PHYSICAL TEST OF STAINLESS STEEL 316 BETWEEN DIFFERENT MANUFACTURES

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PHYSICAL TEST OF STAINLESS STEEL 316 BETWEEN DIFFERENT MANUFACTURES

ZAITUL AQMAR BT MOHD ASRI

Thesis submitted in partial fulfilment of the requirements
for the award of the degree of
Bachelor of Chemical Engineering (Gas Technology)

Faculty of Chemical & Natural Resources Engineering
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SUPERVISOR'S DECLARATION

We hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Bachelor of Chemical Engineering (Gas Technology).

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Name of main supervisor : PROF DR ZULKEFLI YAACOB
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Date : 5 JULY 2013

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature :
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ID Number : KC 09036
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Dedication

To my family and supervisor for helping me a lot

ACKNOWLEDGEMENT

First and foremost, I praised to Allah S.W.T., the Almighty for the strength and health that He gives me to initiate my steps in all my way until I have finished up my undergraduate research project within due course of time. Additionally, it is my pleasure, that Allah has enabled me to prepare my thesis within the short time period where I manage to explore, understand, and gain more knowledge which is related to my research study.

Indeed, I want to take this opportunity to give my big thanks and heartfelt appreciation to my supervisor Prof Dr Zulkefli Bin Yaacob for his kind supervision, constant encouragement and inspiring guidance throughout my research project progression. After all, I also want to give my warmest appreciation to UMP staff of FKKSA (especially to En. Mohd Masri Bin A. Razak and En. Mohd Firdaus Bin Mohd Lazim) and FKASA (especially to En. Muhammad Nurul Fakhri Bin Rusli, En. Zu Iskandar Bin Kamaruddin, En. Mohd Hafiz Al-Kasah Bin Jamal Akhsah and En. Ahmad Shuhaimi Bin Embong) for their kind cooperation to help me with my purchasing of tubing and laboratory testing.

At last, I am very glad to express my sincere appreciation to my parents for their blessing and my fellow friends that always prayed for me and assisted me directly or indirectly for the successful completion of this research project.

ABSTRACT

Tubing is usually used in crude oil instrumentation system, natural gas, industrial gas, and food industry. With the involvement of the oil and gas tubing, many products would be affordable to be manufactured and the costs to convey these products to market would be economical. Products marking in the tubes include manufacture name or brand, specification number and grade on tubes. Different manufacture has different material characteristic although it is of the same grade. Thus, this research is perform to determine the modulus of elasticity, tensile strength and yield strength of stainless steel 316 from different manufactures. Comparison of modulus of elasticity, tensile strength and yield strength of stainless steel 316 from different manufactures are made. By appropriate scaling, load and displacement data that were obtained in the test were calibrated and cross-plotted to give an engineering stress-strain curve for each and every specimen. From the Universal Tensile Machine, graph of force versus displacement is generated. From the stress-strain curve, values of modulus of elasticity, ductility, tensile strength and yield strength for Sample A were 12869.22 MPa, 44.04501932%, 548 MPa, and 332.7333 MPa respectively. And for values of modulus of elasticity, ductility, tensile strength and yield strength for Sample B were 12722.43 MPa, 36.09215017%, 536.6667 MPa, and 314 MPa respectively. From the values that were obtained, the material characteristics of Sample A are found to be stronger than Sample B.

ABSTRAK

Tiub biasanya digunakan dalam sistem peralatan minyak mentah, gas asli, gas industri, dan industri makanan. Dengan penglibatan minyak dan tiub gas, banyak produk akan dapat dikeluarkan dan kos untuk menyampaikan produk-produk ini ke pasaran akan menjimatkan. Label pada tiub termasuk nama pembuatan atau jenama, spesifikasi dan bilangan gred. Pengeluar yang berlainan mempunyai ciri-ciri bahan yang berbeza walaupun ia adalah gred yang sama. Oleh itu, kajian ini dilaksanakan untuk menentukan modulus keanjalan, kekuatan tegangan dan kekuatan alah keluli tahan karat 316 dari pengeluar yang berbeza. Perbandingan modulus keanjalan, kekuatan tegangan dan kekuatan alah keluli tahan karat 316 dari berbeza pengeluar dibuat. Oleh itu skala, beban dan anjakan data yang sesuai yang diperolehi dalam ujian telah dikalibrasi dan merentas merancang untuk memberi lengkung tegasan-terikan kejuruteraan bagi setiap spesimen. Dari Mesin tegangan Universal, graf daya melawan anjakan dihasilkan. Daripada lengkung tegasan-terikan, nilai modulus keanjalan, kemuluran, kekuatan tegangan dan kekuatan alah bagi Sampel A adalah 12.869,22 MPa, 44,04501932%, 548 MPa, dan 332,7333 MPa masing-masing. Dan untuk nilai modulus keanjalan, kemuluran, kekuatan tegangan dan kekuatan alah bagi Sampel B adalah 12.722,43 MPa, 36,09215017%, 536,6667 MPa dan 314 MPa masing-masing. Dari nilai-nilai yang telah diperolehi, ciri-ciri bahan Sampel A didapati lebih kuat daripada Sampel B.

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LIST OF ABBREVIATIONS

A_0	original cross sectional area
e/ϵ	engineering strain
$\Delta l/Lf - Lo$	elongation of the gage length of the specimen
Lo	original gage length
M	meter
Mm	millimetre
P	load
S/σ	engineering stress

r1	internal diameter
r2	outer diameter
TS	tensile strength
YS	yield strength
E	modulus of elasticity
MPa	megapascal
%EL	ductility

1 INTRODUCTION

1.1 Motivation and statement of problem

Tubing is usually used in crude oil, instrumentation system, natural gas, industrial system, and food industry. With the involvement of the oil and gas tubing, many products would be affordable to be manufactured and the costs to convey these products to market would be economical. Many industries using stainless steel tube in their plant. Usually is in the appliances they used in their plant such as in heat exchanger. The effectiveness of the tubes is partially feature by their practicality and safety. As tubes are a competent means for the transportation of oil and gas, their important and safety have concerned a great deal of interest. It is necessary that some knowledge of the maximum pressure load of tubing can support without leakage or catastrophic fracture be acknowledgeable to the designer and user for a gas installation system to be used safely. Therefore, an important deliberation in the design for safety and integrity evaluation of tubing is the accuracy prediction of their burst pressure has been stated by Zhu & Leis (2012). Various materials are focus to forces or loads for examples the aluminum alloy is constructed on an airplane wing and the stainless steel on installation of gas pipeline system. In such conditions it is required to identify the feature of the materials and to design the member from which it is made therefore to facilitate whichever consequential deformation will not be excessive and fracture will not happen. The mechanical performances of material indicate the relationship between its response or deformation to an applied load or force. Significant mechanical properties are strength, hardness, ductility, and stiffness.

Various parties (e.g., producers and consumers of materials, research organizations, government agencies) that have dissimilar significant have concern about mechanical properties. Thus, it is essential that there be some regularity in the technique in which tests are conducted, and in the analysis of their results. This regularity is accomplished by using standardized testing methods. Professional societies are usually corresponding to the establishment and publication of these standards. The most active organization in the United States is the American Society for Testing and Materials (ASTM). Their Annual Book of ASTM Standards (http://www.astm.org) consists of a lot of volumes, which are issued and updated annually; a large number of these standards associate to mechanical testing methods. One of the most general mechanical stress-strain tests is carry out in tension. The tension test can be used to ascertain several mechanical properties of materials that are significant in design. Usually in fracture, a specimen is deformed with a gradually rising tensile load that is applied uniaxially along the long axis of a specimen. These mechanical explanations have been explained by Callister & Rethwisch (2008).

One of the importance on testing and evaluation of tube performance is the increasing complexity of tubing systems. The stress at the maximum on the engineering stress-strain curve is the tensile strength. This relates to the maximum stress that can be continued by a structure in tension; if this stress is applied and maintain, fracture will result. It also can determine the exact limits of component's design because many companies do not have specialized pressure testing facilities of their own. Product marking is only including manufacture name or brand, specification number and grade on tubes. Different manufacture has different material characteristic although it is the same grade.

1.2 Objectives

The following are the objectives of this research:

- To determine modulus of elasticity of stainless steel 316 from difference manufacture.
- To determine tensile strength and yield strength of stainless steel 316 from difference manufacture.
- Comparison of modulus of elasticity, tensile strength and yield strength of stainless steel 316 from difference manufacture.

1.3 Scope of this research

The following are the scope of this research:

i) Tensile test is one of the tests to know the characteristics of materials.
ii) Universal tensile machine is one of the equipment to tests the tensile strength.
iii) With the specimens of 316 stainless steel with tube outer diameter 3/8" x 0.035" wall thickness.
iv) Universal tensile machine speed test is 5 mm/min.

1.4 Main contribution of this work

The following are the contributions in this paper:

- After doing this research, data obtained has indicates that different tubing has difference material characteristics although it has the same outer diameter and wall thickness.
- In the market there are various stainless steel with different grade and there are varieties of material properties. Between the manufactures there are also different values of material characteristics so no actual value are available.

1.5 Organisation of this thesis

The structure of the reminder of the thesis is outlined as follow:

Chapter 2 presents review of literature from previous study. When doing a testing, the selections of suitable tubing are important for compatibility of the tubing with the media to be connected. Stainless steel tubing have many grades that differ from every grade is their component elements. Stainless steel 316 is one of the austenitic stainless steel. One of the tests to know the material characteristics is tensile test. From the stress-strain curve, we can determine their material characteristics.

Chapter 3 consists of materials and methods used in this paper. Specimens used are from Sample A and Sample B that is stainless steel 316 tubes with outer diameter 3/8” and wall thickness is 0.035” with 6 meter length. Tensile test is the method used in this research.

Chapter 4 presents results from Universal Tensile Machine that is graph force versus displacement from 15 samples of Sample A and 3 samples of Sample B. Then these graph than normalized to stress-strain curve. From the stress-strain curve, their material characteristics were obtained and this paper also calculated their ductility.

Chapter 5 draws together a summary of the thesis and outlines the future work which might be derived from the model developed in this work.

2 LITERATURE REVIEW

2.1 Overview

This chapter presents review of literature from previous study. When doing a testing, the selections of suitable tubing are important for compatibility of the tubing with the media to be connected. Stainless steel tubing have many grades that differ from every grade is their component elements. Stainless steel 316 is one of the austenitic stainless steel. One of the tests to know the material characteristics is tensile test. From the stress-strain curve, their material characteristics were determined.

2.2 Introduction

This chapter contains review of literature from past study. It contains types of tubes that discussed about tubing selection, stainless steel described about the families of stainless steel, austenitic stainless steel and characteristic of stainless steel. Last subchapter is about tensile test.

2.3 Types of Tubes

2.3.1 Tubing Selection

When doing a testing, the selected tubing should similar to the tubing normally used in industries. The involvement of special selection or treatment should be avoided. If tubing used in industries not easy to get to, specifics recommended by fitting manufacturers, or to ASTM or other applicable standards for tubing can also be bought. These recommendations have been made by Callahan (1998).

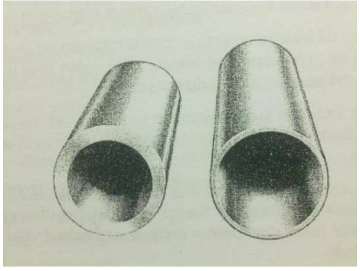


Figure 2-1: Thick and thin wall stainless steel tubing.

Parker Hannifin Corporation (2010) stated that the most significant deliberation in the selection of suitable tubing for any application is the compatibility of the tubing material with the media to be connected. Table 2-1 lists common materials and their associated general application. Table 2-1 also lists the minimum and maximum operating temperature for the various tubing materials.

Table 2-1: Lists common materials and their associated general application.

Tubing Material	General Application	Recommended Temperature Range
Stainless Steel (Type 316)	High Pressure, High Temperature, Generally Corrosive Media	-425°F to 1,200°F (-255°C to 605°C)
Carbon Steel	High Pressure, High Temperature Oil, Air, Some Specialty Chemicals	-20°F to 800°F (-29°C to 425°C)
Copper	Low Temperature, Low Pressure Water, Oil, Air	-40°F to 400°F (-40°C to 205°C)
Aluminium	Low Temperature, Low Pressure Water, Oil, Air, Some Specialty Chemicals	-40°F to 400°F (-40°C to 205°C)
Monel® 400	Recommended for Sour Gas Applications Well Suited for Marine and General Chemical Processing Applications	-325°F to 800°F (-198°C to 425°C)
Hastelloy®C-276	Excellent Corrosion Resistance to Both Oxidizing and Reducing Media and Excellent Resistance to Localized Corrosion Attack	-325°F to 1000°F (-198°C to 535°C)
Carpenter® 20	Applications Requiring Resistance to Stress Corrosion Cracking in Extreme Conditions	-325°F to 800°F (-198°C to 425°C)
Inconel® Alloy 600	Recommended for High Temperature Applications with Generally Corrosive Media	-205°F to 1200°F (-130°C to 650°C)
Titanium	Resistant to Many Natural Environments such as Sea Water, Body Fluids and Salt Solutions	-75°F to 600°F (-59°C to 315°C)

2.3.2 Stainless steel

Basically, stainless steel is an alloy of steel with a minimum of 11% chromium and more than 50% iron in it. It is highly strain, corrosion resistant and rust resistant that requires minimum maintenance. Some of these properties can be modified by adding metals like molybdenum, titanium, nickel, etc. in the substance of stainless steel which will gives increase to changes in its mechanical and physical properties. Because of their changes, there is hundreds of stainless steel grades can be created and used for a variety of function. Because of the features of stainless steel, most of industries used stainless steel tubes in gas installation system. As explained by Jadhav (2010).

As described in Atlas Steels Australia (2013), chemical formula for stainless steel grade 316 are Fe, <0.03% C, 16-18.5% Cr, 10-14% Ni, 2-3% Mo, <2% Mn, <1% Si, <0.045% P, and <0.03% S. Grade 316 is the standard molybdenum- bearing grade, second in importance to 304 amongst the austenitic stainless steels. The molybdenum gives 316 better overall corrosion resistant properties than Grade 304, particularly higher resistance to pitting and crevice corrosion in chloride environments. It has excellent forming and welding characteristics. It is readily brake or roll formed into a variety of parts for applications in the industrial, architectural, and transportation fields. Grade 316 also has outstanding welding characteristics. Post-weld annealing is not required when welding thin sections. Grade 316L, the low carbon version of 316 and is immune from sensitisation (grain boundary carbide precipitation). Thus it is extensively used in heavy gauge welded components (over about 6mm). Grade 316H, with its higher carbon content has application at elevated temperatures, as does stabilised grade 316Ti. The austenitic structure also gives these grades excellent toughness, even down to cryogenic temperatures.

One of the stainless steel type is currently being used as most important structural alloys in complicated nuclear systems and other dangerous and significant fields, where they are often exposed to complex thermo-mechanical loading histories is called austenitic stainless steel. In detail, many stainless steel elements are subjected throughout their manufacture, while in service or because of an accident, to complicated loading positions which can increase to multiaxial stress condition, strain-rate excursions covering numerous series of magnitude, unloading, reversed loading and cyclic loading. Correct information, understanding and description of the resulting non-conventional material feature are then demand for the safe and economic use of these structures. These explanations have been stated by Eleiche, Albertini & Montagnani (1985).

2.3.2.1 The Families of Stainless Steels

As discussed in Atlas Steels Australia (2013), stainless steels are iron-based alloys containing a minimum of about 10.5% chromium; this forms a protective self-healing oxide film, which is the reason why this group of steels has their characteristic "stainlessness" or corrosion resistance. The ability of the oxide layer to heal itself means that the steel is corrosion resistant, no matter how much of the surface is removed. This is not the case when carbon or low alloy steels are protected from corrosion by metallic coatings such as zinc or cadmium or by organic coatings such as paint.

Although all stainless steels depend on the presence of chromium, other alloying elements are often added to enhance their properties. The categorisation of stainless steels is unusual amongst metals in that it is based upon the nature of their metallurgical structure - the terms used denote the arrangement of the atoms which make up the grains of the steel, and which can be observed when a polished section through a piece of the material is viewed at high magnification through a microscope. Depending upon the exact chemical composition of the steel the microstructure may be made up of the stable phase’s austenite or ferrite, a "duplex" mix of these two, the phase martensite created when some steels are rapidly quenched from a high temperature, or a structure hardened by precipitated micro- constituents.

The relationship between the different families is as shown in Figure 2-2. A broad brush comparison of the properties of the different families is given in Table 2-2 and Table 2-3.

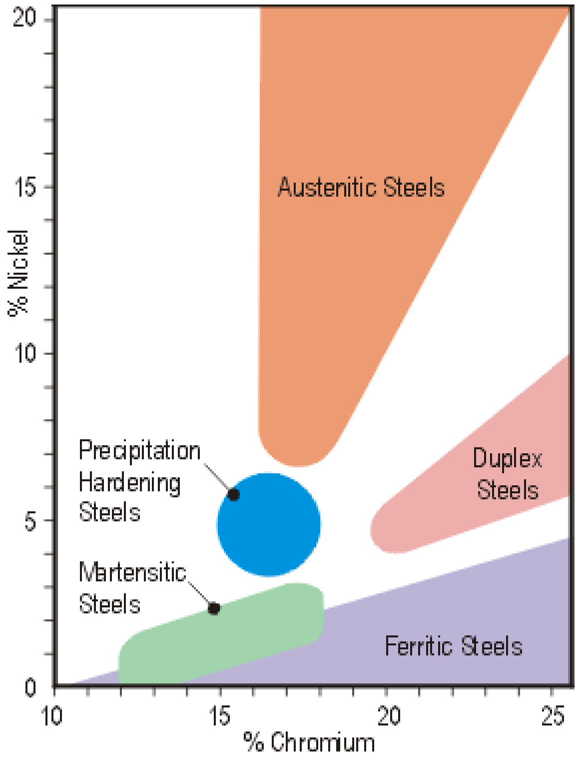


Figure 2-2: Families of stainless steels.

2.3.2.2 *Austenitic Stainless Steels*

This group contains at least 16% chromium and 6% nickel (the basic grade 304 is referred to as 18/8) and range through to the high alloy or "super austenitics" such as 904L and 6% molybdenum grades. Additional elements can be added such as molybdenum, titanium or copper, to modify or improve their properties, making them suitable for many critical applications involving high temperature as well as corrosion resistance. This group of steels is also suitable for cryogenic applications because the effect of the nickel content in making the steel austenitic avoids the problems of brittleness at low temperatures, which is a characteristic of other types of steel.

The relationship between the various austenitic grades is shown in Figures 2-3.

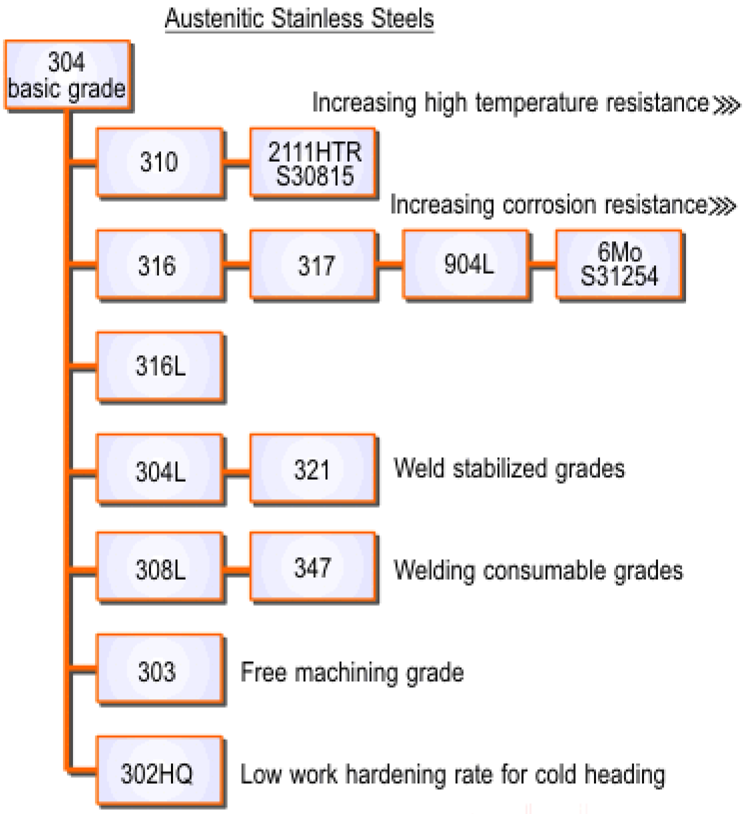


Figure 2-3: The Austenitic Stainless Steels.

2.3.2.3 Characteristics of Stainless Steels

The characteristics of the broad group of stainless steels can be viewed as compared to the more familiar plain carbon "mild" steels. As a generalisation the stainless steels have:

- Higher work hardening rate
- Higher ductility
- Higher strength and hardness
- Higher hot strength
- Higher corrosion resistance
- Higher cryogenic toughness
- Lower magnetic response (austenitic only)
- Must retain corrosion resistant surface in the finished product.

These properties apply particularly to the austenitic family and to varying degrees to other grades and families. These properties have implications for the likely fields of application for stainless steels, but also influence the choice of fabrication methods and equipment.

Table 2-2: Comparative Properties of stainless steel families.

Alloy Group	Magnetic Response[1]	Work Hardening Rate	Corrosion Resistance[2]	Hardenable
Austenitic	Generally No	Very High	High	By Cold Work
Duplex	Yes	Medium	Very High	No
Ferritic	Yes	Medium	Medium	No
Martensitic	Yes	Medium	Medium	Quench & Temper
Precipitation Hardening	Yes	Medium	Medium	Age Harden

1 = Attraction of steel to a magnet. Note some grades can be attracted to a magnet if cold worked.

2= Varies significantly within between grades within each group e.g. free machining grades have lower corrosion resistance, those grades higher in molybdenum have higher resistance.

Table 2-3: Comparative Properties of stainless steel families.

Alloy Group	Ductility	High Temperature Resistance	Low Temperature Resistance[3]	Weldability
Austenitic	Very High	Very High	Very High	Very High
Duplex	Medium	Low	Medium	High
Ferritic	Medium	High	Low	Low
Martensitic	Low	Low	Low	Low
Precipitation Hardening	Medium	Low	Low	High

3= Measured by toughness or ductility at sub-zero temperatures. Austenitic grades retain ductility to cryogenic temperatures.

2.4 Tensile test

One of the most significant of all materials test is tensile test. The information from this test is more accurate and gives more information on the strength of the materials. It is particularly suitable for steel of low carbon content (0.12-0.25%). In construction of steels, low carbon steel is the most significant and is used in the manufacture of cars, ships and bridges.

Gedney (2002) have described that a graphical description of the quantity of deflection under load for a given material is called the stress-strain curve as figure below. Engineering stress (S) is calculated by dividing the load (P) at any provided time by the original cross sectional area (A_o) of the sample.

$$S = P/A_O \qquad (2\text{-}1)$$

Engineering strain (e) is calculated by dividing the elongation of the gage length of the specimen (Δl) by the original gage length (l_o).

$$e = \Delta l/l_o = (l-l_o)/l_o \qquad (2\text{-}2)$$

The stress-strain curve feature of the shape and magnitude depend on the type of metal being tested. In figure below, point A shows the proportional limit of a material. Permanent deformation occurs when a material loaded in tension beyond point A even when the load is removed. Point B correspond the offset yield strength, and is found by constructing a line X-B parallel to the curve in the elastic region. Offset a strain amount O-X, which is typically 0.2% of the gage length for metals, is line X-B. Point C stands for the yield strength by extension under load (EUL), and can be found by constructing a vertical line Y-C. Offset a strain quantity O-Y, which is typically 0.5% of gage length, is line Y-C. Point D represents the tensile strength or peak stress. Depicted as strain and it shows the total elongation or the quantity of uniaxial strain at fracture is at point Z.

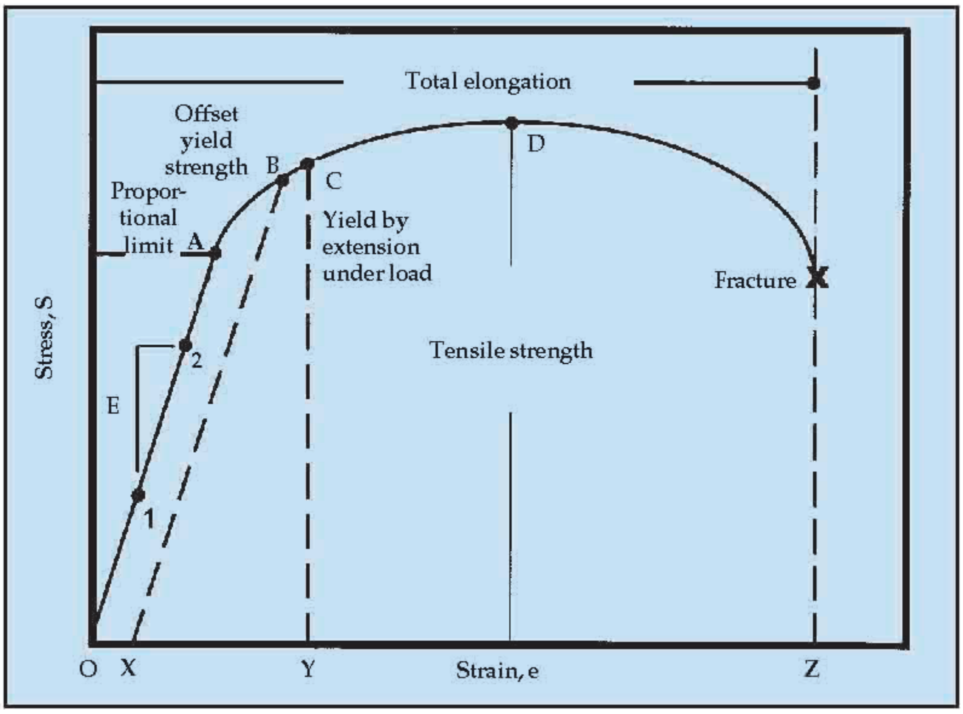


Figure 2-4: Stress-strain curve.

Modulus of elasticity as in The OHIO State University (n.d) defines as the ratio of stress to strain during elastic deformation when material is under uniaxial tension. Also known as Young's modulus. As in Granta (2011), yield strength often identify with the 0.2% offset, that is, the stress at which the stress- strain curve for axial loading deviates by a strain of 0.2% from the linear-elastic line as shown in Figure 2-4 (this 0.2% offset point is also associated with plastic strain). The ultimate (tensile) strength is the maximum engineering stress (applied load divided by the original cross-sectional area of the specimen) in a uniaxial stress-strain test.

Majority ASTM or same test methods need a shaped specimen that focuses the stress within the gage length. If the specimen is wrongly machined, it may have fracture outside the gage length, resulting in strain errors was discussed by Gedney (2002).

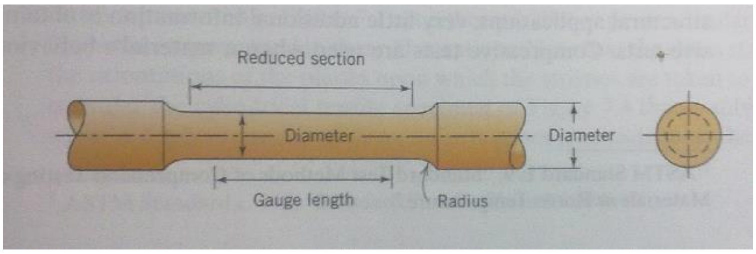


Figure 2-5: A standard tensile specimen with circular cross section.

2.5 Summary

This chapter contains review of literature from past study. It contains types of tubes that discussed about tubing selection, stainless steel described about the families of stainless steel, austenitic stainless steel and characteristic of stainless steel. Last subchapter is about tensile test.

3 MATERIALS AND METHODS

3.1 Overview

This chapter consists of materials and methods used in this paper. Specimens used are term as Sample A and Sample B that is stainless steel 316 tubes with outer diameter 3/8” and wall thickness is 0.035” with 6 meter length. Sample A and Sample B are stainless steel 316 tubes manufactured by different company. Tensile test is the method used in this research.

3.2 Introduction

This chapter described materials and methods used in the research. Subchapters are covers specimens, Universal Tensile Machine and data collection.

3.3 Tensile Test

Before testing any specimen, its dimensions, especially its diameter and length, was carefully measured. It is then loaded in the Universal Tensile Machine, at constant cross-head speed at 5 mm/min, unloaded, carefully removed from the setup and remeasured.

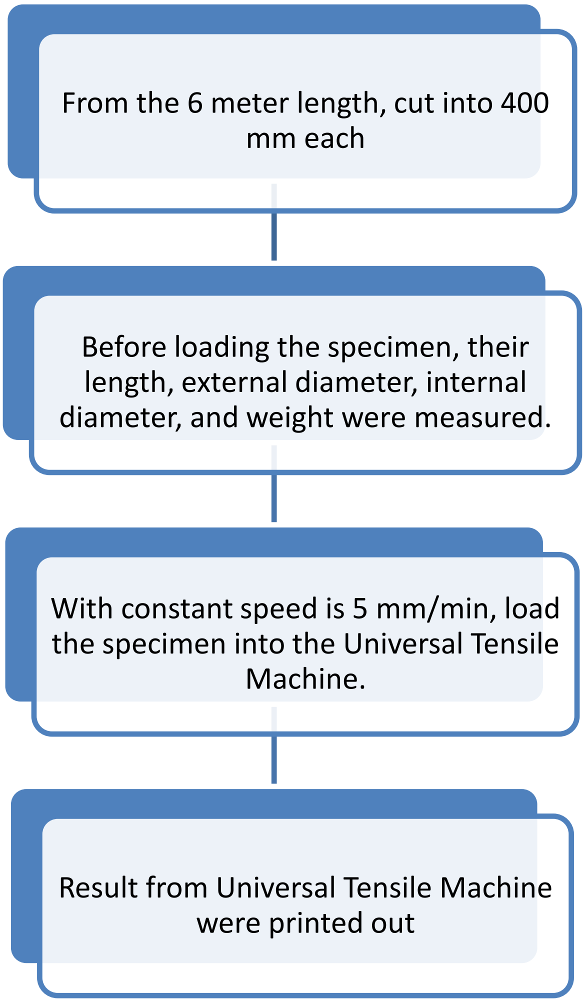
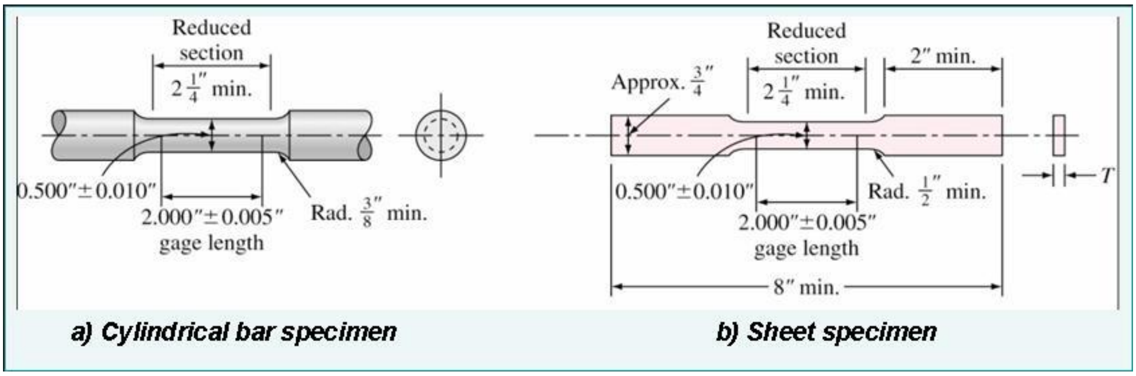


Figure 3-1: Illustrate the Research Design.

3.3.1 Specimens

Udomphol (n.d.) explained that a standard specimen is equipped in a around or a square section along the gauge length as represent in figure 3-2 a) and b) respectively, depending on the standard used. Both ends of the samples should have enough length and a surface circumstance such that they are firmly gripped during test. The initial gauge length Lo is standardized (in some countries) and differs with the diameter (Do) or the cross-sectional area (Ao) of the specimen as listed in Table 3-1. If the gauge length is too long it will cause the percentage of elongation may be underestimated in this case.



a) Cylindrical bar specimen **b) Sheet specimen**

Figure 3-2: Standard tensile specimens

Table 3-1: Dimensional relationships of tensile specimens used in different countries

Type specimen	United State (ASTM)	Great Britain	Germany
Sheet ($L_o/\sqrt{A_o}$)	4.5	5.65	11.3
Rod ($L_o/\sqrt{D_o}$)	4.0	5.0	10.0

In this research, samples used are stainless steel 3/8 inch tubing with wall thickness 0.035 inch from Sample A and Sample B. Each manufacturer has 6 meter length tubing. From 6 meter, it is cut into 400 mm. Sample A have 15 samples and Sample B has 3 samples which look like Figure 3-3. Before loading into Universal Tensile Machine, their dimensions have been taken which are length, external diameter, internal diameter, and weight by using vernier calliper, ruler, and analytical balance.

Figure 3-3: Tensile specimens

3.3.2 Universal Tensile Machine

Gedney (2002) stated that universal testers are the most usual testing machines, which test materials in tension, compression, or bending. To generate the stress-strain curve is their main function. After the diagram is created, a pencil and straight-edge, or a computer algorithm, may calculate yield strength, Young’s modulus, tensile strength, or total elongation. Some of the types of testing machine are electromechanical or hydraulic. The method by which the load is applied is the only principal difference.

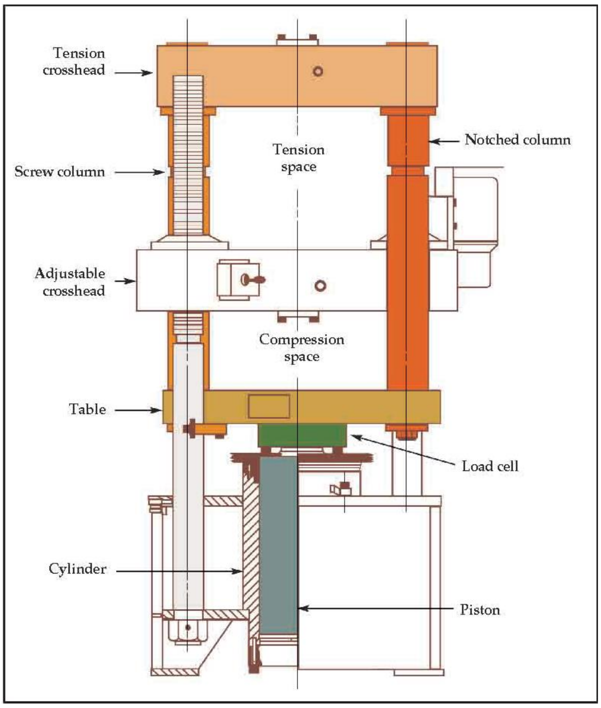


Figure 3-4: Anatomy of a hydraulic universal testing machine

In this research, constant speed is used that is 5 mm/min. After loading the specimen, a graph of force versus displacement is generated. Figure 3-5 is the Universal Tensile Machine that is used in this research.

Figure 3-5: Universal testing machine

3.3.3 Collecting Data

As stated by Eleiche, Albertini & Montagnani (1985), the test will be consist of interrupting the quasi-static loading of tensile specimens after some uniform straining, unloading, then dynamics reloading up to fracture. The result obtained is graph force versus displacement.

3.4 Summary

This chapter described materials and methods used in the research. Subchapters are covers specimens, Universal Tensile Machine and data collection.

4 TENSILE TEST

4.1 Overview

This chapter presents results from Universal Tensile Machine that is graph force versus displacement from 15 samples of Sample A and 3 samples of Sample B. Then these graph than normalized to stress-strain curve. From the stress-strain curve, their material characteristics are known and this paper also calculated their ductility.

4.2 Introduction

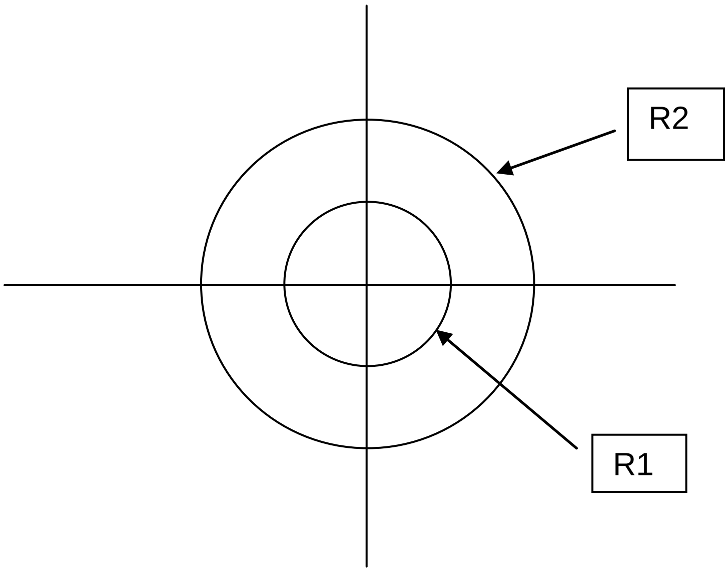
This chapter presents results and discussions of stainless steel 316 tubing. It contains subchapter of results from Universal Tensile Machine, Stress-strain curve and ductility.

4.3 Result from Universal Tensile Machine

There are a few parameters that being measured before loading the tube. The parameters are list in Table 4-1 for Sample A and Table 4-2 for Sample B. The areas of the specimens are calculated by using equation (4-1) as follows:

$$\int_0^{2\pi} \int_{r1}^{r2} r \, dr \, d\theta \tag{4-1}$$

Where,



Calculation for area:

Sample 1 (Sample A)

$$A = \int_{0}^{2\pi} \int_{3.82}^{4.76} r \, dr \, d\theta$$

$$= \int_{0}^{2\pi} \left[\frac{r^2}{2}\right]_{3.82}^{4.76} d\theta$$

$$= \int_{0}^{2\pi} \frac{4.76^2}{2} - \frac{3.82^2}{2} \, d\theta$$

$$= \int_{0}^{2\pi} 4.0326 \, d\theta$$

$$= [4.0326\, \theta]_{0}^{2\pi}$$

$$= 4.0326\,(2\pi) - 0$$

$$= 25.33757307 \text{ mm}^2$$

- Same method of calculation to calculate area for other samples but using their outer and internal diameter.

Table 4-1: Parameters for Sample A

sample no	L1 (mm)	L2 (mm)	ΔL	weight (g)	outer diameter (mm)	internal diameter (mm)	r1 (mm)	r2 (mm)	area (mm2)	break
1	383	547	164	71.46	9.52	7.64	3.82	4.76	25.33757	174.934
2	400	585	185	75.54	9.56	7.64	3.82	4.78	25.93699	195.721
3	405	584	179	76.25	9.56	7.66	3.83	4.78	25.69666	195.213
4	402	584	182	75.33	9.56	7.67	3.835	4.78	25.57626	196.883
5	403	590	187	75.37	9.56	7.65	3.825	4.78	25.8169	201.444
6	401	588	187	75.43	9.56	7.62	3.81	4.78	26.17669	203.859
7	402	575	173	74.74	9.55	7.59	3.795	4.775	26.38498	187.876
8	404	576	172	75.62	9.56	7.64	3.82	4.78	25.93699	186.73
9	405	573	168	75.72	9.56	7.68	3.84	4.78	25.4557	182.794
10	402	575	173	75.15	9.56	7.63	3.815	4.78	26.05692	188.484
11	405	595	190	75.54	9.54	7.63	3.815	4.77	25.7569	204.809
12	384	562	178	71.49	9.56	7.65	3.825	4.78	25.8169	193.261
13	386	556	170	72.08	9.55	7.67	3.835	4.775	25.42617	184.861
14	385	551	166	72.14	9.57	7.62	3.81	4.785	26.32694	181.159
15	386	534	148	72.72	9.54	7.57	3.785	4.77	26.47318	162.315

Table 4-2: Parameters for Sample B

sample no	L1 (mm)	L2 (mm)	ΔL	weight (g)	outer diameter (mm)	internal diameter (mm)	r1 (mm)	r2 (mm)	area (mm2)	break
1	390	533	143	123.63	9.53	5.48	2.74	4.765	47.74475	126.138
2	392	537	145	124.27	9.53	5.37	2.685	4.765	48.68212	159.815
3	390	525	135	123.41	9.51	5.97	2.985	4.755	43.03919	139.474

Calculation for sample 1 of Sample A:

Modulus of elasticity

$E = \frac{Stress}{Strain}$ (slope of the graph)

$$= \frac{(3.4851E + 02) - (6.9004E - 03)}{0.026111279 - 0}$$

$$= 13346.91136$$

Difference in strength for modulus of elasticity:

$$= \frac{modulus\ of\ elasticity\ from\ slope\ of\ the\ graph - modulus\ of\ elasticity\ from\ ASTM}{modulus\ of\ elasticity\ from\ ASTM}$$

$$= \frac{13346.91136 - 193000.00}{193000.00}$$

$$= -0.93$$

Difference in strength for tensile strength:

$$= \frac{tensile\ strength\ f\text{rom the graph} - \text{tensile strength from ASTM}}{tensile\ strength\ from\ ASTM}$$

$$= \frac{562 - 485.00}{485.00}$$

$$= 0.16$$

Difference in strength for yield strength:

$$= \frac{yield\ strength\ from\ graph - yield\ strength\ from\ ASTM}{yield\ strength\ from\ ASTM}$$

$$= \frac{348 - 170.00}{170.00}$$

$$= 1.05$$

- Same method of calculation for other samples but using their values from graph.

Table 4-3: Material characteristics of 316 stainless steel from Sample A.

sample no	Modulus Elasticity (MPa)	Modulus Elasticity (MPa) (ASTM A249)	Difference in strength	Tensile Strength (MPa)	Tensile Strength (MPa) (ASTM A249)	Difference in strength	Yield Strength (MPa)	Yield Strength (MPa) (ASTM A249)	Difference in strength
1	13346.91	193000.00	-0.93	562	485.00	0.16	348	170.00	1.05
2	12662.24	193000.00	-0.93	548	485.00	0.13	324	170.00	0.91
3	13373.27	193000.00	-0.93	562	485.00	0.16	329	170.00	0.94
4	13244.97	193000.00	-0.93	562	485.00	0.16	340	170.00	1.00
5	13026.3	193000.00	-0.93	560	485.00	0.15	338	170.00	0.99
6	12951.32	193000.00	-0.93	560	485.00	0.15	330	170.00	0.94
7	12559.3	193000.00	-0.93	520	485.00	0.07	320	170.00	0.88
8	12887.33	193000.00	-0.93	542	485.00	0.12	322	170.00	0.89
9	13251.75	193000.00	-0.93	560	485.00	0.15	322	170.00	0.89
10	12935.12	193000.00	-0.93	540	485.00	0.11	338	170.00	0.99
11	13003.39	193000.00	-0.93	542	485.00	0.12	340	170.00	1.00
12	12299.02	193000.00	-0.94	542	485.00	0.12	340	170.00	1.00
13	12516.99	193000.00	-0.94	540	485.00	0.11	330	170.00	0.94
14	12206.75	193000.00	-0.94	540	485.00	0.11	330	170.00	0.94
15	12773.59	193000.00	-0.93	540	485.00	0.11	340	170.00	1.00
average	12869.22	193000.00	-0.93332012	548	485.00	0.129897	332.7333	170.00	0.957255

Table 4-4: Material characteristics of 316 stainless steel from Sample B.

sample no	Modulus Elasticity (MPa)	Modulus Elasticity (MPa) (ASTM A249)	Difference in strength	Tensile Strength (MPa)	Tensile Strength (MPa) (ASTM A249)	Difference in strength	Yield Strength (MPa)	Yield Strength (MPa) (ASTM A249)	Difference in strength
1	15742.63	193000.00	-0.92	562	485.00	0.16	360	170.00	1.12
2	10823.66	193000.00	-0.94	498	485.00	0.03	282	170.00	0.66
3	11601.01	193000.00	-0.94	550	485.00	0.13	300	170.00	0.76
average	12722.43	193000.00	-0.934080649	536.6667	485.00	0.106529	314	170.00	0.847059

Table 4-5: Comparison of material characteristics between Sample A and Sample B.

sample	Modulus Elasticity (MPa)	Modulus Elasticity (MPa) (ASTM A249)	Difference in strength	Tensile Strength (MPa)	Tensile Strength (MPa) (ASTM A249)	Difference in strength	Yield Strength (MPa)	Yield Strength (MPa) (ASTM A249)	Difference in strength
Sample A	12869.22	193000.00	-0.93332012	548	485.00	0.129897	332.7333	170.00	0.957255
Sample B	12722.43	193000.00	-0.934080649	536.6667	485.00	0.106529	314	170.00	0.847059

Ductility calculation:

$$\%EL = \frac{L_f - L_o}{L_o} x100 \qquad (4\text{-}4)$$

$$\%EL = \frac{L_f - L_o}{L_o} \times 100$$

For Sample A:

$$\%EL = \frac{174.8 - 396.8666667}{396.8666667}$$

$$= 44.04501932$$

For Sample B:

$$\%EL = \frac{141 - 390.6666667}{390.6666667}$$

$$= 36.09215017$$

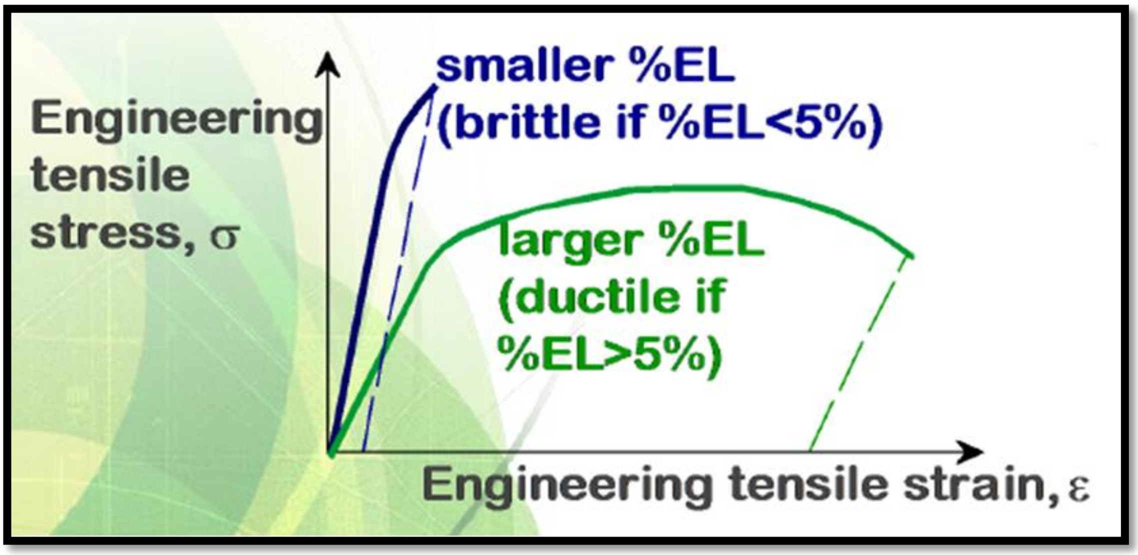


Figure 4-1: A graph of stress-strain for ductility comparison.

In this test, from the constant speed that is 5 mm/min the graph of force versus displacement were obtained for tubing 3/8 inch diameter for 15 samples from Sample A and 3 samples from Sample B. Every graph has different break point because along the specimen, there are difference weak points that will break at difference point. Following are the graphs that were obtained:

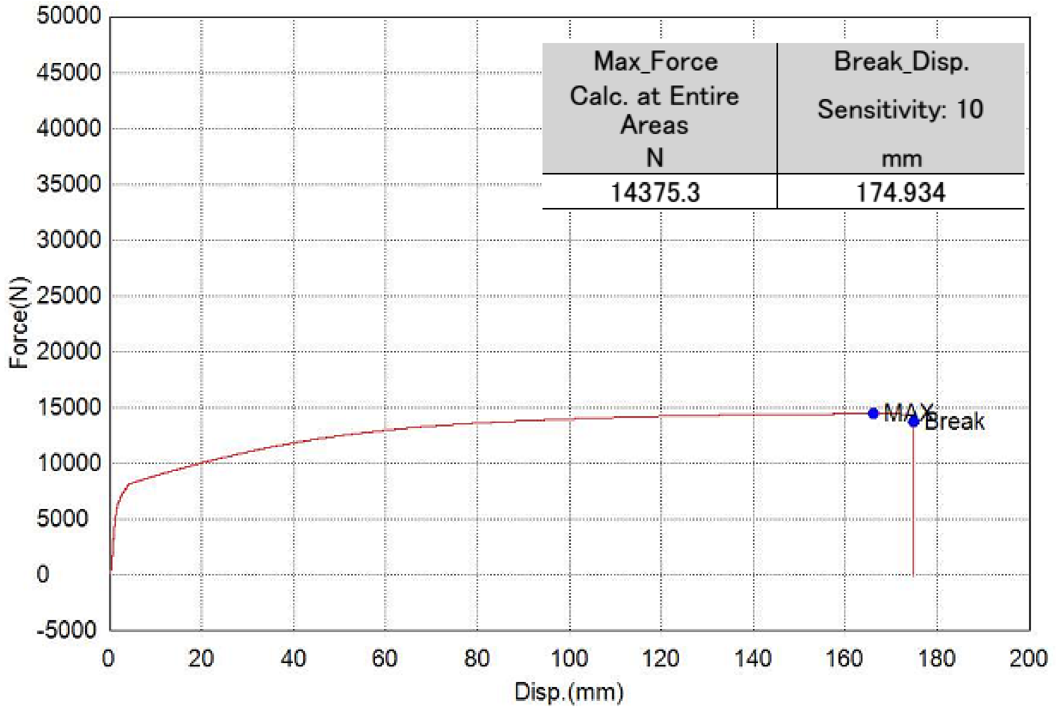


Figure 4-2: A graph of force versus displacement for sample 1 from Sample A.

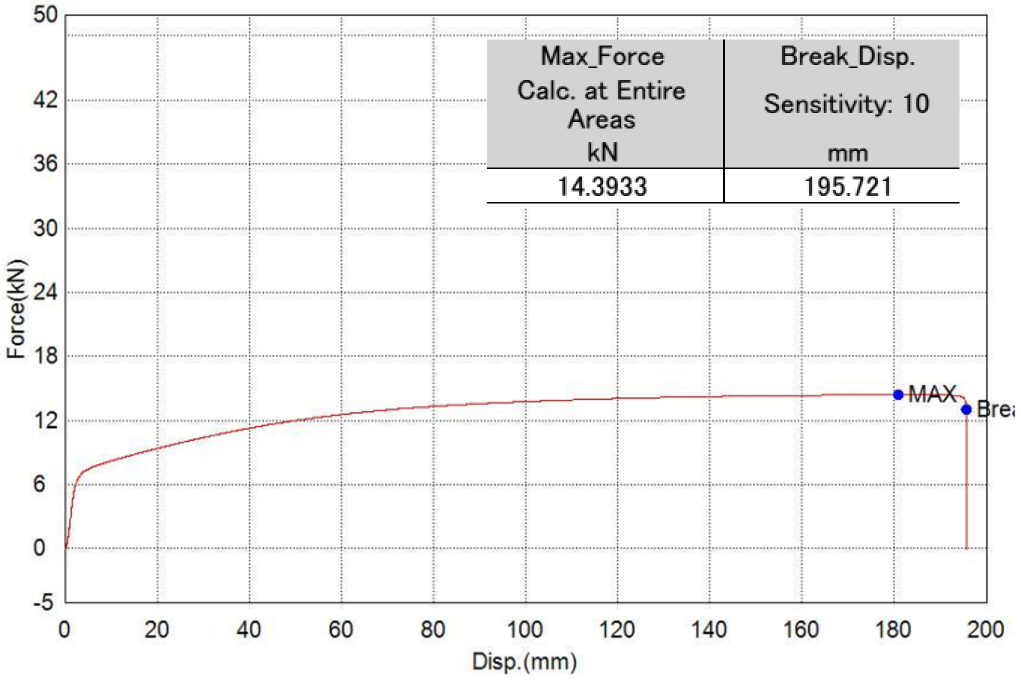


Figure 4-3: A graph of force versus displacement for sample 2 from Sample A.

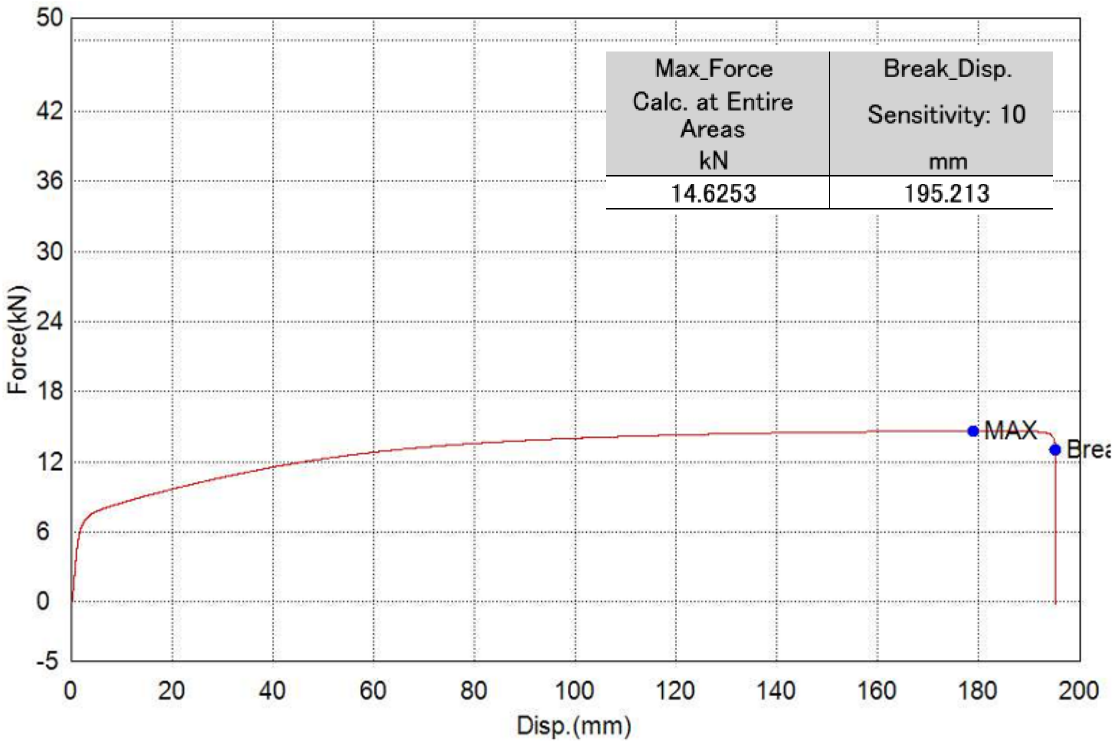


Figure 4-4: A graph of force versus displacement for sample 3 from Sample A.

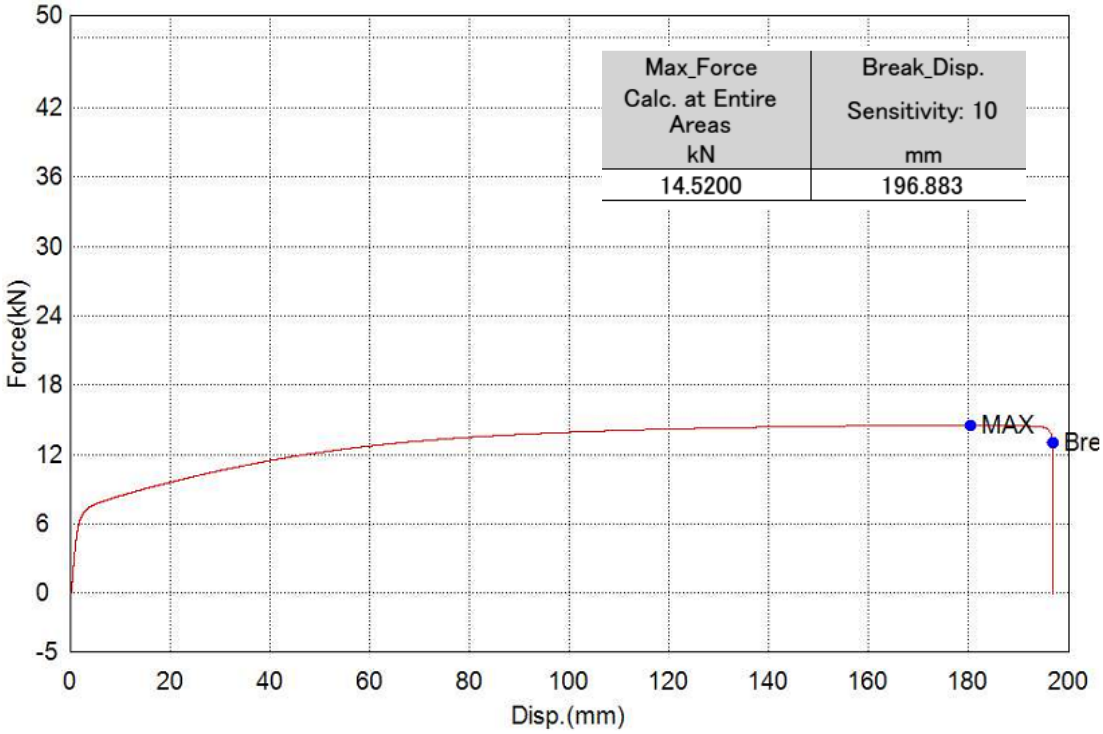


Figure 4-5: A graph of force versus displacement for sample 4 from Sample A.

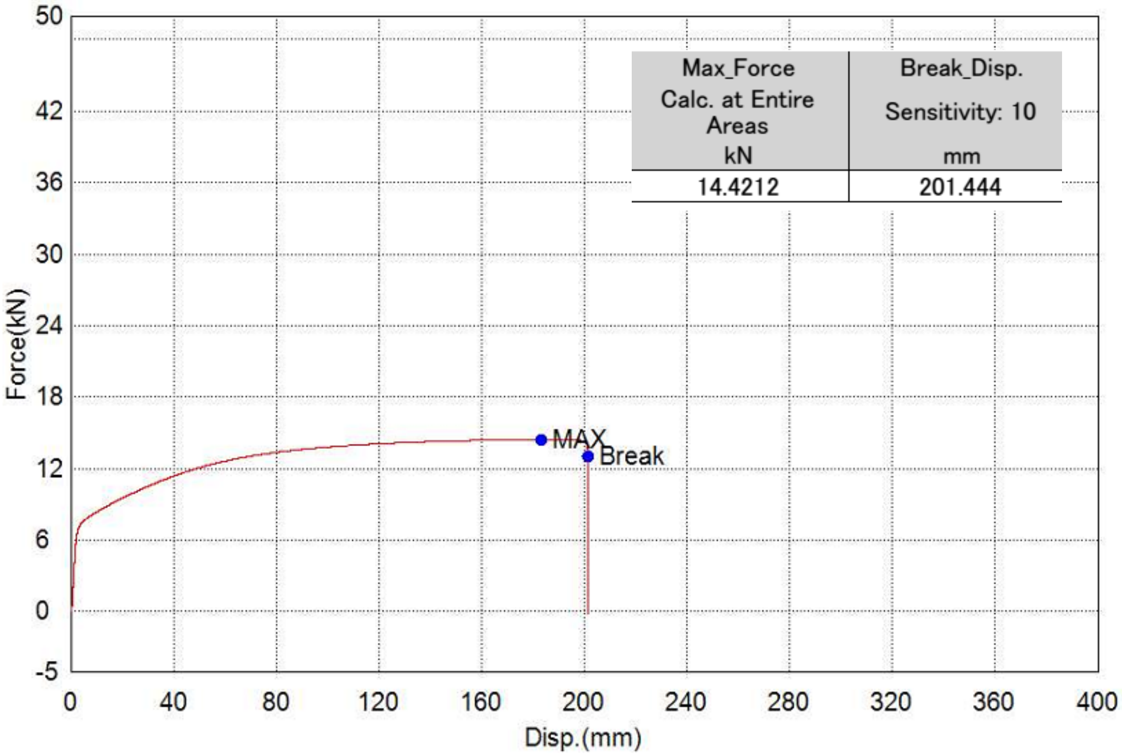


Figure 4-6: A graph of force versus displacement for sample 5 from Sample A.

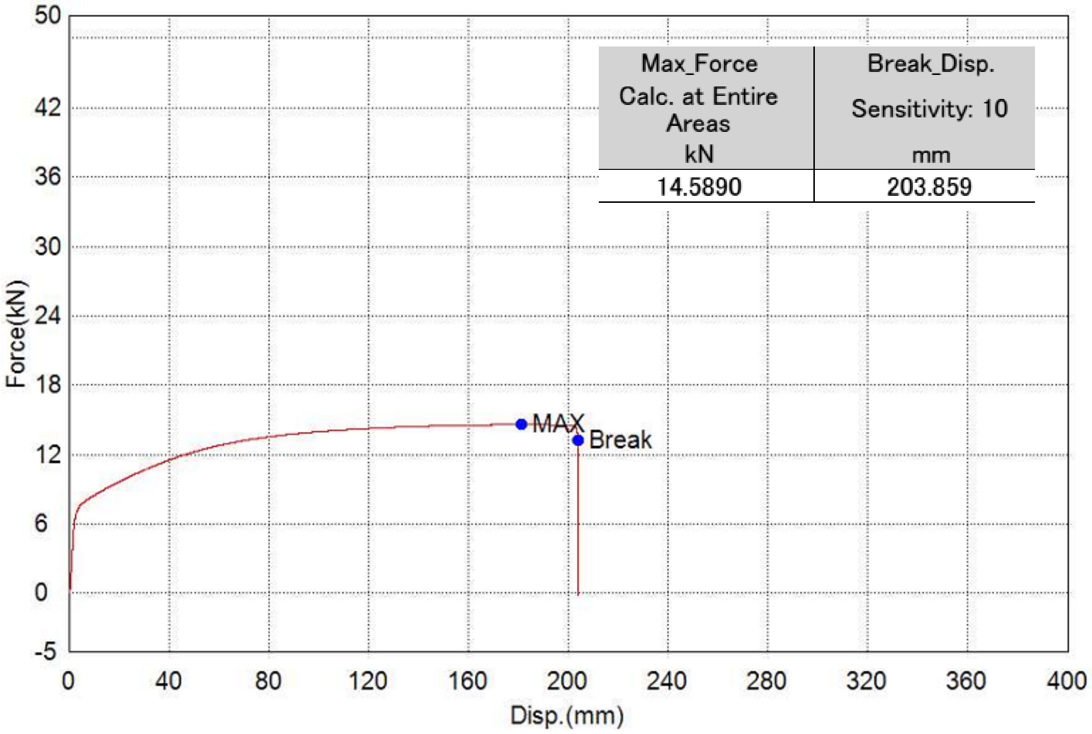


Figure 4-7: A graph of force versus displacement for sample 6 from Sample A.

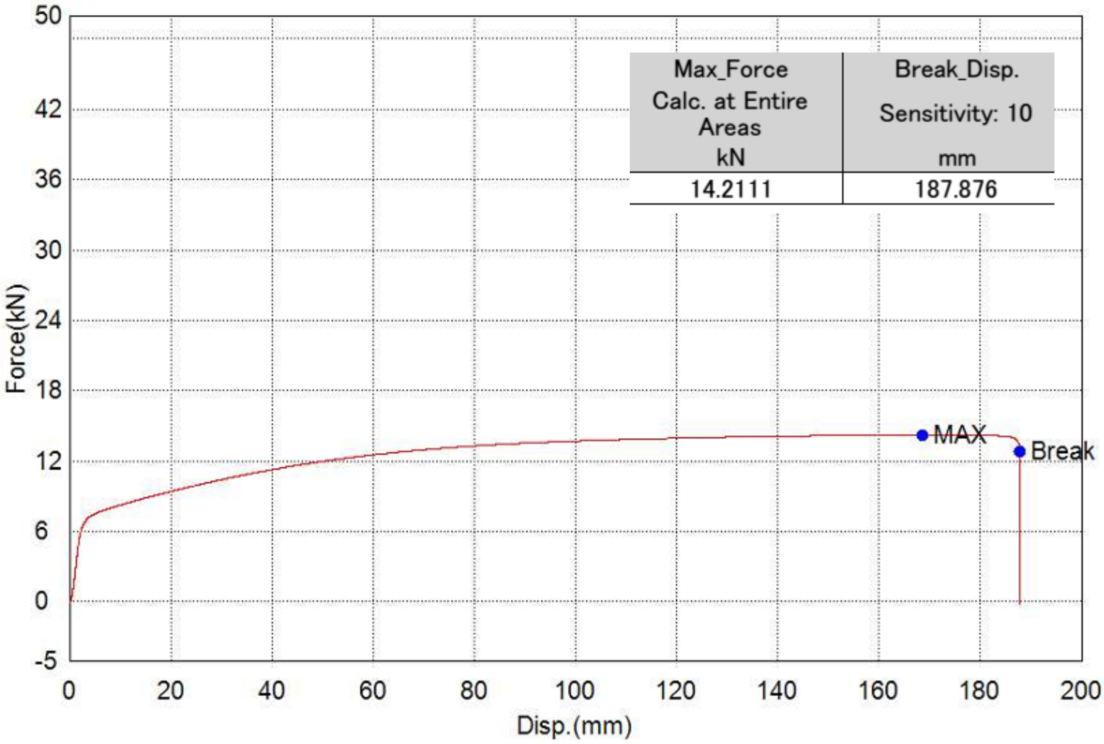


Figure 4-8: A graph of force versus displacement for sample 7 from Sample A.

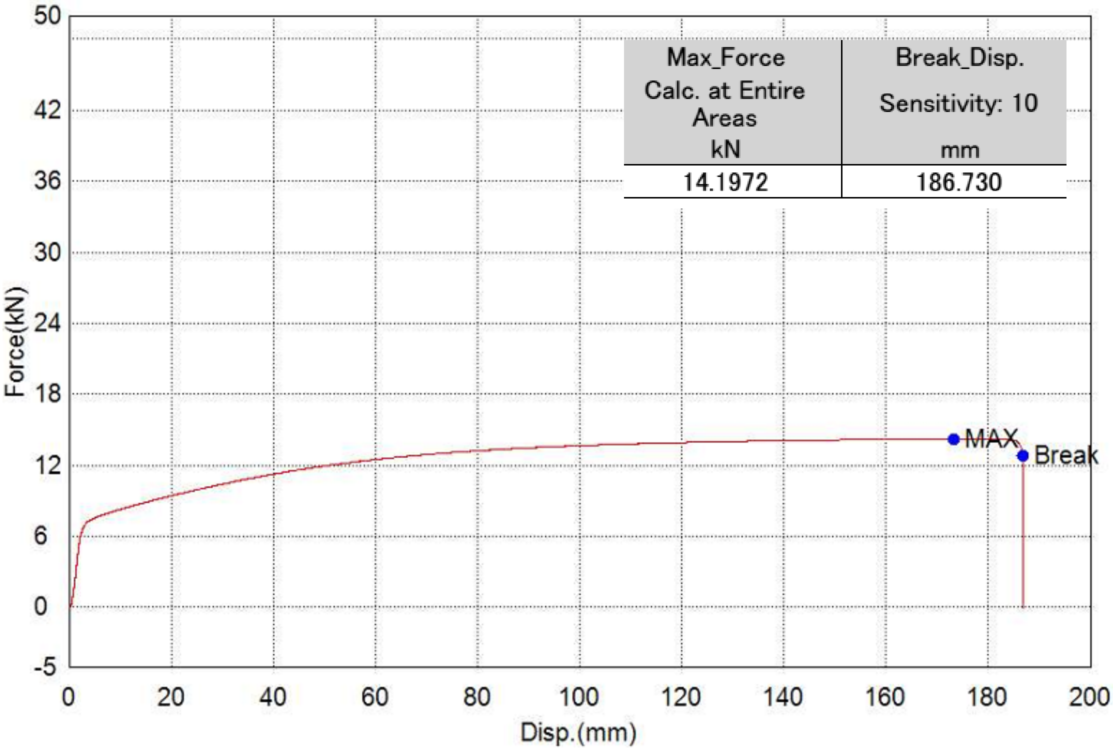
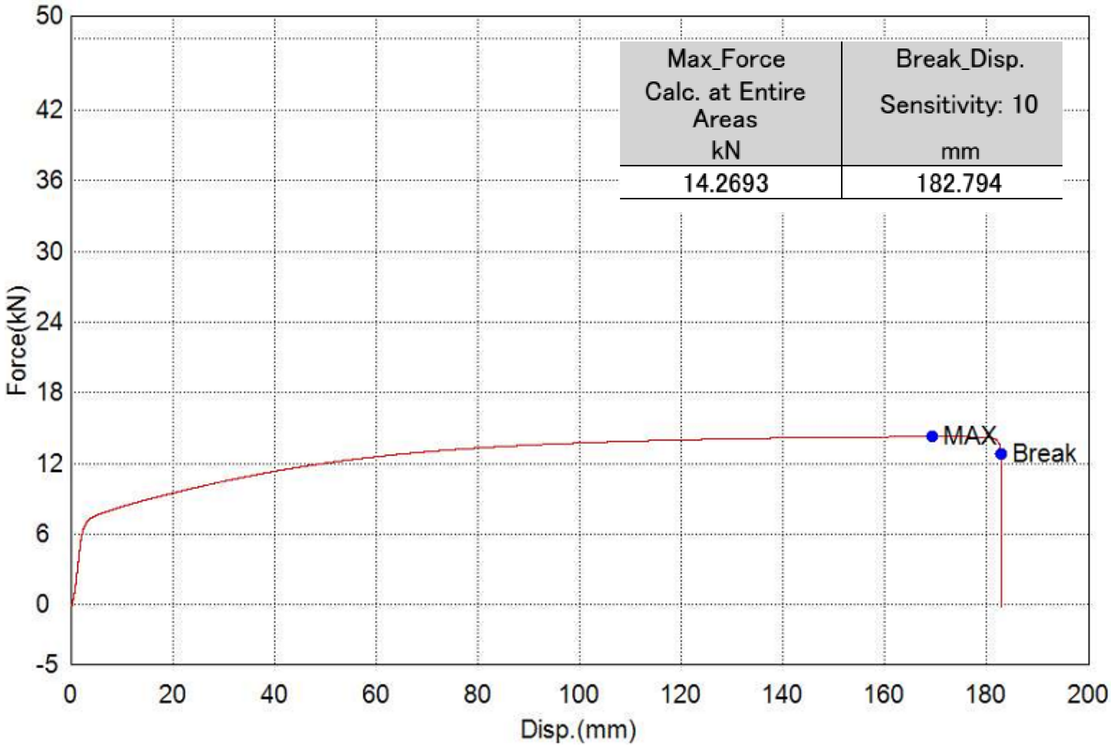
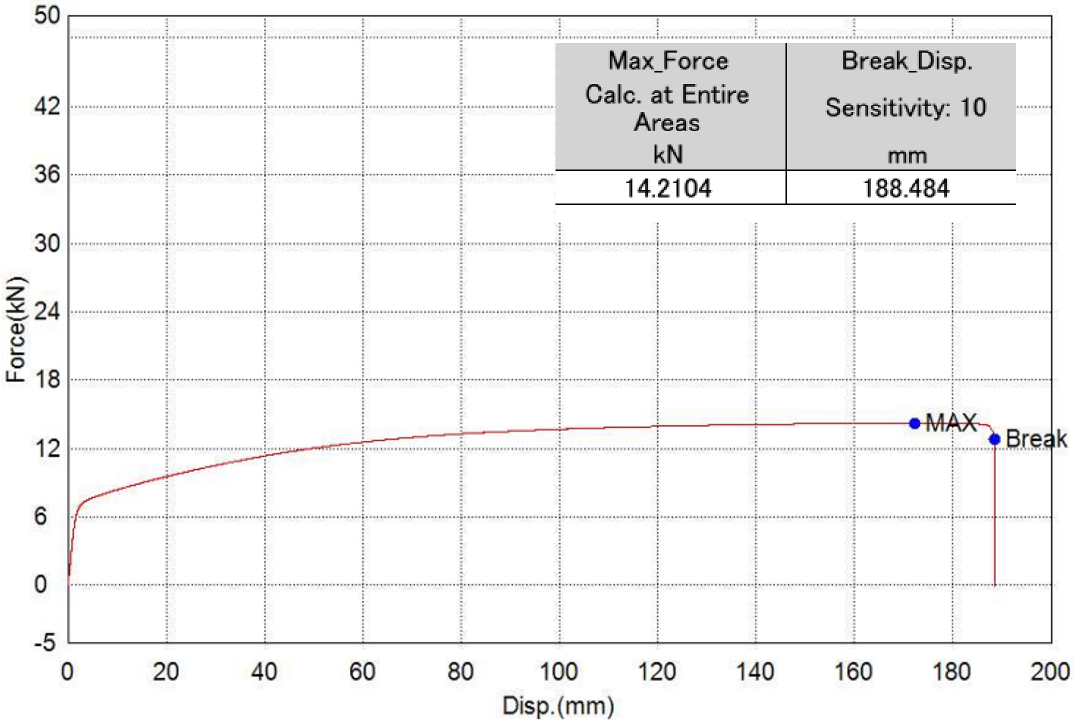


Figure 4-9: A graph of force versus displacement for sample 8 from Sample A.



Max_Force Calc. at Entire Areas kN	Break_Disp. Sensitivity: 10 mm
14.2693	182.794

Figure 4-10: A graph of force versus displacement for sample 9 from Sample A.



Max_Force Calc. at Entire Areas kN	Break_Disp. Sensitivity: 10 mm
14.2104	188.484

Figure 4-11: A graph of force versus displacement for sample 10 from Sample A.

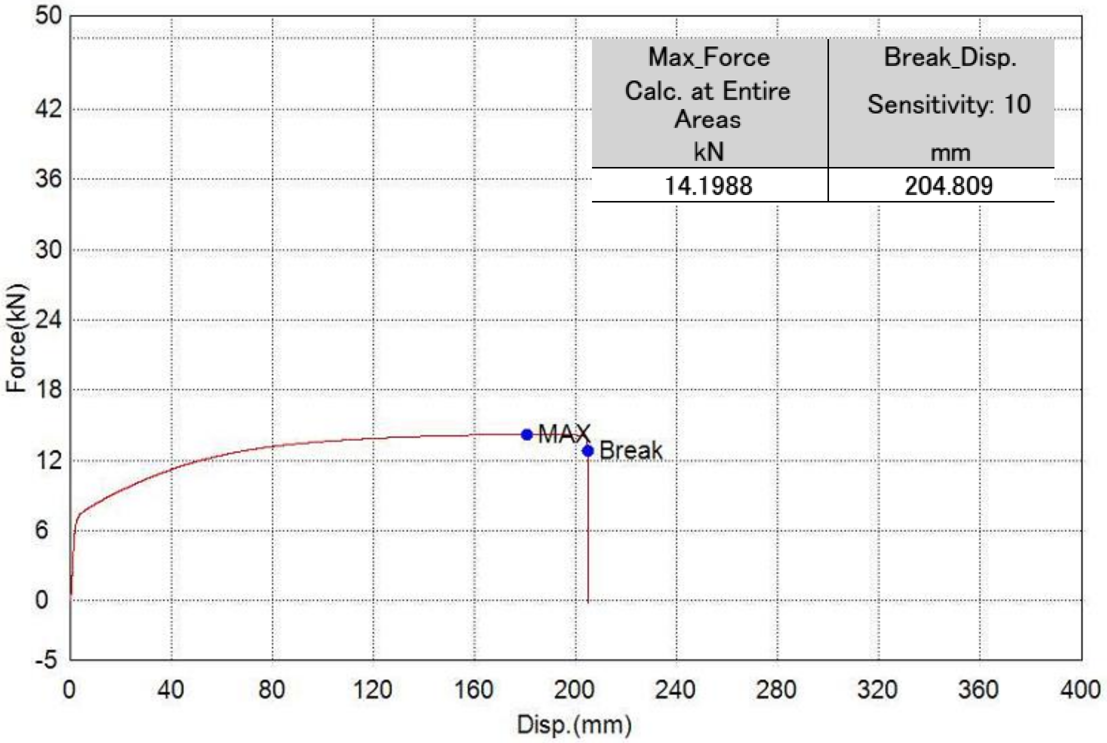


Figure 4-12: A graph of force versus displacement for sample 11 from Sample A.

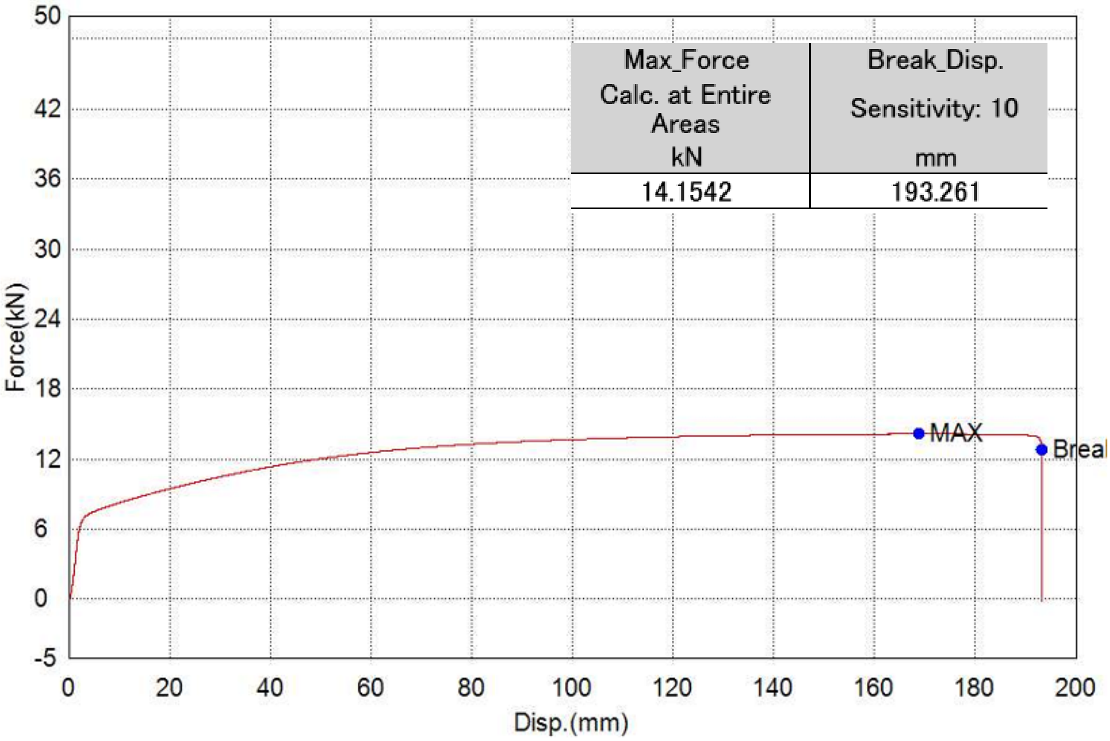


Figure 4-13: A graph of force versus displacement for sample 12 from Sample A.

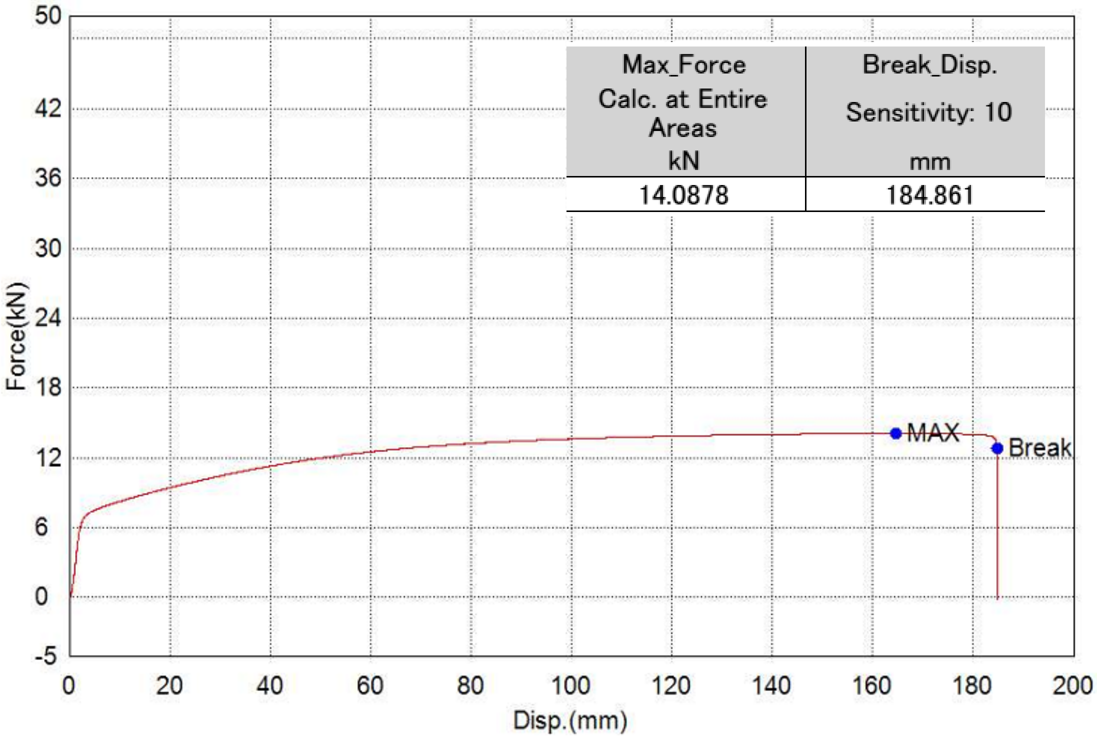


Figure 4-14: A graph of force versus displacement for sample 13 from Sample A.

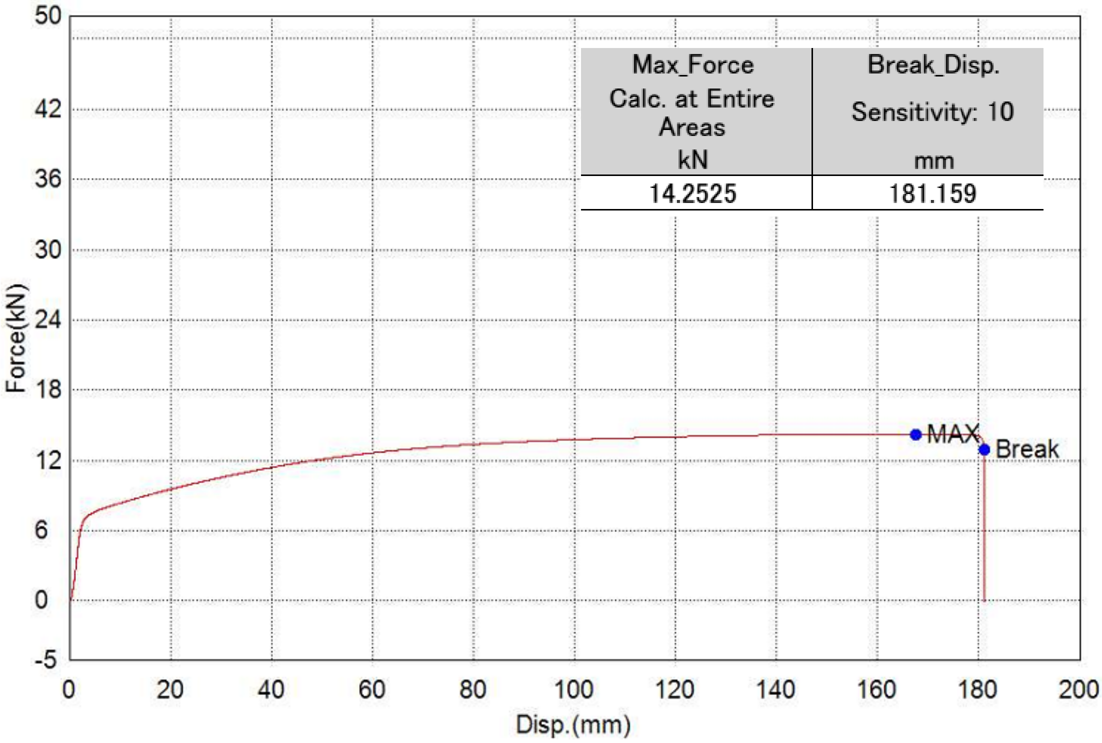


Figure 4-15: A graph of force versus displacement for sample 14 from Sample A.

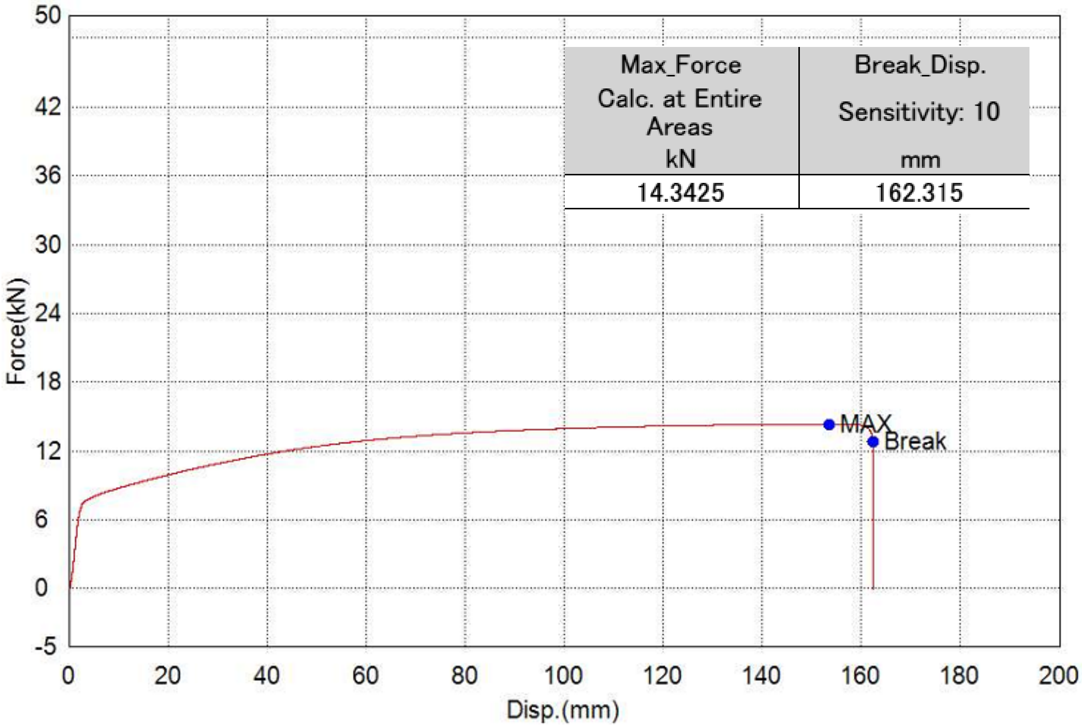


Figure 4-16: A graph of force versus displacement for sample 15 from Sample A.

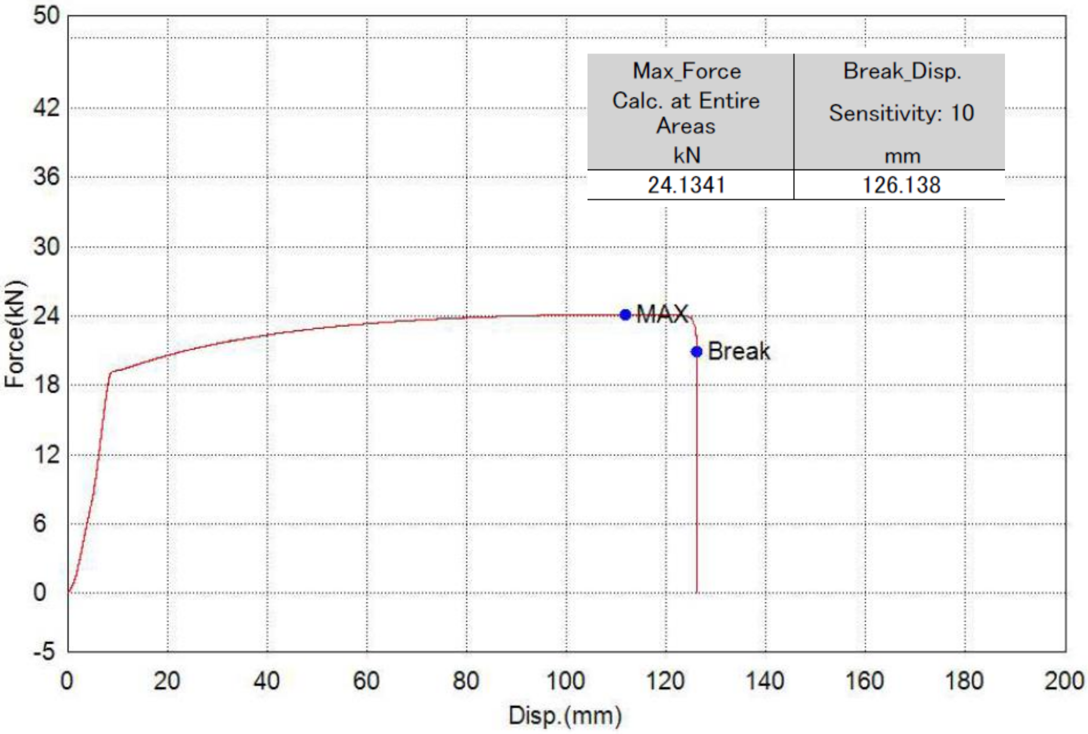


Figure 4-17: A graph of force versus displacement for sample 1 from Sample B.

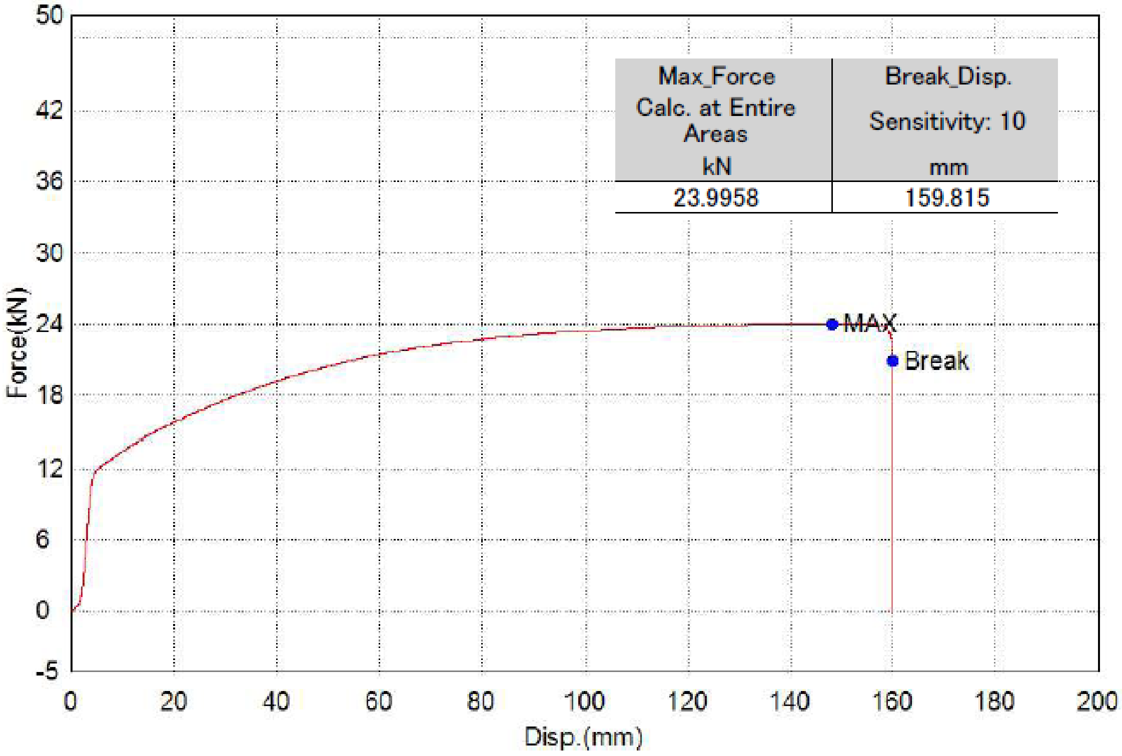


Figure 4-18: A graph of force versus displacement for sample 2 from Sample B.

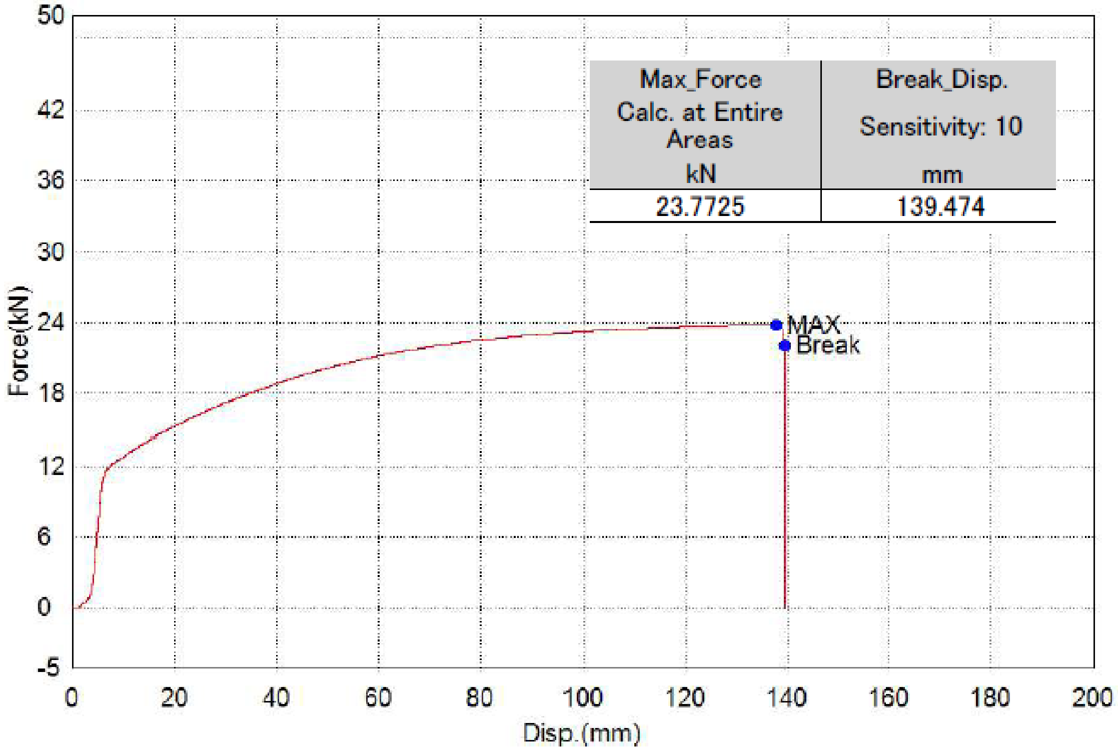


Figure 4-19: A graph of force versus displacement for sample 3 from Sample B.

Graph shown in the Figure 4-1 until Figure 4-18, there are varieties of break point that is because of the weak point in the tube are not the same. From Sample A, sample no 15 breaks around 160 mm and for sample no 1, 9, 13 and 14 break point are around 180 mm and for the break point around 200 mm are sample no 2, 3, 4, 5, 6, 7, 8, 10, 11, and 12. For Sample B, their break point are 120 mm for sample no 1, 150 mm for sample no 2 and 140 mm for sample no 3.

4.4 Stress-strain curve

From the graph force versus displacement, it has to normalized to stress-strain curve using equation (4-2) and (4-3).

$$\sigma = \frac{P}{A_0} \tag{4-2}$$

$$\in = \frac{\Delta l}{l_0} \tag{4-3}$$

From stress-strain curve, some information about material characteristics of the stainless steel 316 tube that were obtained are modulus of elasticity, tensile strength, yield strength, and ductility. Figure 4-19 to figure 4-36 are the stress-strain curve for 15 samples from Sample A and 3 samples from Sample B. Figure 4-37 is the comparison of stress-strain curve between Sample A and Sample B. Stress-strain curve of Sample A is higher than Sample B.

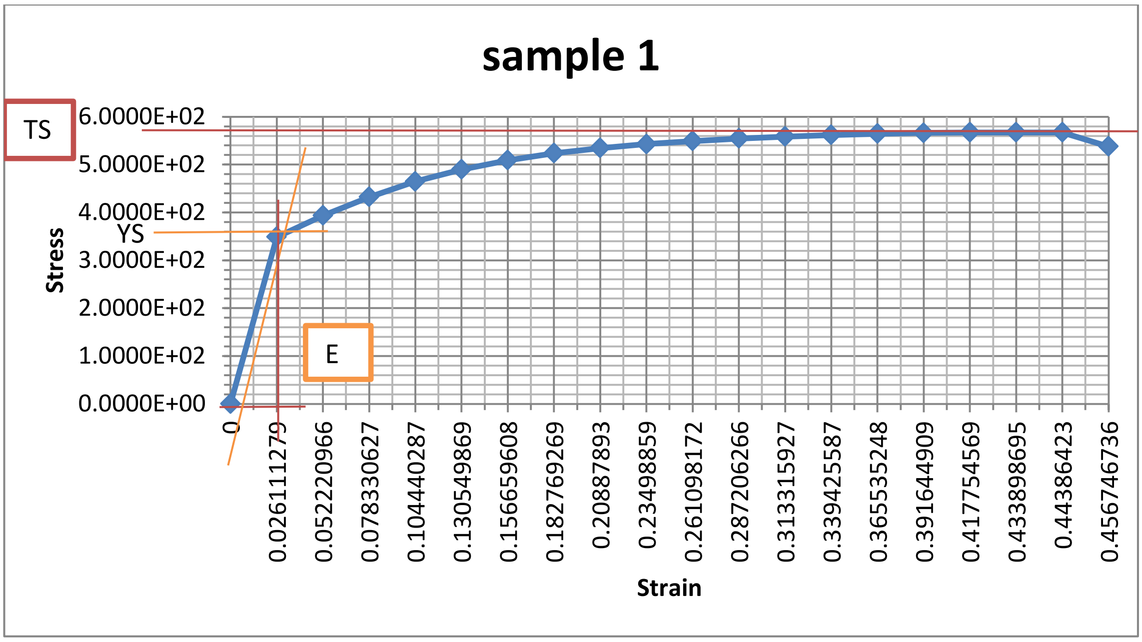


Figure 4-20: A graph of stress versus strain for sample 1 from Sample A.

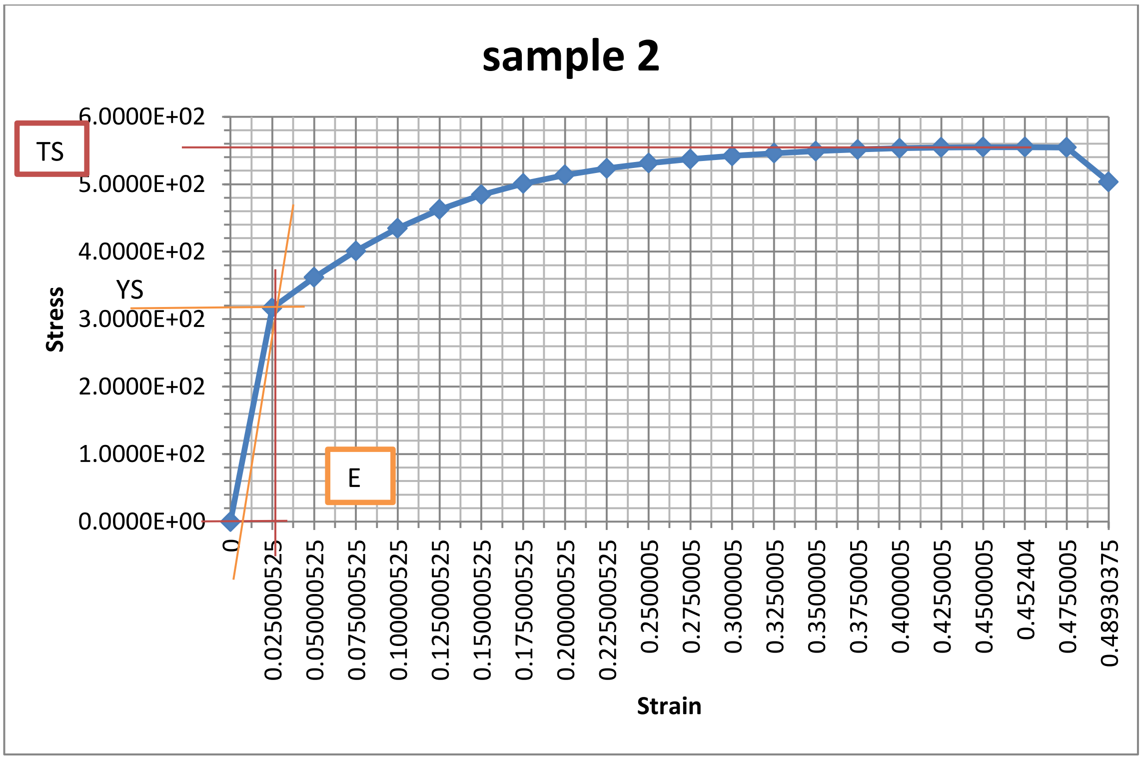


Figure 4-21: A graph of stress versus strain for sample 2 from Sample A.

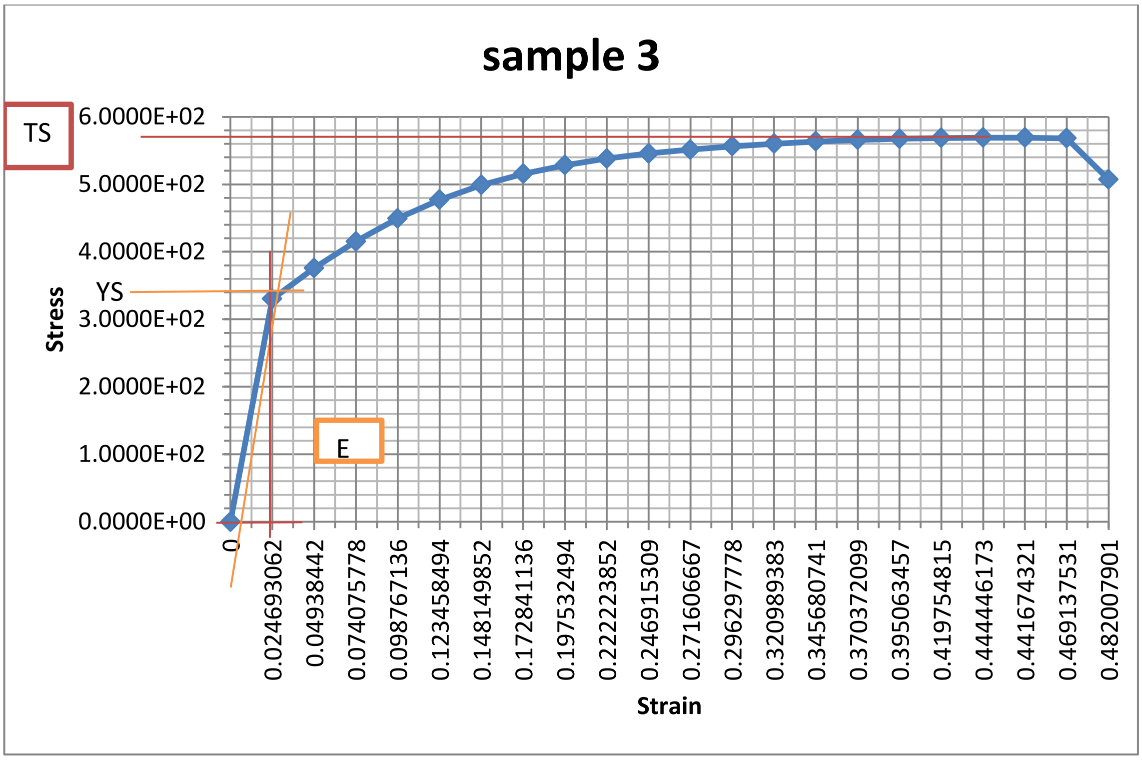


Figure 4-22: A graph of stress versus strain for sample 3 from Sample A.

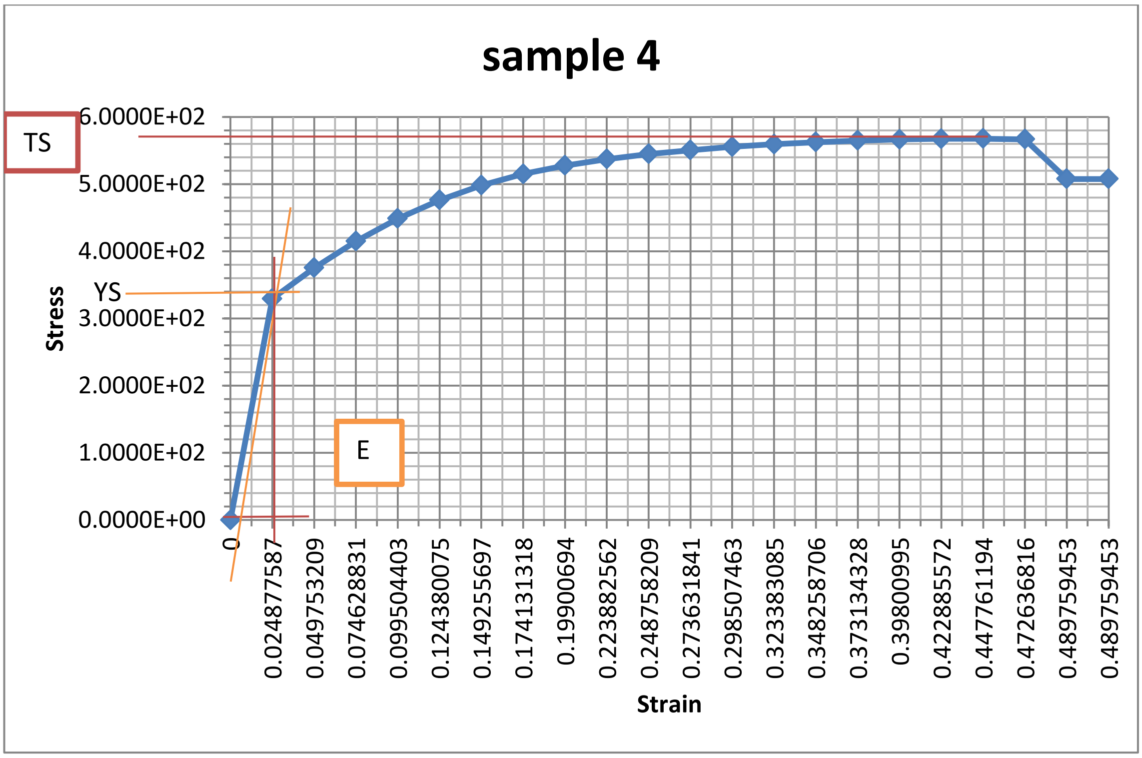


Figure 4-23: A graph of stress versus strain for sample 4 from Sample A.

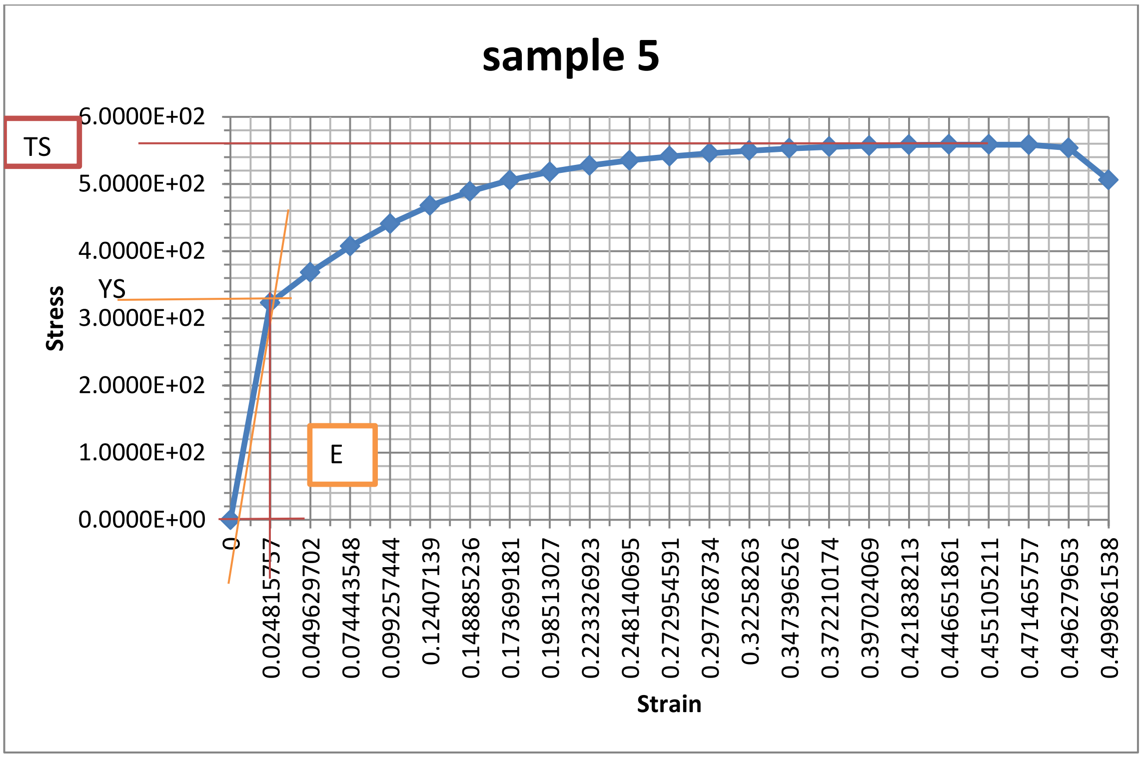


Figure 4-24: A graph of stress versus strain for sample 5 from Sample A.

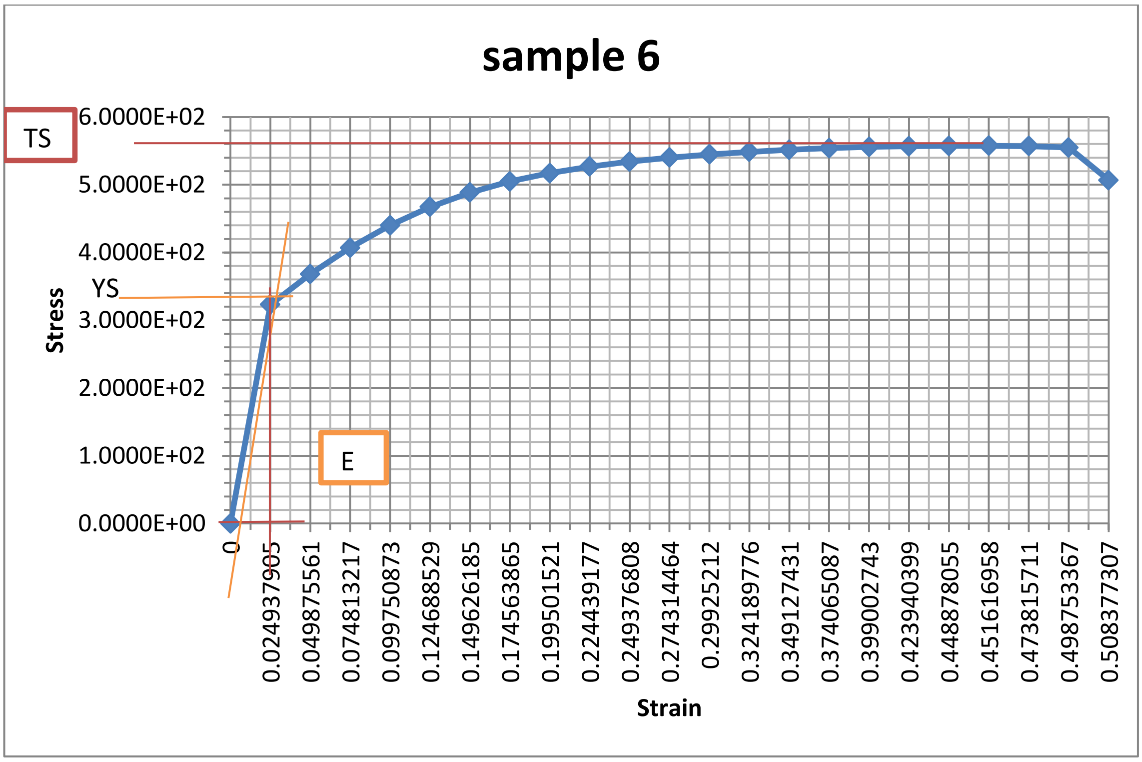


Figure 4-25: A graph of stress versus strain for sample 6 from Sample A.

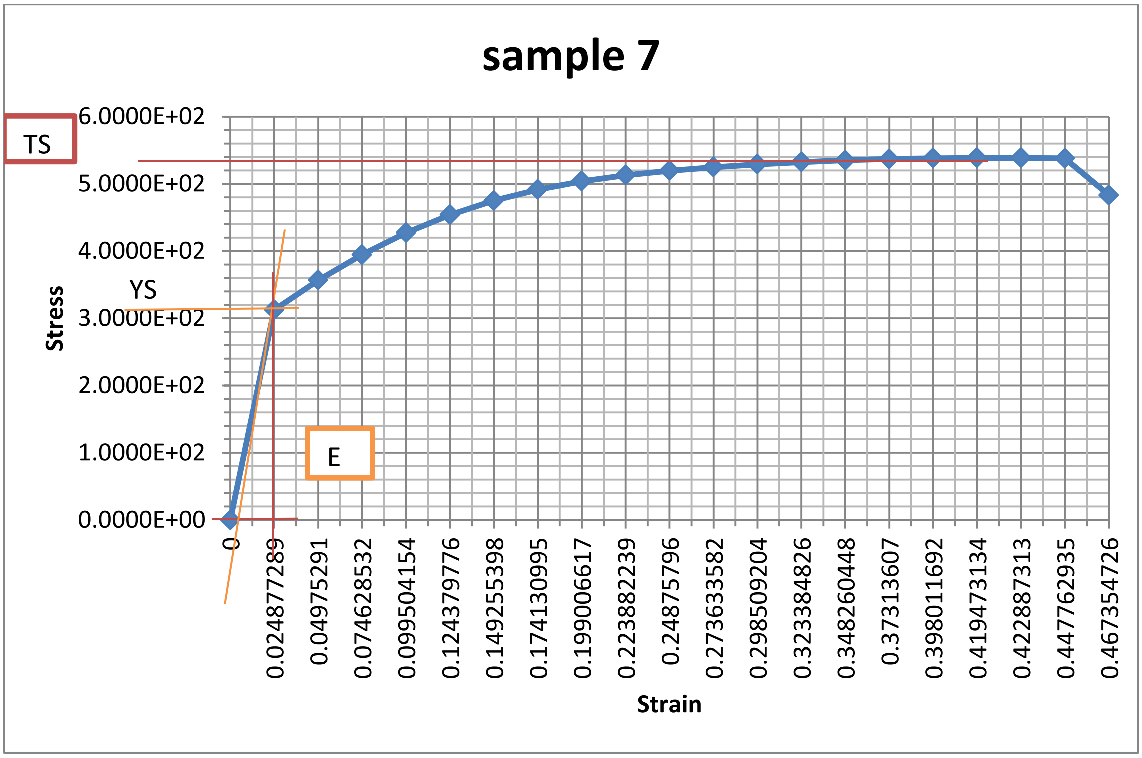


Figure 4-26: A graph of stress versus strain for sample 7 from Sample A.

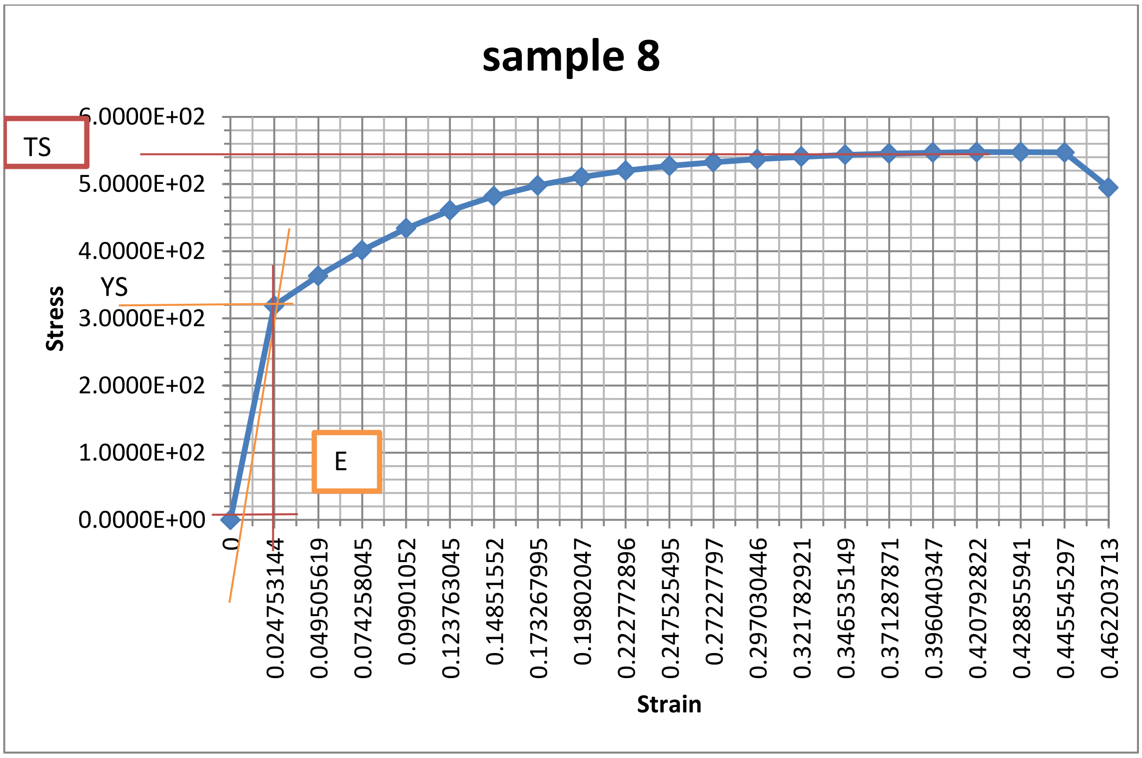


Figure 4-27: A graph of stress versus strain for sample 8 from Sample A.

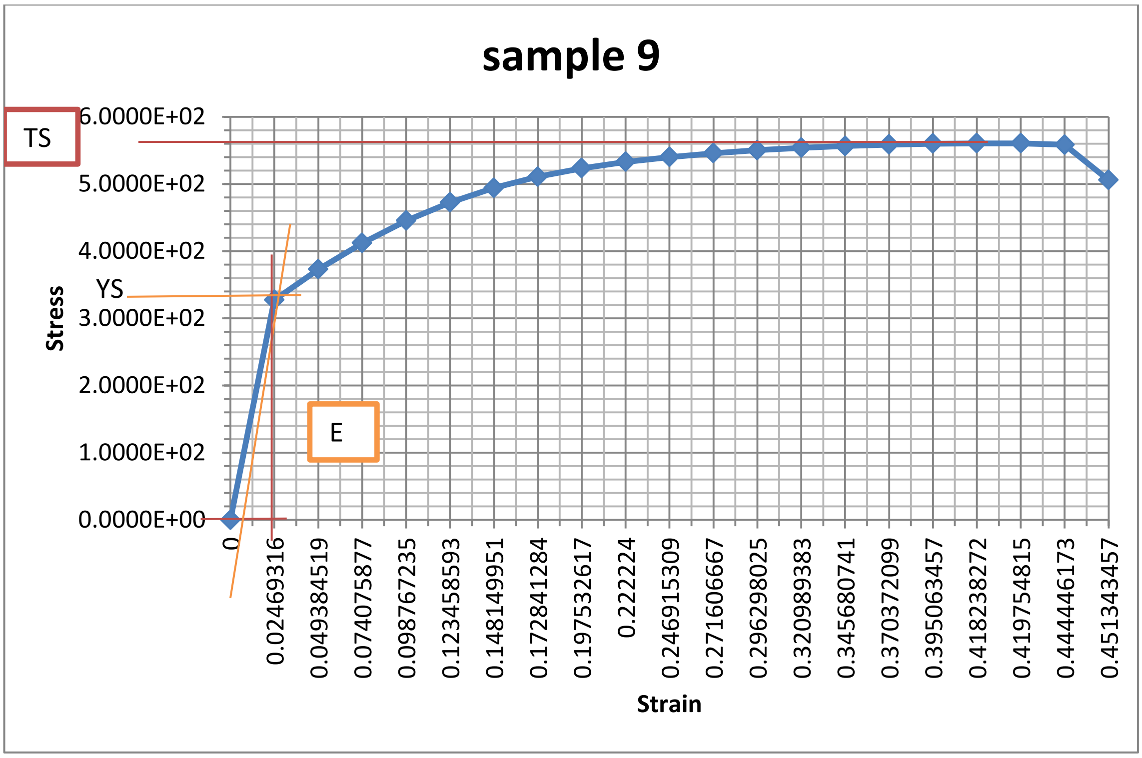


Figure 4-28: A graph of stress versus strain for sample 9 from Sample A.

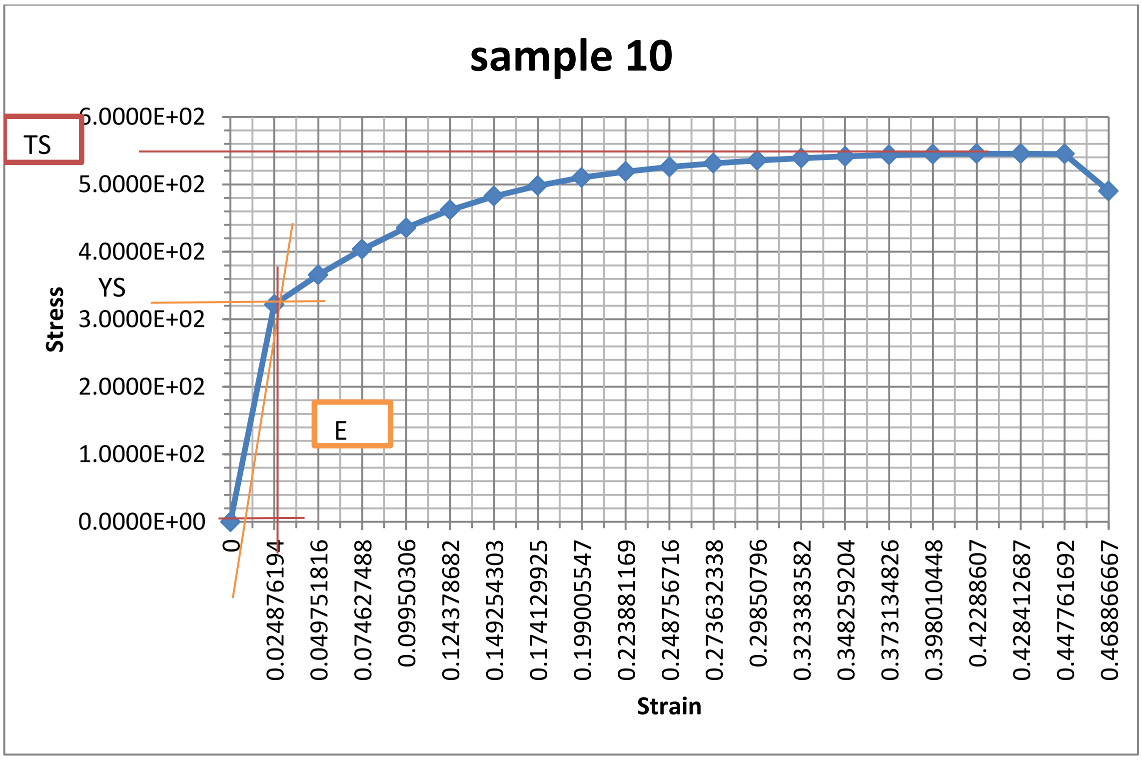


Figure 4-29: A graph of stress versus strain for sample 10 from Sample A.

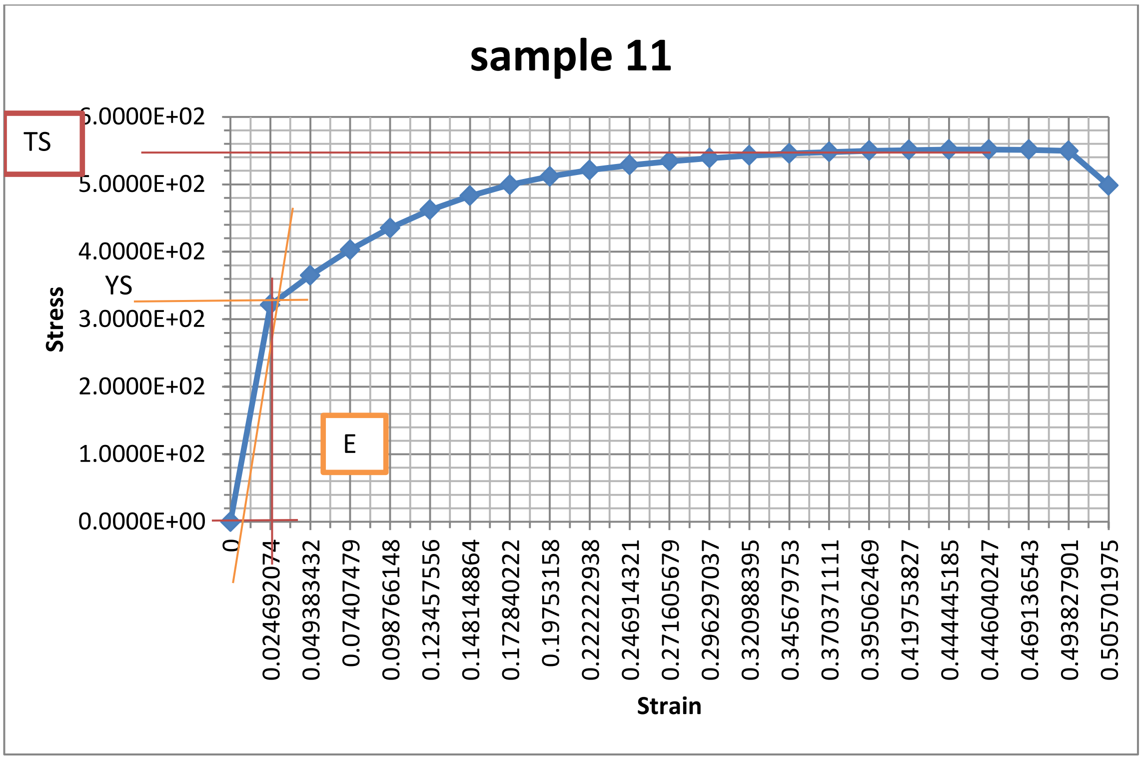


Figure 4-30: A graph of stress versus strain for sample 11 from Sample A.

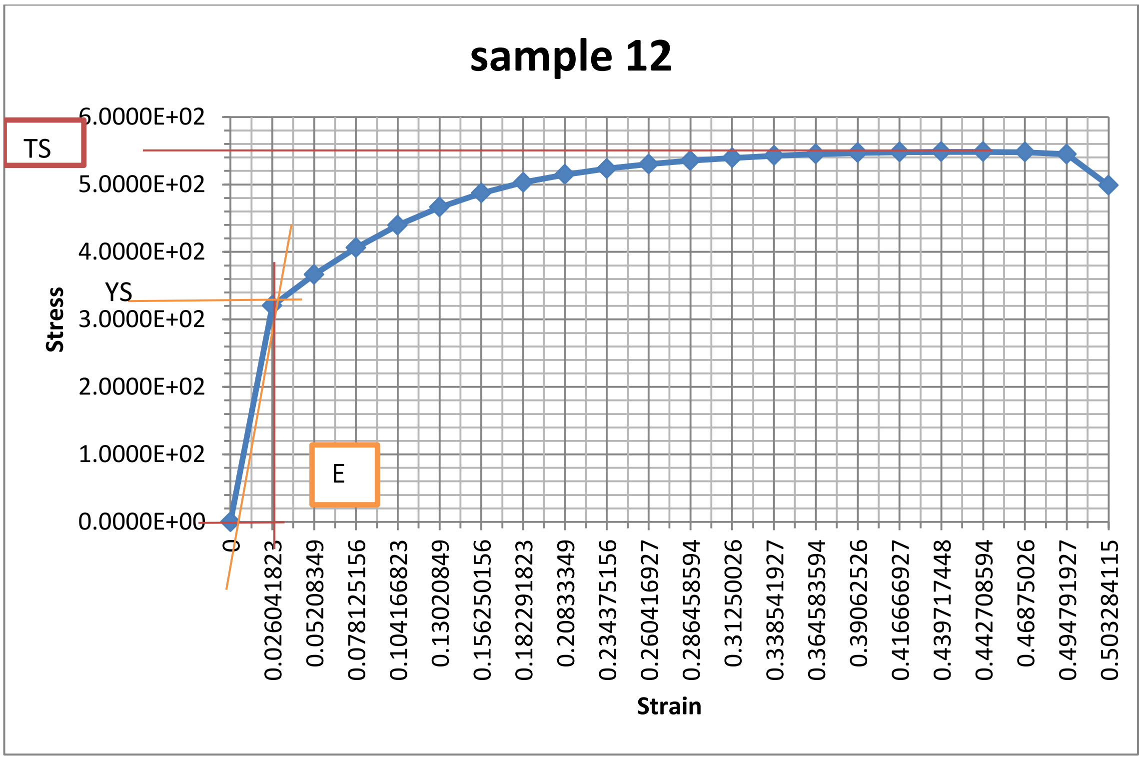


Figure 4-31: A graph of stress versus strain for sample 12 from Sample A.

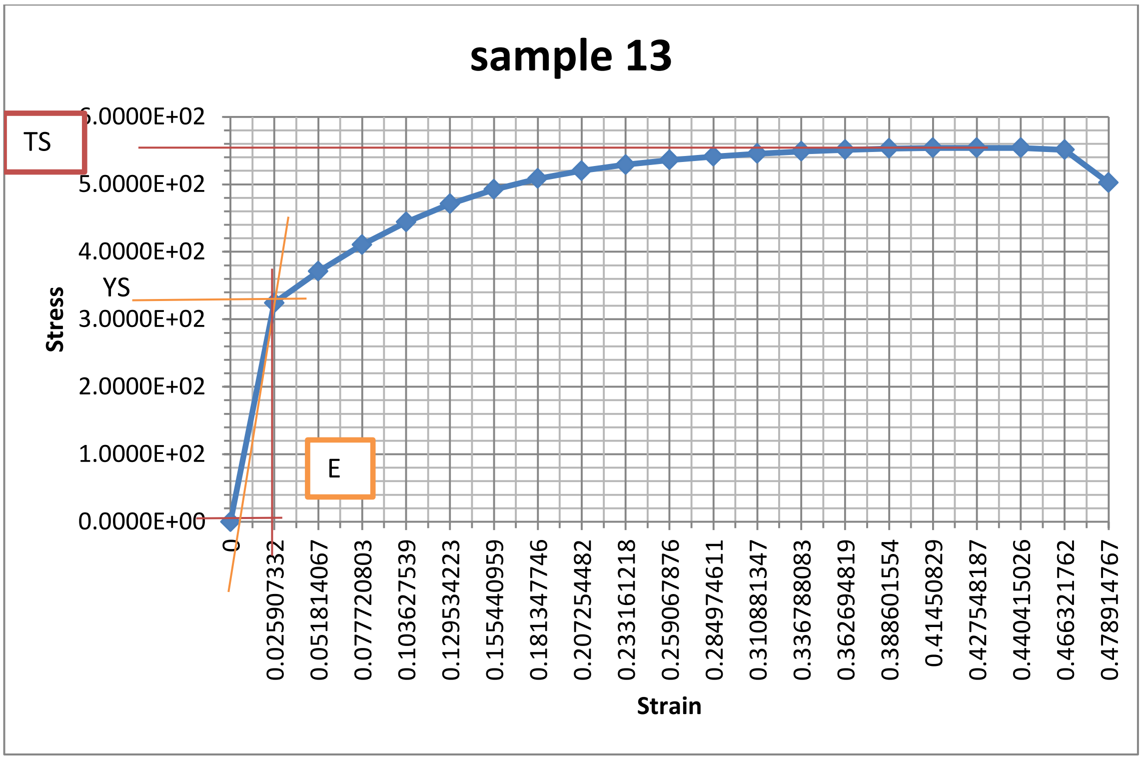


Figure 4-32: A graph of stress versus strain for sample 13 from Sample A.

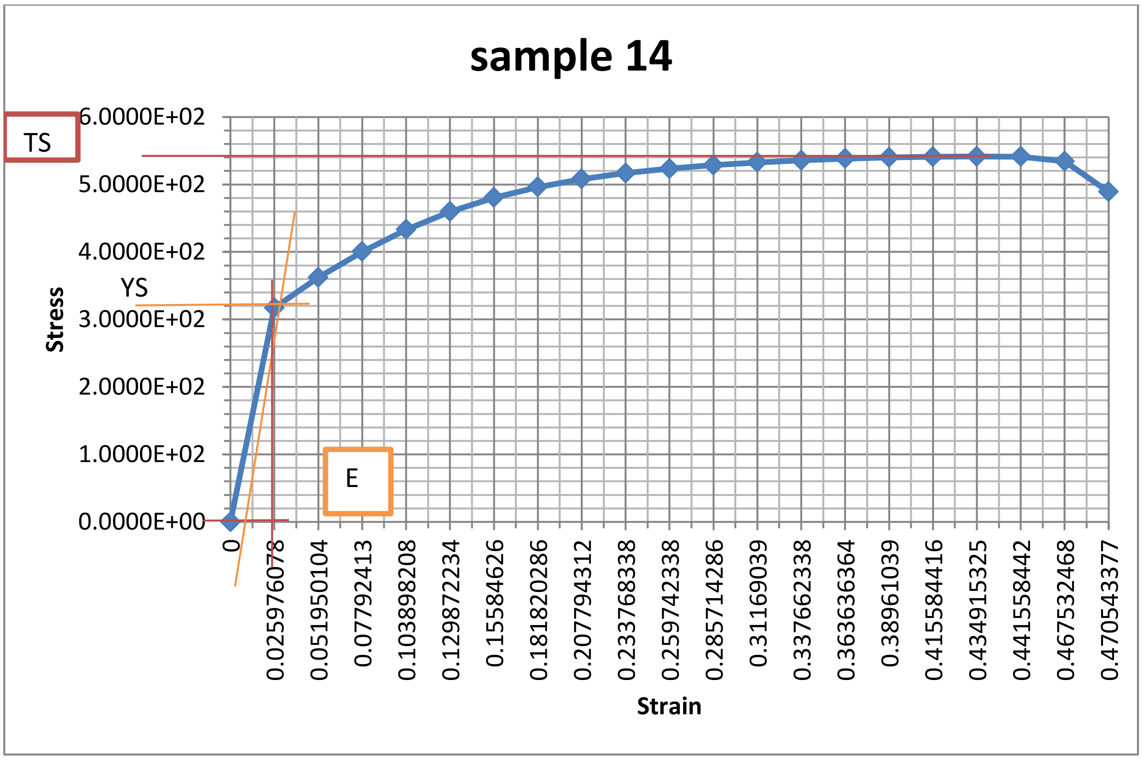


Figure 4-33: A graph of stress versus strain for sample 14 from Sample A.

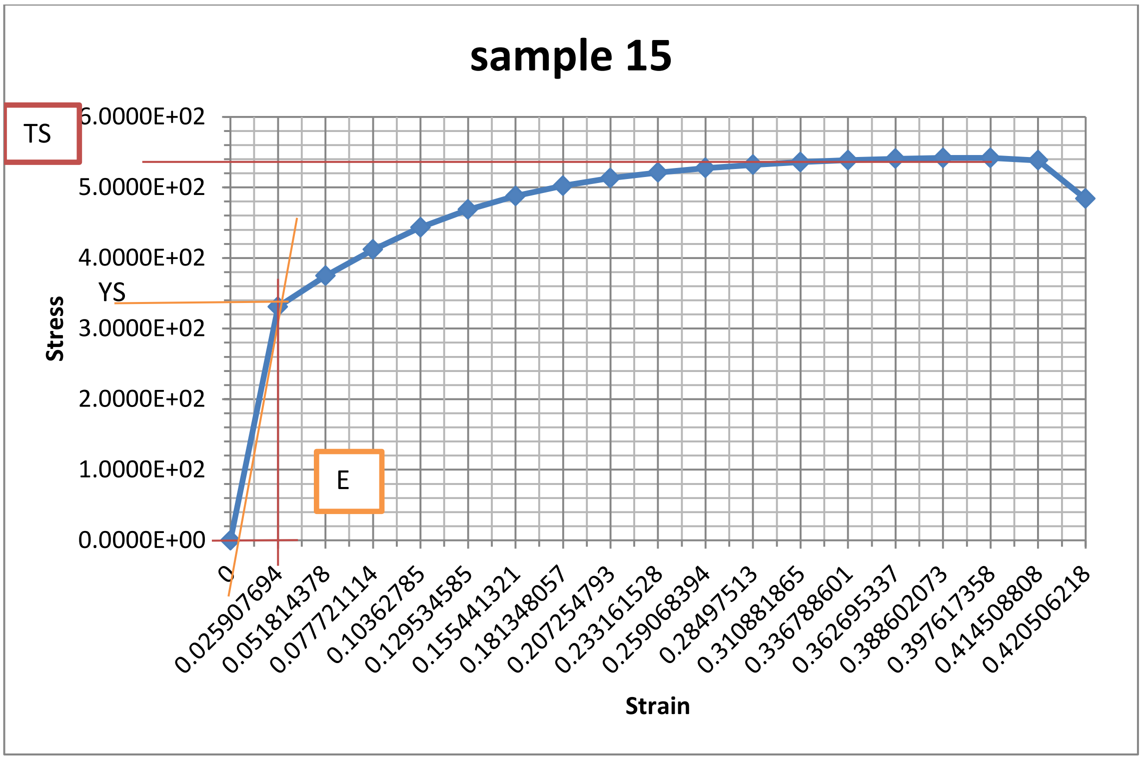


Figure 4-34: A graph of stress versus strain for sample 15 from Sample A.

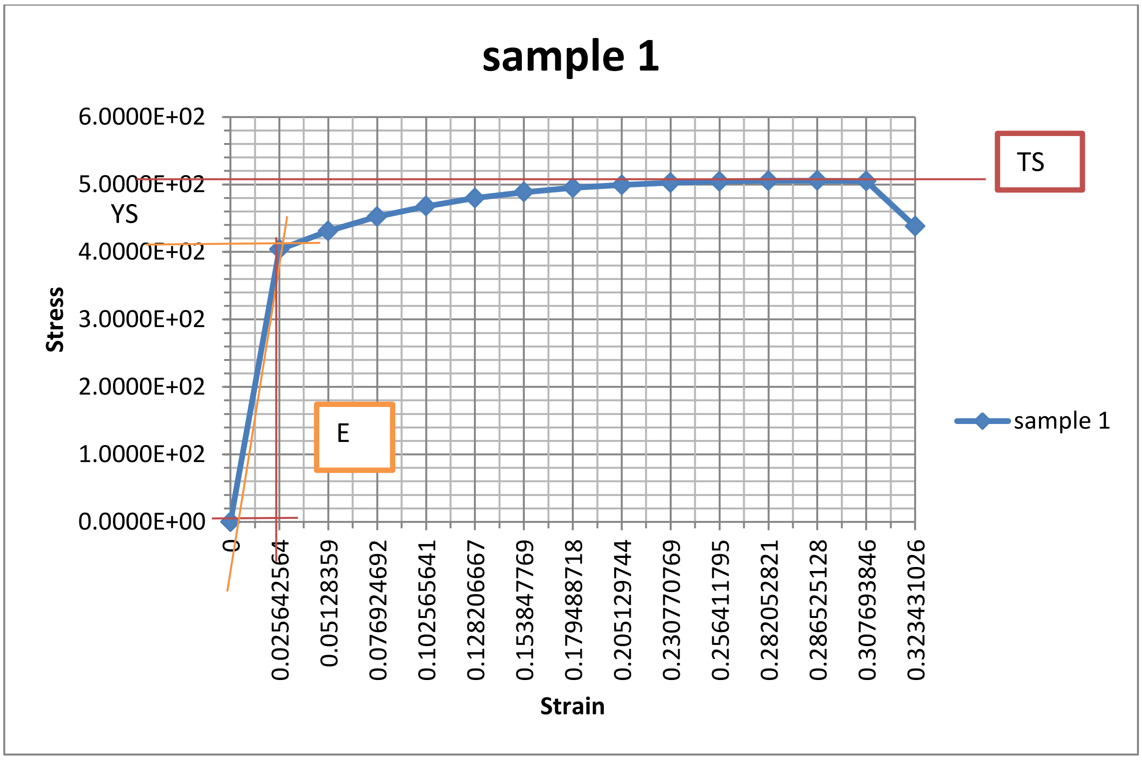


Figure 4-35: A graph of stress versus strain for sample 1 from Sample B.

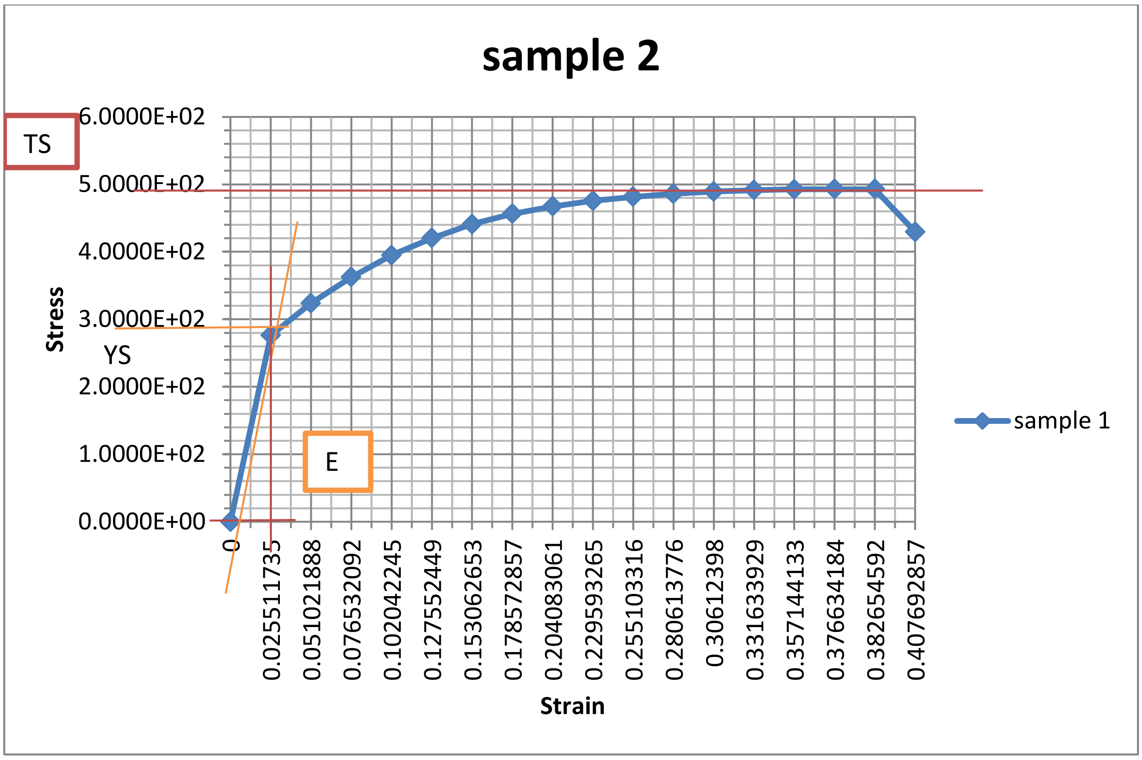


Figure 4-36: A graph of stress versus strain for sample 2 from Sample B.

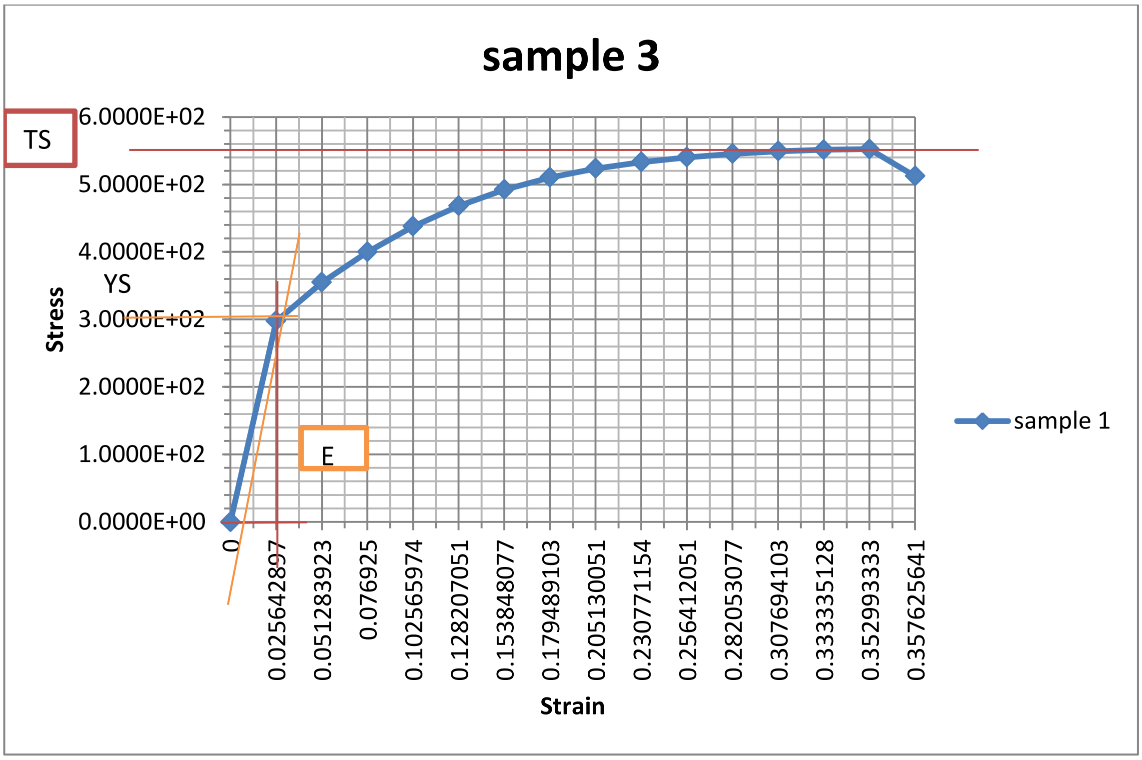


Figure 4-37: A graph of stress versus strain for sample 3 from Sample B.

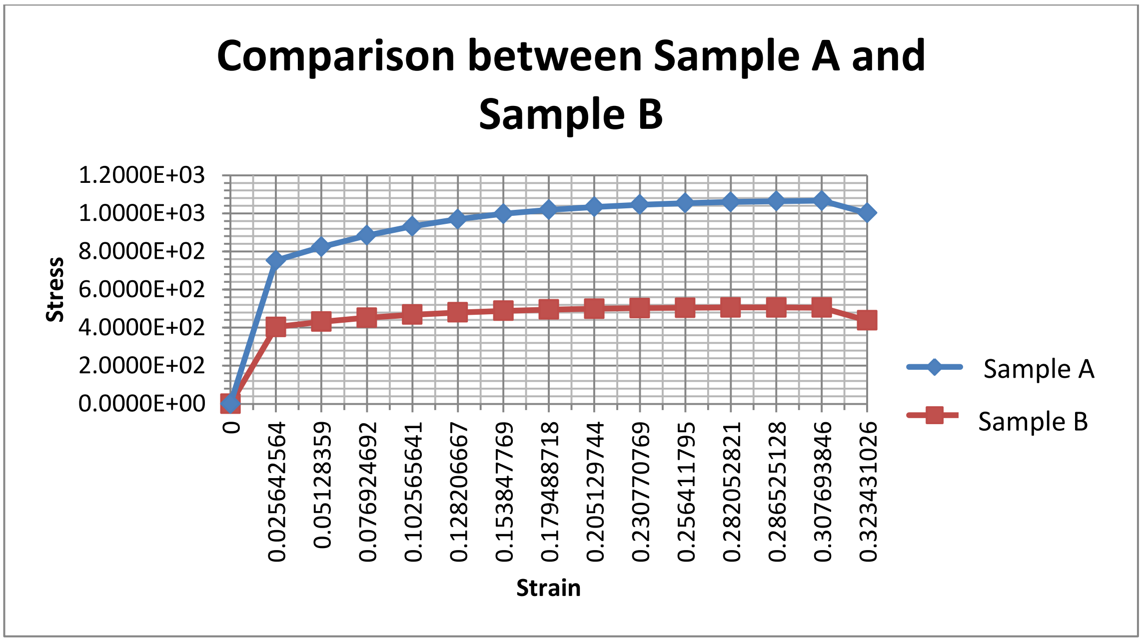


Figure 4-38: A graph of comparison of stress-strain curve between Sample A and Sample B.

From the stress-strain curve, Table 4-3 and Table 4-4 were tabulated which include the modulus of elasticity, tensile strength, yield strength and difference in strength. Table 4-5 is the comparison between Sample A and Sample B. From Table 4-5, it is found that Sample A has higher in modulus of elasticity, tensile strength and yield strength with 12869.22 MPa, 548 MPa, and 332.7333 MPa respectively than Sample B. Tensile strength means the pulling stress required to break a material. If a material has high tensile strength then it is stronger. The higher the modulus of elasticity, the stiffer the material and the harder it is to stretch it. Same goes to yield strength, the higher the yield strength the stronger the material. So, Sample A is stronger than Sample B because the modulus of elasticity, tensile strength and yield strength for Sample B are 12722.43 MPa, 536.6667 MPa, and 314 MPa respectively.

Graph that generated from Universal Tensile Machine are graph of force versus displacement. From the equation of (4-2) and (4-3), stress-strain curve were obtained. From this curve, values of tensile strength, yield strength and modulus of elasticity were obtained. From Figure 4-19, tensile strength is 562.00 MPa, yield strength is 348.00 MPa, and young modulus is 13346.91136 MPa. For Figure 4-20, tensile strength, yield strength and modulus of elasticity are 548.00 MPa, 324.00 MPa, and 12662.24122 MPa respectively. The values for other samples are tabulated in Table 4-3 for Sample A and Table 4-4 for Sample B.

4.4.1 Ductility

Ductility is quantified as the percent elongation at failure. It were calculated using equation (4-4) and the comparison were compared with the Figure 4-38. Table 4-6 is the comparison of ductility between Sample A and Sample B. Both manufactures are larger than 5% so both are ductile.

Table 4-6: Comparison of ductility between Sample A and Sample B.

	Sample A	Sample B
%EL	44.04501932	36.09215017

4.5 Summary

This chapter presents results and discussions of stainless steel 316 tubing. It contains subchapter of results from Universal Tensile Machine, Stress-strain curve and ductility.

6 CONCLUSION

6.1 Conclusion

From the stress-strain curve, values obtained were the modulus of elasticity, ductility, tensile strength and yield strength for Sample A which are 12869.22 MPa, 44.04501932%, 548 MPa, and 332.7333 MPa respectively. And for value of modulus of elasticity, ductility, tensile strength and yield strength for Sample B were 12722.43 MPa, 36.09215017%, 536.6667 MPa, and 314 MPa respectively. From values that obtained, the material characteristics of Sample A are found to be stronger than Sample B.

6.2 Future work

For future study, it is essential to test more characteristic such as toughness and burst pressure test. Use more specimens with various wall thicknesses and outer diameter is better. Take various manufactures for more variety in results.

REFERENCES

Atlas Steels Australia. (2013). *Stainless Steel - Grade 316 (UNS S31600).*Retrieved from http://www.azom.com/article.aspx?ArticleID=863

Atlas Steels Australia. (2013). *Stainless Steels - Introduction To The Grades And Families.* Retrieved from http://www.azom.com/article.aspx?ArticleID=470

Callahan F.J. (1998). *Swagelok: Tube Fitter's Manual.* Ohio: Swagelok Company.

Callister W.D. & Rethwisch D.G. (2008). Fundamentals of Materials Science and Engineering. (3rd ed.). *Chapter 7: Mechanical Properties of Solids* (p. 186-241). United States: John Wiley & Sons, Inc.

Eleiche A.M., Albertini C. & Montagnani M. (1985). The Influence of Strain-Rate History on the Ambient Tensile Strength of AISI Type 316 Stainless Steel. *Nuclear Engineering and Design 88* (p.131-141). Retrieved 8 April, 2012, from Science Direct.

Granta. (2011). *Yield strength, elastic limit, and ultimate strength*. Retrieved from http://inventor.grantadesign.com/en/notes/science/material/S04%20Yield%20strength.htm

Gedney R. (2002). Guide to Testing Metals Under Tension. *Advanced Materials & Processes.* Retrieved 10 April, 2012, from http://admet.com/assets/PracticalGuidetoMetalsTestinginTension.pdf

Jadhav A. (2010). Stainless Steel Types and Properties. *Buzzle.com.* Retrieved 8 April, 2012, fromhttp://www.buzzle.com/articles/stainless-steel-types-and-properties.html

Parker Hannifin Corporation. (2010). *Instrument Tubing Selection Guide.* Retrieved fromhttp://www.moodyprice.com/customer/moprll/pdf/tube%20selection%20guide.pdf

The OHIO State University. (n.d). *Modulus of Elasticity*. Retrieved from http://stampingsimulation.com/engineering-definitions-details/modulus-of-elasticity/

Udomphol T. (n.d.). Laboratory 3: Tensile Testing. *Mechanical metallurgy laboratory*. Retrieved 9 April, 2012, from http://eng.sut.ac.th/metal/images/stories/pdf/ Lab_3Tensile_Eng.pdf

Zhu X.-K. & Leis B.N. (2012). Evaluation of burst pressure prediction models for line pipes. *International Journal of Pressure Vessels and Piping*. Retrieved 20 March, 2012, from Science Direct.

APPENDICES

Figure 0-1: Test specimens before loading.

Figure 0-2: Test specimens after fracture.

Figure 0-3: Specimen in Universal Tensile Machine.

Figure 0-4: Specimen after break.

PHYSICAL TEST OF STAINLESS STEEL 316 BETWEEN DIFFERENT MANUFACTURES

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ABSTRACT

Tubing is usually used in crude oil instrumentation system, natural gas, industrial gas, and food industry. With the involvement of the oil and gas tubing, many products would be affordable to be manufactured and the costs to convey these products to market would be economical. Products marking in the tubes include manufacture name or brand, specification number and grade on tubes. Different manufacture has different material characteristic although it is of the same grade. Thus, this research is performing to determine the modulus of elasticity, tensile strength and yield strength of stainless steel 316 from different manufactures. Comparison of modulus of elasticity, tensile strength and yield strength of stainless steel 316 from different manufactures are made. By appropriate scaling, load and displacement data that were obtained in the test were calibrated and cross-plotted to give an engineering stress-strain curve for each and every specimen. From the Universal Tensile Machine, graph of force versus displacement is generated. From the stress-strain curve, values of modulus of elasticity, ductility, tensile strength and yield strength for Sample A were 12869.22 MPa, 44.04501932%, 548 MPa, and 332.7333 MPa respectively. And for values of modulus of elasticity, ductility, tensile strength and yield strength for Sample B were 12722.43 MPa, 36.09215017%, 536.6667 MPa, and 314 MPa respectively. From the values that were obtained, the material characteristics of Sample A are found to be stronger than Sample B.

Keywords: Tubing, Stainless Steel, SS 316, tensile test, stress-strain curve, Universal Tensile Machine.

INTRODUCTION

Basically, stainless steel is an alloy of steel with a minimum of 11% chromium and more than 50% iron in it. It is highly strain, corrosion resistant and rust resistant that requires minimum maintenance. Some of these properties can be modified by adding metals like molybdenum, titanium, nickel, etc. in the substance of stainless steel which will gives increase to changes in its mechanical and physical properties. Because of their changes, there is hundreds of stainless steel grades can be created and used for a variety of function. Because of the features of stainless steel, most of industries used stainless steel tubes in gas installation system. As explained by Jadhav (2010).

As described in Atlas Steels Australia (2013), chemical formula for stainless steel grade 316 are Fe, <0.03% C, 16-18.5% Cr, 10-14% Ni, 2-3% Mo, <2% Mn, <1% Si, <0.045% P, and <0.03% S. Grade 316 is the standard molybdenum- bearing grade, second in importance to 304 amongst the austenitic stainless steels. The molybdenum gives 316 better overall corrosion resistant properties than Grade 304, particularly higher resistance to pitting and crevice corrosion in chloride environments. It has excellent forming and welding characteristics. It is readily brake or roll formed into a variety of parts for applications in the industrial, architectural, and transportation fields. Grade 316 also has outstanding welding characteristics. Post-weld annealing is not required when welding thin sections. Grade 316L, the low carbon version of 316 and is immune from sensitisation (grain boundary carbide precipitation). Thus it is extensively used in heavy gauge welded components (over about 6mm). Grade 316H, with its higher carbon content has application at elevated temperatures, as does stabilised grade 316Ti. The austenitic structure also gives these grades excellent toughness, even down to cryogenic temperatures.

When doing a testing, the selected tubing should similar to the tubing normally used in industries. The involvement of special selection or treatment should be avoided. If tubing used in industries not easy to get to, specifics recommended by fitting manufacturers, or to ASTM or other applicable standards for tubing can also be bought. These recommendations have been made by Callahan (1998).

MATERIALS AND METHODS

Specimens

In this research, samples used are stainless steel 3/8 inch tubing with wall thickness 0.035 inch from Sample A and Sample B. Each manufacturer has 6 meter length tubing. From 6 meter, it is cut into 400 mm. Sample A have 15 samples and Sample B has 3 samples which look like Figure 3-3. Before loading into Universal Tensile Machine, their dimensions have been taken which are length, external diameter, internal diameter, and weight by using vernier calliper, ruler, and analytical balance.

Universal Tensile Machine

Gedney (2002) stated that universal testers are the most usual testing machines, which test materials in tension, compression, or bending. To generate the stress-strain curve is their main function. After the diagram is created, a pencil and straight-edge, or a computer algorithm, may calculate yield strength, Young’s modulus, tensile strength, or total elongation. Some of the types of testing machine are electromechanical or hydraulic. The method by which the load is applied is the only principal difference. In this research, constant speed is used that is 5 mm/min. After loading the specimen, a graph of force versus displacement is generated.

Collecting Data

As stated by Eleiche, Albertini & Montagnani (1985), the test will be consist of interrupting the quasi-static loading of tensile specimens after some uniform straining, unloading, then dynamics reloading up to fracture. We get the result of graph force versus displacement.

RESULTS AND DISCUSSION

There are a few parameters that we measured before loading the tube. The parameters are list in Table 1 for Sample A and Table 2 for Sample B.

Table 1: Parameters for Sample A

sample no	L1 (mm)	L2 (mm)	ΔL	weight (g)	outer diameter (mm)	internal diameter (mm)	r1 (mm)	r2 (mm)	area (mm2)	break
1	383	547	164	71.46	9.52	7.64	3.82	4.76	25.33757	174.934
2	400	585	185	75.54	9.56	7.64	3.82	4.78	25.93699	195.721
3	405	584	179	76.25	9.56	7.66	3.83	4.78	25.69666	195.213
4	402	584	182	75.33	9.56	7.67	3.835	4.78	25.57626	196.883
5	403	590	187	75.37	9.56	7.65	3.825	4.78	25.8169	201.444
6	401	588	187	75.43	9.56	7.62	3.81	4.78	26.17669	203.859
7	402	575	173	74.74	9.55	7.59	3.795	4.775	26.38498	187.876
8	404	576	172	75.62	9.56	7.64	3.82	4.78	25.93699	186.73
9	405	573	168	75.72	9.56	7.68	3.84	4.78	25.4557	182.794
10	402	575	173	75.15	9.56	7.63	3.815	4.78	26.05692	188.484
11	405	595	190	75.54	9.54	7.63	3.815	4.77	25.7569	204.809
12	384	562	178	71.49	9.56	7.65	3.825	4.78	25.8169	193.261
13	386	556	170	72.08	9.55	7.67	3.835	4.775	25.42617	184.861
14	385	551	166	72.14	9.57	7.62	3.81	4.785	26.32694	181.159
15	386	534	148	72.72	9.54	7.57	3.785	4.77	26.47318	162.315

Table 2: Parameters for Sample B

sample no	L1 (mm)	L2 (mm)	ΔL	weight (g)	outer diameter (mm)	internal diameter (mm)	r1 (mm)	r2 (mm)	area (mm2)	break
1	390	533	143	123.63	9.53	5.48	2.74	4.765	47.74475	126.138
2	392	537	145	124.27	9.53	5.37	2.685	4.765	48.68212	159.815
3	390	525	135	123.41	9.51	5.97	2.985	4.755	43.03919	139.474

In this test, from the constant speed that is 5 mm/min the graph of force versus displacement were obtained for tubing 3/8 inch diameter for 15 samples from Sample A and 3 samples from Sample B. Every graph has different break point because along the specimen, there are difference weak points that will break at difference point. Following are some of the graphs that were obtained:

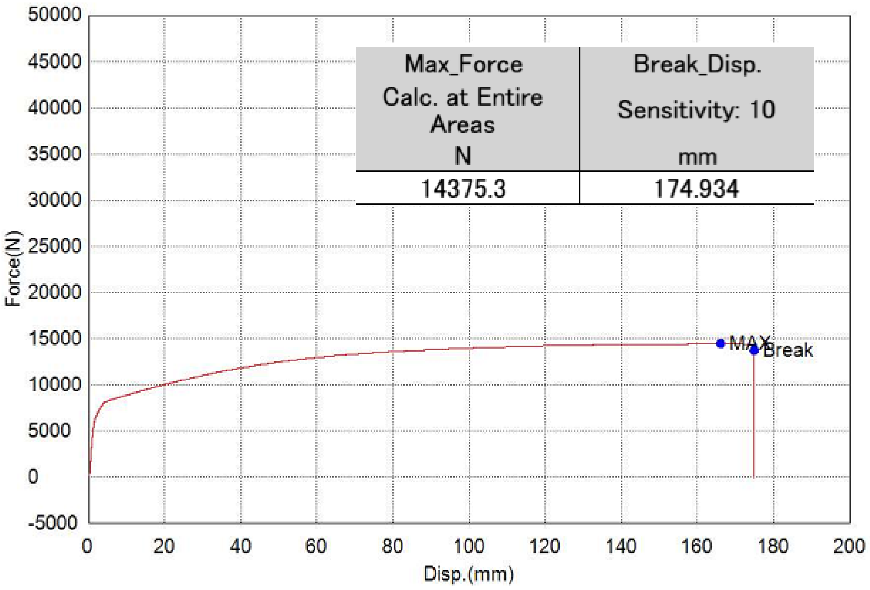

Figure 5: A graph of force versus displacement for sample 1 from Sample A.

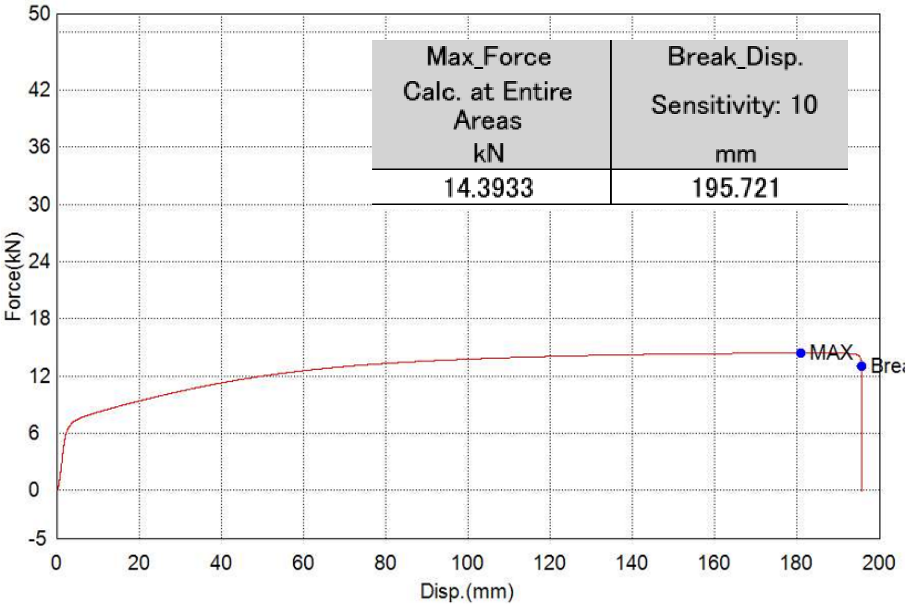

Figure 6: A graph of force versus displacement for sample 2 from Sample A.

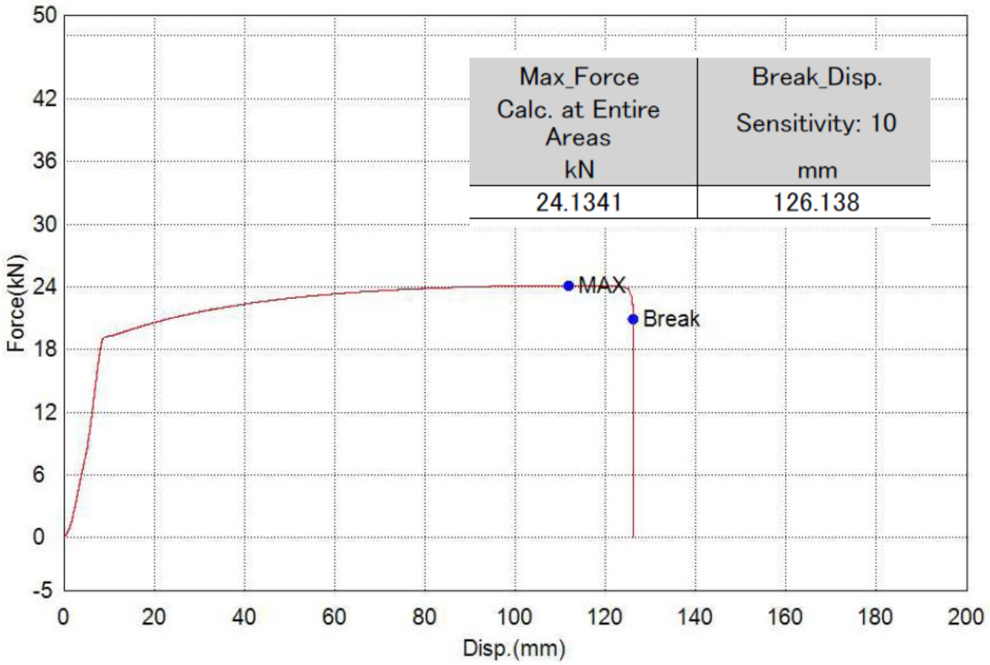

Figure 3: A graph of force versus displacement for sample 1 from Sample B.

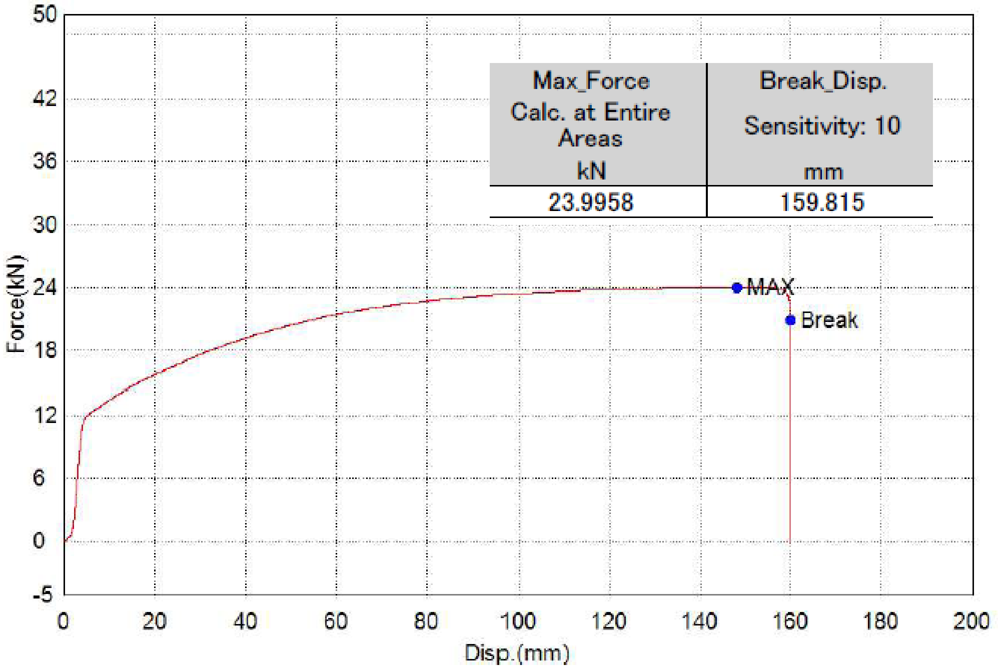

Figure 4: A graph of force versus displacement for sample 2 from Sample B.

From the graph force versus displacement, normalized the graph to stress-strain curve using equation (1) and (2).

(1)

$$\in = \frac{\Delta l}{l_0}$$

(2)

From stress-strain curve, some information about material characteristics of the stainless steel 316 tube were obtained that are modulus of elasticity, tensile strength, yield strength, and ductility. Figure 5 to figure 6 are the stress-strain curve. Figure 7 is the comparison of stress-strain curve from Sample A and Sample B. Stress-strain curve of Sample A is higher than Sample B.

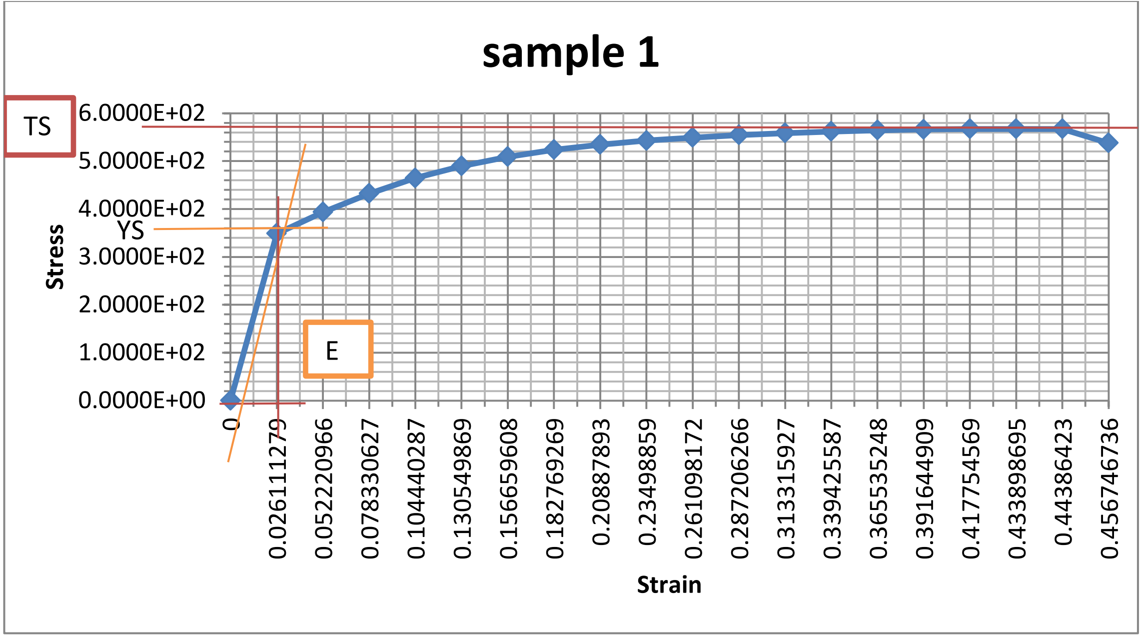

Figure 5: A graph of stress versus strain for sample 1 from Sample A.

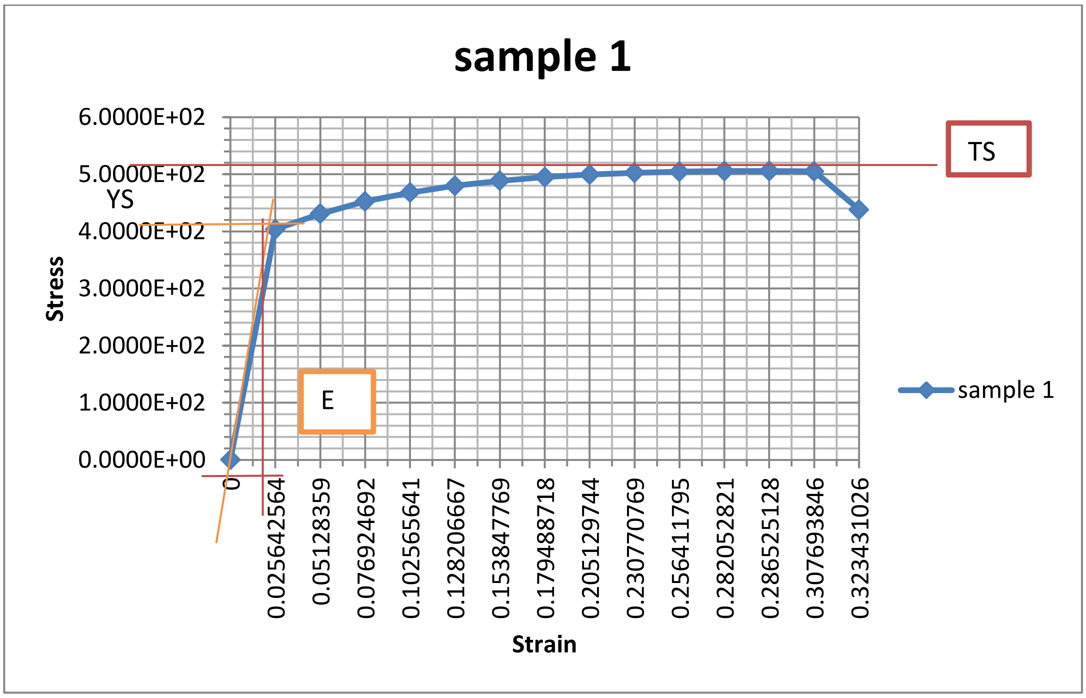

Figure 6: A graph of stress versus strain for sample 1 from Sample B.

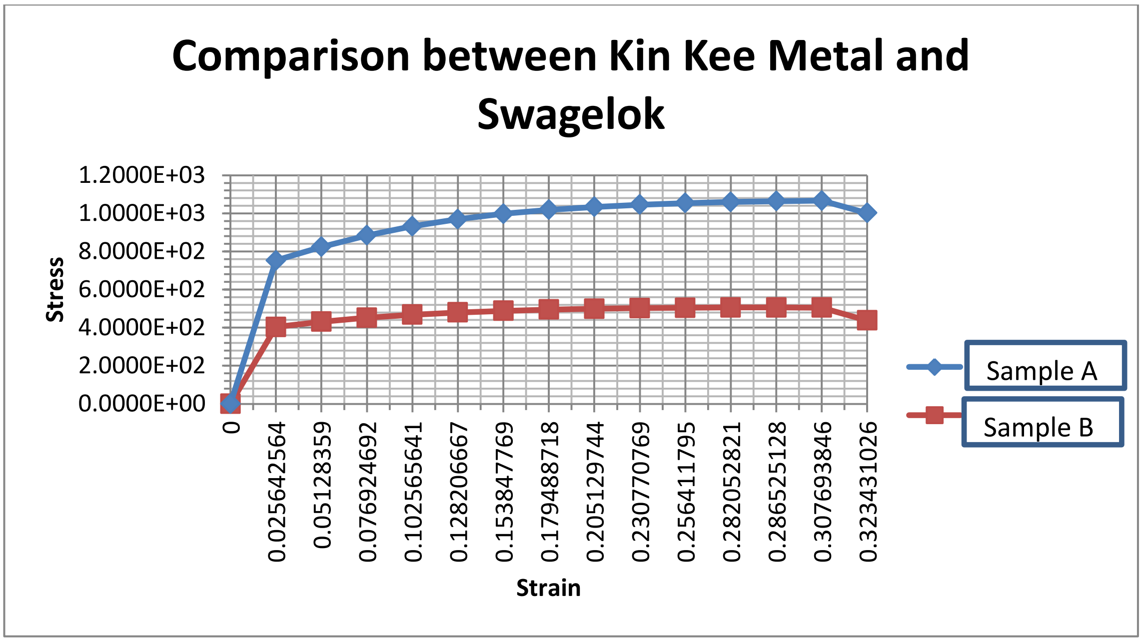

Figure 7: A graph of comparison of stress-strain curve between Sample A and Sample B.

From the stress-strain curve, Table 3 is the comparison between Sample A and Sample B. From Table 3, it is found that Sample A has higher in modulus of elasticity, tensile strength and yield strength with 12869.22 MPa, 548 MPa, and 332.7333 MPa respectively that Sample B. Tensile strength means the pulling stress required to break a material. If a material has high tensile strength then it is stronger. The higher the modulus of elasticity, the more stiffer the material and the harder it is to stretch it. Same goes to yield strength, the higher the yield strength the stronger the material. So, Sample A is stronger than Sample B because the modulus of elasticity, tensile strength and yield strength for Sample B are 12722.43 MPa, 536.6667 MPa, and 314 MPa respectively.

Table 3: Comparison of material characteristics between Sample A and Sample B.

sample	Modulus Elasticity (MPa)	Tensile Strength (MPa)	Yield Strength (MPa)
Sample A	12869	548	333
Sample B	12722	537	314

Ductility is quantified as the percent elongation at failure. It were calculated using equation (3) and the comparison were compared with the Figure 8. Table 4 is the comparison of ductility between Sample A and Sample B. Both manufactures are larger than 5% so both are ductile.

$$\%EL = \frac{L_f - L_o}{L_o} x100 \qquad (3)$$

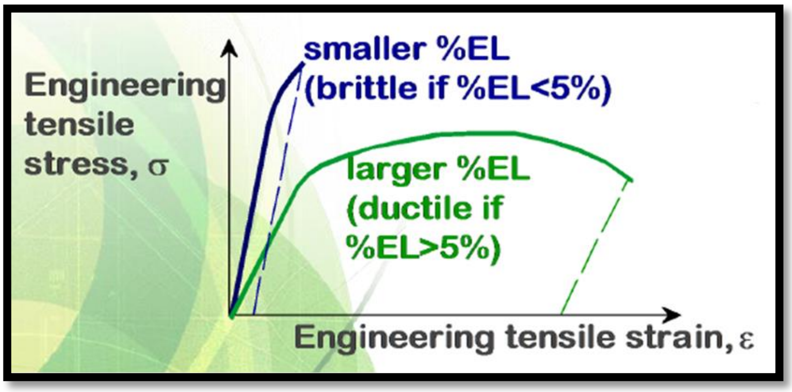

Figure 8: A graph of comparison of stress-strain curve between Sample A and Sample B.

Table 4: Comparison of ductility between Sample A and Sample B.

	Sample A	Sample B
%EL	44.04501932	36.09215017

CONCLUSION

From the stress-strain curve, values obtained were the modulus of elasticity, ductility, tensile strength and yield strength for Sample A which are 12869.22 MPa, 44.04501932%, 548 MPa, and 332.7333 MPa respectively. And for value of modulus of elasticity, ductility, tensile strength and yield strength for Sample B were 12722.43 MPa, 36.09215017%, 536.6667 MPa, and 314 MPa respectively. From values that obtained, the material characteristics of Sample A are found to be stronger than Sample B.

REFERENCES

Atlas Steels Australia. (2013). *Stainless Steel - Grade 316 (UNS S31600).*Retrieved from http://www.azom.com/article.aspx?ArticleID=863

Callahan F.J. (1998). *Swagelok: Tube Fitter's Manual.* Ohio: Swagelok Company.

Eleiche A.M., Albertini C. & Montagnani M. (1985). The Influence of Strain-Rate History on the Ambient Tensile Strength of AISI Type 316 Stainless Steel. *Nuclear Engineering and Design 88* (p.131-141). Retrieved 8 April, 2012, from Science Direct.

Gedney R. (2002). Guide to Testing Metals Under Tension. *Advanced Materials & Processes.* Retrieved 10 April, 2012, from http://admet.com/assets/PracticalGuidetoMetalsTestinginTension.pdf

Jadhav A. (2010). Stainless Steel Types and Properties. *Buzzle.com.* Retrieved 8 April, 2012, fromhttp://www.buzzle.com/articles/stainless-steel-types-and-properties.html