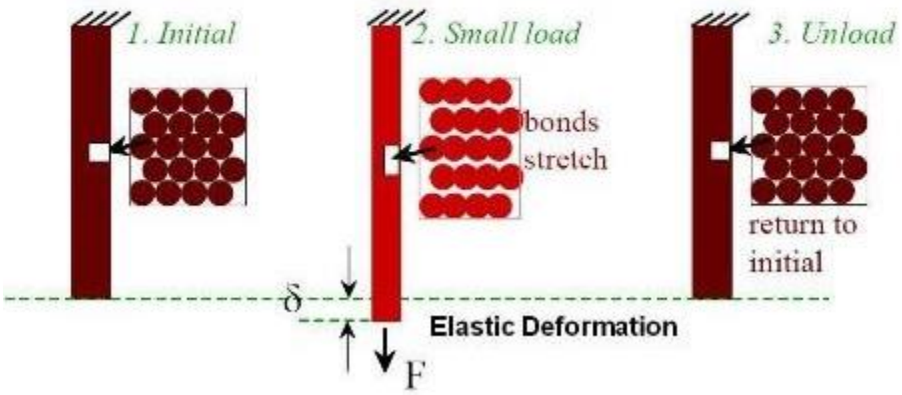


Figure 2.4 Schematic diagram for elastic deformation (Practicalmaintenance.net, 2018)

2.3.1.2 YIELD STRENGTH

Yield point is a point that the materials start to behave as a plastic deformation which it is permanent deformation. From the stress-strain curve, the materials start to yield when its deviates from the straight line relationship and not comply to the Hooke's Law. This occurs when the strain increase faster than the stress that applied. This situation commonly occurs in the ductile materials while in brittle materials, there is no plastic deformation or only a little plastic deformation. In brittle materials, the fracture occurs nearly at the end of the elastic part of curve.

From the atomic study, the plastic deformation of materials occurs due to the break of the bond between the atoms. The atoms will reform new bond with its neighbours atoms. Hence, the atoms will move relatively to another. This movement of the atom due to breaking of the bond cause the permanent change and do not return to original shape (Callister and Rethwisch, 2007).

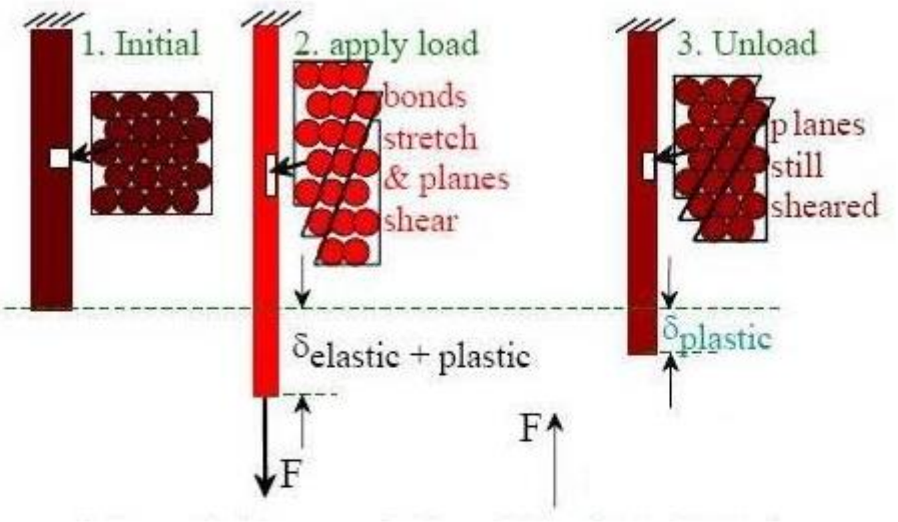


Figure 2.5 Schematic diagram for elastic deformation (Practicalmaintenance.net, 2018)

From the Figure 2.5 , there a point that known as the yield strength point. Yield strength representative stress that requires producing a small amount of plastic deformation. Yield strength is measure by constructing the offset straights line that parallel to the elastic part of the stress-strain curve. It is usually about 0.002 offset. The theoretical value of yield strength for aluminium, copper and galvanize steel are276 MPa, 33.3 MPa and 350 MPa respectively.

2.3.1.3 ULTIMATE TENSILE STRENGTH

Ultimate tensile strength also known as the tensile strength is a maximum engineering stress at achieve by the materials in the tension test. Ultimate tensile strength is the highest point in stress-strain curve. The materials will sustained the maximum stress in tension and if the stress is applied and maintained, the materials will start to fracture. At the maximum stress, the materials start to deform which is small constriction or neck will form at the middle of the materials. The necking that occurs on the materials will cause the materials failed. Figure 2.6 shows the typical engineering stress-strain behaviour to fracture.

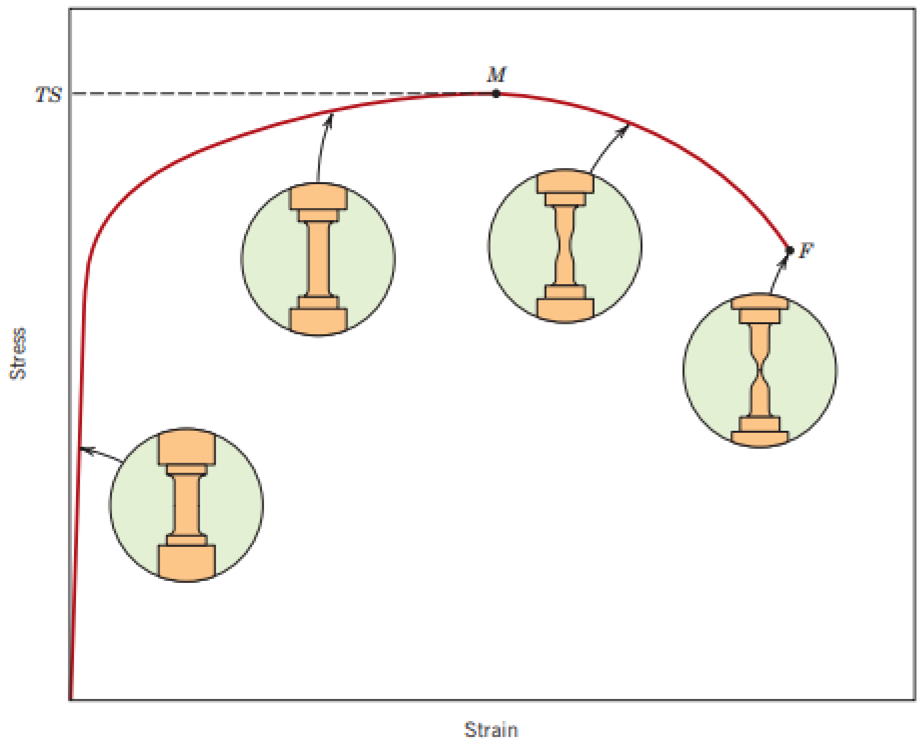


Figure 2.6 Typical engineering stress-strain behaviour to fracture (Callister and Rethwisch, 2007)

The theoretical value of ultimate tensile strength for aluminium, copper and galvanize steel are 310 MPa, 210 MPa and 420 MPa respectively.

2.3.1.4 DUCTILITY

Ductility is one of the important properties in the tensile. Ductility will help the manufacturers or engineers to design the product that can withstand the load before fracture occurs. Ductility is defines as the degree of plastic deformation that has been sustained before the fracture occurs. The ductility is measure by elongation of the materials and reduction area at fracture (ASM International, 2004). The materials that experience very small plastic deformation are called brittle materials. Figure below shown the stress-strain behaviour of ductile and brittle materials.

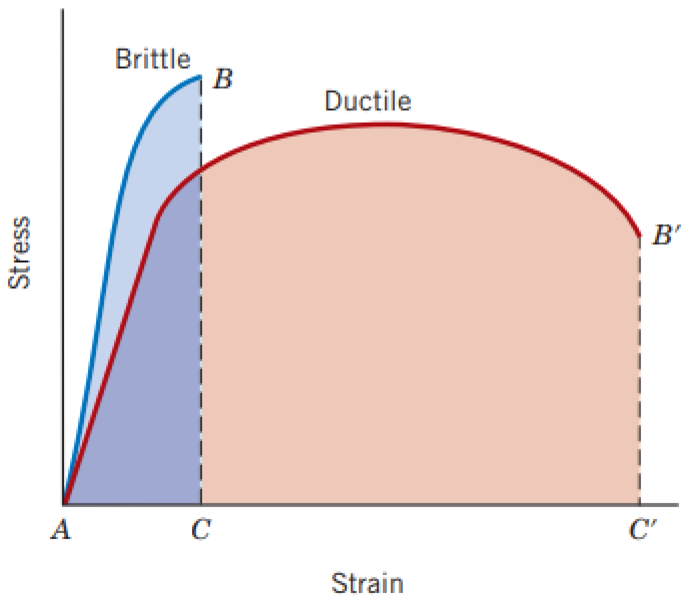


Figure 2.7 Schematic diagram of tensile stress-strain behaviour for brittle and ductile materials loaded to fracture (Callister and Rethwisch, 2007)

Ductility is important properties because a few reasons such as it will help to know the degrees of plastic deformation of materials before it fracture. After that, it indicates the degree at which the materials will deform plastic deformation during the fabrication process.

2.3.2 HARDNESS PROPERTIES

Hardness is also the important mechanical properties of the materials. It is defined as the materials resistant to localized plastic deformation. Hardness is measure by applying small indenter with certain load to the surface of materials under controlled condition. Then, the hardness number wills determined by the depth or size of indenter that formed on the surface. The hardness value is defines as the ratio of the indentation load or the residual indents of surface or projected area (Zhang, Li and Zhang, 2011). The theory in the hardness state that the softer the materials, the deeper and larger the indentation that formed and lower the hardness index number. Besides, the hardness is frequently used because a few factors such as hardness test is simple and inexpensive compare to others mechanical testing. Then, it also not cause the damage to the sample and only small deformation that occurs on the surface due to indentation. After that, from the hardness test, there are few mechanical properties that can be estimated from the hardness result such as tensile strength (Callister and Rethwisch, 2007). There are a few type of hardness test which is Rockwell and superficial Rockwell, Knoop mircohardness, Vickers microhardness and Brinell.

2.3.2.1 VICKERS MICROHARDNESS

Vickers hardness is the hardness test that used diamond pyramid indenter. The diamond pyramid is load on the surface of sample with a certain load. The load usually in range 1 and 1000g. These loads are much smaller than other hardness test such as Rockwell and Brinell. The indentation for the Vickers hardness are observed and measured under microscope. Then, from the size of indentation are converted into the hardness number (Hv). Before performed the testing, the sample preparation is the crucial step because to make sure well-define the indentation on the sample and can measured it.