Sudan University of science and Technology

College of Graduate Studies

The Suitability of using steel Alloy series 4118 Instead of AISI4140 as a gun barrel

ملائمة إستخدام سلسلة الصلب السبائكي 4118 كبديل للصلب AISI4140 في ماسورة مدفع

This proposal has been submitted for Partial Fulfillment of the Degree of M.Sc. in Mechanical Engineering (Production)

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الاستهلال

قال تعالى:

بسم الله الرحمن الرحيم

{وَقُلِ اعْمَلُواْ فَسَيَرَى اللّهُ عَمَلَكُمْ وَرَسُولُهُ
وَالْمُؤْمِنُونَ وَسَتُرَدُّونَ إِلَى عَالِمِ الْغَيْبِ وَالشَّهَادَةِ
فَيُنَبِّئُكُم بِمَا كُنتُمْ تَعْمَلُونَ}

صدق الله العظيم

سورة التوبة الآية (105)

Dedication

I would like to dedicate this work to my
Father Soul, Mother, my brothers, Sisters, friends, and Everybody who taught me a letter for Their endless and generous support,,,,

Acknowledgment

First, I would like to express all my deepest thanks to Allah for his grate help in completing this thesis.

I would like to express my most sincere thanks to my supervisor:

Dr. Hassan Osman and Dr. Gafar Abdalhamed for their patience, guidance and encouragement, and the tremendous amount of effort and help that offered to me

I would like to express my most profound gratitude to the staff at the Department Of Mechanical Engineering, Sudan University for generous assistance in different ways and for valuable comments.

I would like to thank all my colleagues for their help.

Finally, am forever indebted to my family for their endless patience and encouragement, when it was most required.

Abstract

In this research two types of materials are investigated. The medium carbon steel alloy type AISI) 4140) which is been used internationally in military for barrel tube. The steel alloy is been use currently in Sudan and trying to replace AISI (4140). This work focused on applies mechanical test and characterization for the two materials to compare and investigated their properties. SPARK EMISSIONS SPECTROMETR (SES) is used for the chemical composition analysis according to stander ASTM E716-16. The result shows that AISI (4140) has 1.04% Chromium and 0.29 Silicon which explain the higher hardness. Two tensile tests were done at room temperature and at high temperature (650ºC). The material under investigation steel AISI(4xxx) Suffer from degradation in strength from 607.3MPa at room temperature to 175.7MPa at high temperature.

المستخلص

هذا البحث قام بدراسة نوعين من المواد متوسطة الكربون, الحديد AISI(4140) مستخدم عالميا في ماسورة الاسلحة العسكرية بينما في السودان تستخدم سبيكة حديد متوسط الكربوناخرى بدلا عن النوع (AISI(4140 بجانب ذلك ركز هذا البحث علي اجراءاختبارات للخواص الميكانيكية لدراسة ومقارنة خصائص النوعين استخدم SPARK EMISSIONS SPECTROMETR (SES) لدراسة الخواص الكيميائية ولمعرفة عناصر المادة AISI(4xxx) بناء عليالمعيار ASTM. E716-16 تبين ان عناصر السبيكة AISI(4140) تحتوي علي104% كروم و 0.29% سليكون مما ادي الي تحسين صلادتها اجريت اختبارات شد للمادة (AISI(xxx4 في درجة حرارة الغرفة وعند درجة حرارةعالية 650 درجة مئوية ,اتضح من المخطط انخفاض اجهاد الشد بدرجة كبيرة من607.3 ميقا باسكال عند درجة حرارة الغرفة الي175.3 ميقاباسكال عند درجة الحرارة العالية.

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CHAPTER ONE

INTRODUCTION

CHAPTER ONE

1.1 Introduction:

AISI4140 alloy steel is a chromium –molybdenum and manganese containing, law alloy steel is has high fatigue strength abrasion and impact resistance toughness and torsional strength.

The chromium content provides good hardness penetration and molybdenum content ensures uniform hardness and high strength.

The source of high temperature and dynamic loads in the gun barrel is due to the thermo chemical burning of the solid propellant. The burning of the solid propellant takes place in three stages; the burning of the propellant under constant volume till the projectile starts moving in the barrel is the first phase, the movement of the projectile from the start till the end of the barrel is the second phase and the final phase is burning at atmospheric conditions just on the onset of leaving the barrel. Due to all these the replyof fire of high performance and limited, those limits the service life.

1-2 Research Problems:

The alloy steel under investigation AISI (4xxx)were used as a replacement of AISI4140, thus mechanical properties and structure analysis is needed.

1-3 Research importance:

Steel alloy AISI4140 is very expensive and not available so looking for material use as replacement ofAISI4140 to withstand it is applications.

1-4 Objectives:

-investigate the mechanical property of AISI (4xxx) at room temperature and high temperature (650 ^{o}C).

-Microstructure analysis.

-compare the mechanical properties of AISI (4xxx)& AISI (4140)

-Quantitative analysis for selecting material for specific application.

CHAPTER TWO

THEORETICAL STUDIES AND LITERATURE REVIEW

CHAPTER TWO

2-1 Introduction:

The degtyaryov shpagina krupnok aliberny (Dshka) machine gun is used for combating low- flying attacking air craft and dive bombers .There are two generally recognized classes of weapons identified as heavy machine guns. The first are weapons from World War I identified as "heavy" due to the weight and encumberment of the weapons themselves. The second are large-caliber (12.7x99mm, 12.7×108mm, 14.5×114mm, or larger) machine guns.
Russia introduced the degtyaryov shpagina krupnok aliberny (dshka) in 1938 and the weapon served as the soviet primary heavy machine gun during the Second World War. It remains one of the most widely used in variety of voles including as an anti-aircraft weapon (alone or in triple configuration), mounted on armored vehicles and as an infantry support weapon – in the latter case , the weapon is sometimes mounted on a small tow wheeled carriage for ease of mobility . the weapon recognizable characteristics include its barrel, which features vertical fins along its length, and a large oval muzzle brake.
(Barrel, 2019)

The technical data of the latest models of this machine gun are as following:

- Caliber 12.7mm
- Muzzle/initial velocity 860 m/s
- The barrel has eight grooves with a pitch of 381mm
- Length of barrel 1m or 1070mm
- Length of groove part 89mm

- Technical rate of fire 600 shots per minute
- Practical rate of fire 125 shots per minute
- Weight (unloaded) 35.7 kg

And has a sighting systems contain:

- Fore: cylindrical post
- Rear: vertical leaf u back sight
- Operating system: gas automatic feed metallic link belt

Figure (2-1) shows the degtyaryov shpagina krupnok aliberny (dshka)

Figure (2-1): (DSHK)

2-2 Mortar:

A mortar is an artillery weapon which fires explosive shells. The shells are known as (mortar) bombs. They are fired at targets which are close, as mortars do not have long range. It has a short barrel which fires the mortar bomb at a low speed high into the air to reach its target .The mortar shoot 120mm smoth bore mortar have maximum ranges of approximately 7200m to 9500m when firing conventional HE mortar projectiles rocket assisted mortar projectile are also available and these projectile extend the range of the system.

2-2-1The craw-served mortars consisted of three:

1- the barrel
2- the stand

3- the baseple

2-2-2 mortar weapon technical specification:

1- barrel 120mm
2- range Min 1500m – Max 8000m
3- barrel length 1900mm
4- recoil force 25 tons
5- time to shoot 1 min
6- time to scoot 10 s
7- firing sector
8- azimuth +/- 3200
9- elevation 800-1200 mm

Figure: (2-2): below show some type of mortar:

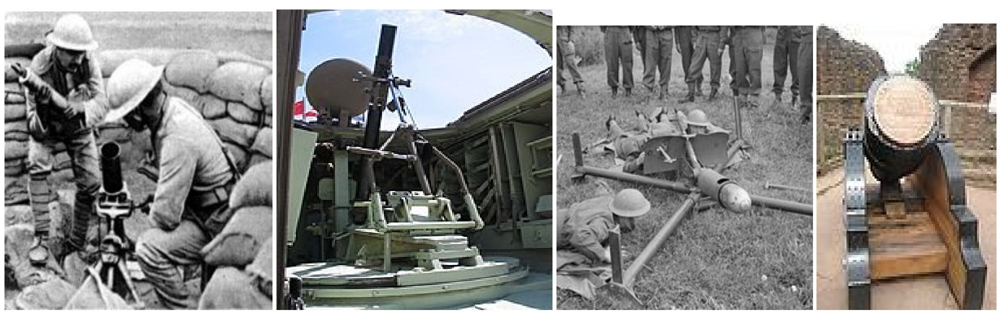


Figure (2-2): (Stokes mortar - Mortar carrier - Spigot mortar - Largest mortars)

(Barrel, 2019)

2-3 Barrel:

A barrel chamber is part of the gun barrel which holds the bullet shell during breach loading. It is the most important part of the gun and very common to fail during the firing process of the bullet. On the basis of the barrel chamber drawing the firearm has been classified for their categories like small arms and heavy machine gun etc. A firearm may be defined as the portable gun heaving a barreled weapon that launches one or more projectile often driven by the action of an explosive or by compressed gas. A gun is a normal tubular weapon or other design to discharge projectile or other material. The projectile may be gas, liquid, solid or energy and may be free as with bullet and artillery shell or captive as with the Taser probe and whaling harpoon. It means the design of the projectile may varies according to the design of the firearm but it usually affected by the action of gas pressure, either by the help of compressed and stored gas by mechanical means or by rapid combustion of propelled material which is more commonly used method for the propulsion of the projectile

The destruction of the target always depends on the design of the projectile and energy hold by the projectile. During the rapid expansion or explosion of the propellant the barrel experience different kinds of stresses. The barrel is one of the most important parts of the firearm. It may be consider the back bone of the firearm. Barrel chamber works under a very high pressure condition more the 360mpa and it is the most common part or component to fail. For that reason the design of the barrel must be designed so that the failures do not occur. (Barrel, 2019).

2-4 Guns:

Is a weapon with a metal tube that fires bullets or other explosives or a device with a tube that shoots objects at target weapon consisting of metal tube from which a projectile is discharged by the force of an explosive, specif.

2-4-1 Tank Gun Tube:

The tank gun barrel envisioned is similar to the existing 120 mm M256. It is Smooth bore, firing AP and HE projectiles with polymeric obturator bands. The "paper gun" has autofrettaged monobloc high strength steel liner/jacket similar to the M256. However, it makes use of increased lethality propellant, which has a high adiabatic flame temperature, and so is quite erosive to steel. Electroplated chromium provides inadequate protection, since the substrate steel melts under the propellant's high flame temperature. Instead, a thick refractory metal is explosively-bonded to the steel substrate. How this would be produced is shown in Figure 2. The explosive bonding process must occur after the barrel forging has been heat-treated, autofrettaged, and the bore rough machined. The wall thickness must be fairly thick during explosive bonding, or else there will be plastic deformation of the tube. If a full-length clad is required, this difficulty can be obviated by the use of a suitable momentum trap around the thinner parts of the barrel.

2-4-2 Artillery Gun Tube:

The "paper" artillery barrel is an artificially-cooled smoothbore, firing folding-fin high capacity projectiles with polymeric obturator bands. It is also an autofrettaged monobloc high strength steel liner/jacket with an explosively-bonded coating. The manufacturing sequence is similar to that for the paper tank gun tube in Figure 2.

However, if it must fire the existing inventory of 155 mm projectiles, it must be rifled.

While the explosively-bonded coating can be made as thick as the depth of rifling, it must also be able to transmit the rifling torque to the projectile. It is unknown at this time whether a sufficiently strong refractory metal can be successfully bonded. The alternative is to initially produce a rounded rifling profile (similar to what is currently done for chromium electroplated rifled tubes). The refractory metal is bonded over that, and the tube is finish rifled. The difficulty of following the original rifling with the finish rifling tooling is acknowledged. The manufacturing sequence is shown in Figure 3.

2-4-3 Aircraft Machine Gun Tube:

Although this application is not large caliber, it makes sense to present some ideas here. Ordinarily, a barrel that is lighter than a steel barrel is not really desirable due to stability issues. However, aircraft design places a high value on weight, and aircraft are inherently unstable firing platforms anyway. These guns are typically rifled with a progressive twist, and fire projectiles with polymeric or metallic rotating bands. For this application, the "paper" gun tube has no coating. It has a zirconia or silicon nitride ceramic liner with a graphite-epoxy composite jacket. The jacket is wrapped in tension over the liner, putting the necessary pre-stress (hoop and axial) on the liner. An ARDEC SBIR and a proposed ARL program are currently addressing this kind of a gun tube. The manufacturing sequence is shown in Figure 4.

2-4-4 Mortar Tube:

Mortar and recoilless rifle barrels should also be lightweight. Titanium alloys have been tried for each [24, 25], but they suffer from extremely rapid erosion. An explosively bonded refractory metal coating would prevent this. However, because it is a fairly thin walled tube, the proper momentum trap must be devised to prevent the tube from plastically deforming during bonding. The tube gets quite hot in service during maximum firing rate, so the titanium must be a high temperature alloy, such as TIMETAL® 1100 or TIMETAL® 21S. The manufacturing sequence is shown in Figure 5. An ARL program is currently examining the feasibility of using metal-matrix composites as a jacket material for mortars. These could be pressure cast around a steel liner.

However, the required fatigue, thermal fatigue and high temperature fatigue must be demonstrated. (Barrel, 2019)

2-5 Material:

Before the fabrication of the geometry of barrel we have to select the material for the fabrication and analysis of the barrel design. Normally there are two materials which are mainly use for the fabrication of the barrel. These two material are used by the U.S. military for the fabrication of the barrel i.e. AISI 4140, UNS S41600.

UNS S41600 is mostly used for the fabrication of the aircraft components because of their mechanical properties. The material is very expensive in its cost as well as the machining cost is also very high. This particular material is only used for the weapon designing and fabrication only when specially designed weapon are ordered. Because of that the production plants of the firearm facility mostly use the AISI 4140 material for the mass production. This material is used because of its ability to withstand the (360 MPa to 560 MPa) pressure ranges of the explosive used and because of its low cost compared to the UNS S41600 material.

But while generating homemade firearm people generally use cheap steel tubes, water pipes and discarded steel material of automobile, which are very weak in their fabrication as well as in their mechanical properties. Due to the weak design the weapon, the firearm itself, becomes more dangerous to the weapon holder.

The material model should include the following parameters: material density ρ, elastic modulus E, expansion coefficient α. For considering the influence of temperature on the physical and mechanical performances of material, all the above parameters varying with temperature are obtained by referring to the engineering material manual and their values are listed in Table (2-1). (Sbornik, 1997)

Table (2-1): Basic Physical Parameters of Gun-Tube Material

Temperature t (°C)	Thermal Conductivity K ($W \cdot m^{-1} \cdot K^{-1}$)	Specific Heat C_P ($J \cdot kg^{-1} \cdot K^{-1}$)	Elastic Modulus E (MPa)	Poisson Ratio μ	Thermal Expansion Coefficient α (K^{-1})	Density ρ ($kg \cdot m^{-3}$)
20	33.8	480.3	2.07×10^5	0.25	1.21×10^{-5}	7801
300	37.9	538.2	2.03×10^5	0.263	1.21×10^{-5}	7801
600	36.8	595.1	1.97×10^5	0.286	1.21×10^{-5}	7801
900	30.5	634.2	1.92×10^5	0.316	1.21×10^{-5}	7801

The chemical components are shown in percentage value in the table: (2-2). As the earlier studies indicate that the chemical composition plays an important role in the material selection process. Physical properties are also considered as the important part of the material selection process. During the working condition, the material experience different kinds of load on it which leads to its failure. There are many other properties which are generally considered while selecting a material for the fabrication purpose. Some of the properties are shown in the table: (2-3). (Barrel, 2019)

Table (2-2): Material elements

Elements	UNS S41600 (%)	AISI 4140(%)	Structural Steel (%)
C	0.15	0.40	0.15
Mn	1.25	0.85	1.25
S	0.15	0.020	0.15
Si	1.0	0.35	1.0
P	0.06	0.015	0.060
Cr	12-14	1.0	12-14

Table (2-3): Material Properties

Properties	UNS S41600	AISI 4140	Structural Steel	Units
Density	7800	7850	7850	Kg/m3
Elastic modulus	200	190-210	200	GPa
Yield strength	795	770	255	MPa
Elongation	13	17	22	%
Tensile strength	1000	930	410	MPa
Hardness	321	275	262	Hb

2-6 Manufacturing barrel tube steps:

1-Choose the type of steel to be used for the gun barrel. The steel chosen must have strength of 100,000 psi (689476 kPA) to withstand the force of the gasses that propel the round. The steel should have a hardness of 25 to 32 on the Rockwell scale so that the steel is strong enough to contain the pressure necessary to propel the round through the barrel, but not so brittle that it will be harmed by the machining operations to be performed.[1] Obtain 1.25 inch (31.75 mm) rods from a specialty steel mill. Ask for a quality certification on the steel. Specify that the steel must be stress relieved at the steel mill{http://www.firearmsid.com/Feature %20Articles/RifledBarrelManuf/BarrelManufacture.htm} Select 4140 chrome moly steel. Chrome moly steel is the least expensive alternative. It also is easier to chemically blacken, if desired, to give a traditional look to the barrel.

Decide on 416 stainless steel. Stainless steel is more expensive than chrome moly Steel. Stainless steel barrels have have a longer service life and are result in a more accurate firearm than do chrome moly steel barrels.

2- Cut a piece of steel for the barrel stock. Cut a length of steel around 28 inches (71.1 cm) to 30 inches (711.2 mm to 762 mm).[3] Ensure that the ends of the barrel stock are true in parallelism to each other, are faced off and are perfectly round.

3- Drill the barrel drill down the interior lengthwise to a diameter about 5 thousandths of an inch (0.127mm) less than the desired finished bore diameter of the barrel. A special drill, known as a deep hole drill, must be used to drill the barrel. The deep hole drill will hold the tungsten carbide drill bit still and spin the barrel to perform the drilling.[4] Drilling will be liquid cooled and will proceed at about 1 inch (25.4 mm) per minute. Total time to drill the hole will be about 30 minutes.

4- Ream the barrel. Work a tungsten carbide bore reamer down the finished drill hole of the barrel, using liquid coolant as the reamer works. The reamer will expand the hole to the desired finished bore, and smooth the inner drilled surface of the barrel as it creates the final desired bore.

5- Rifle the barrel. Rifling consists of spiral grooves in the bore, which will impart a spin to the fired round as it travels down the barrel. This spin will gyro stabilize the flight of the fired round. Determine the number of rifling grooves to be placed in the bore and the amount of twist to be put on the rifling grooves. Consult with experts in the field of gun barrel making to determine this information. Find these experts at specialty gun barrel making shops.

Make the first rifling groove Insert a tube mounted with the rifling hook cutter box down the bore of the barrel. Draw the rifling hook cutter box through the bore while rotating the barrel at a rate recommended by the expert to give the desired rifling spin.

Add more rifling grooves. Index the barrel to the starting position for the next groove. Draw the rifling hook cutter box through the bore while rotating the barrel at a rate recommended by the expert to give the desired rifling spin.

Finish the rifling. Repeat passes through the bore with the rifling hook cutter box as needed.

6- Lap the barrel to fine polish the bore.

Insert the barrel lapping rod into the bore until it is about 4 inches (101.6 mm) from 1 end of the bore. Pour molten lead into the end of the bore and allow it to harden.

Push the lap out of the barrel. Push the lapping rod forward until the now solidified lead slug, called the lead lap, is exposed. Cover the lead lap with lapping paste, which is similar to valve grinding paste.

Complete the lapping. Run the lead lap up and down the length of the barrel about 50 times, applying more lapping paste as necessary. (Barrel, 2019)

2-7 Life estimate of gun tube:

Here the Smith and O'Brasky empirical formula Eq. (2-1) is used to compute the erosion of inner surface after one firing and estimate the life of gun tube.

$$\Delta d = \sum_{i=1}^{N} \Delta d_i = \sum_{i=1}^{N} A\, e^{bT_{wi}} \times 10^{-4} \le \Delta d_{max} \text{ – Eq (2-1)}$$

Where Δd max is the maximum radial erosion of inner surface; Δdi is the erosion at No. i firing; Twi is the peak temperature at No. i

firing; A, b are the empirical constants; N is the number of firing when reaching the life of tube.

When reaching the life of tube, the maximum radial erosion of inner surface will be:

$$\Delta d_{max} = 2\left(t_{sh} + C\right) \text{- Eq (2-2)}$$

Where tsh is the height of rifle; C is a constant and used to be given as 1.0mm~1.6mm for medium and large caliber tube and as the value of tsh for 37mm or smaller caliber tube.(benjing,2003)

2-7-1 Computational Result of Temperature and Stress:

To fully reflect the thermal and stress state of the gun tube, temperature and stress at three sections on the gun tube are selected to be analyzed. Section A is located at the start region of rifling, which is 108.0mm away from the gun breech. Section B is located at the region of largest chamber pressure appearing, which is 223.4mm away from the gun breech. Section C is located at the region of muzzle, which is 1314.0mm away from the gun breech.

Shooting criterions are as follows in figure (2-3). A cycle is composed of 100 rounds of projectiles, and Group 1 (50 rounds) is for the three short firing continuously (7 rounds/sub-group) and a long firing continuously (29 rounds / sub-group), and the interval between short firing continuously is three seconds. Air cooling is 180s. The second group (50 rounds) is carried out in the same way. The water-cooling is used after three minutes of air-cooling until the room temperature is reached. Ambient temperature is 26oC, and the firing rate is 608rounds/minute.

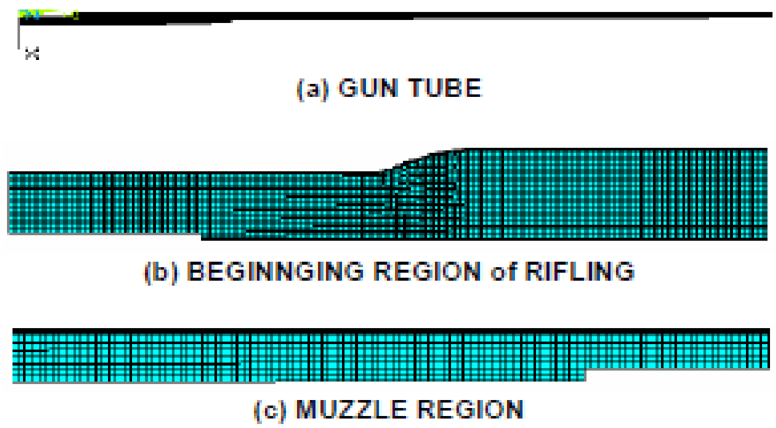
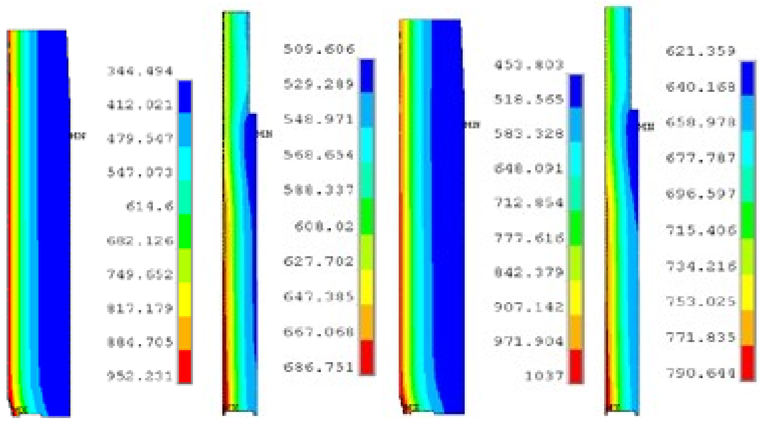


Figure :(2-3) stress state of gun tube

The thermal state of gun tube is illustrated in Fig(2-4) to Fig(2-6) It can be seen that: after the end of group 1 (50 rounds) shoot, in the initial part of rifle, the region near the wall has higher temperature; the farther away from the wall, the lower the temperature and outer temperature are. As the wall is thick, the temperature difference between the inner and outer surface is big. The total difference is 607.7K. The temperature gradient in the tube is big, and the distribution of heat flow is uneven. The largest heat flow appears in the thin layer near the bore. In the muzzle region, for the wall of gun tube is thin, the temperature difference between the inner and outer surface is only 177.1K. The temperature gradient in the tube is small, while the overall temperature is high, and the heat flow is big. After the launch of group 2, the basal temperature of the tube wall rises. In the initial region of rifling, the temperature difference between the inner and outer surface drops. The temperature of inner surface rises 84.8K, and the temperature of outer surface rises 165.1K. The temperature difference between



(a) **(b)** **(c)** **(d)**

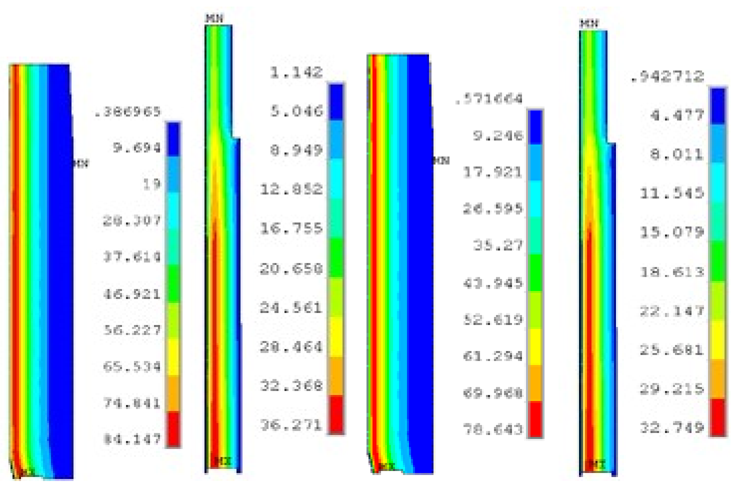
Figure (2-4): Distribution of Temperature on Gun Tube

(a) The maximum chamber-pressure region after 50 rounds shoot

(b) The muzzle region after 50 rounds shoot

(c) The maximum chamber-pressure region after 100 rounds shoot

(d) The muzzle region after 100 rounds shoot



(a) **(b)** **(c)** **(d)**

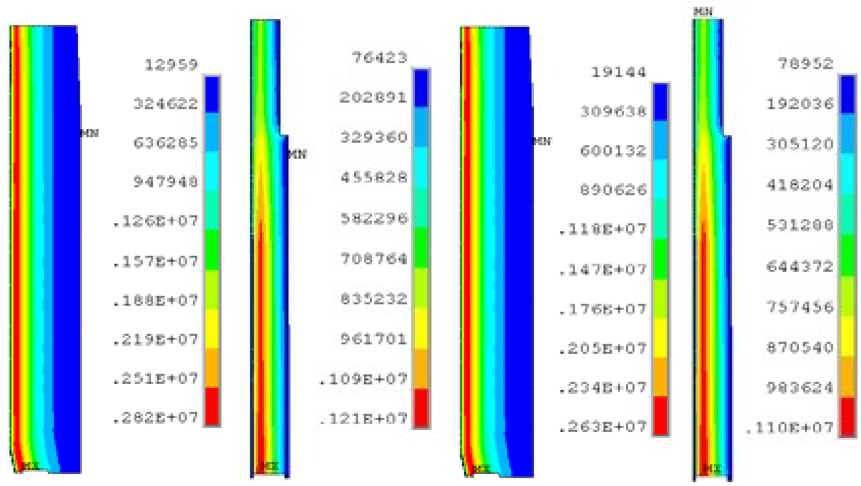
Figure (2-5) Distribution of Temperature Gradient on Gun Tube

(a) The maximum chamber-pressure region after 50 rounds shoot

(b) The muzzle region after 50 rounds shoot

(c) The maximum chamber-pressure region after 100 rounds shoot

(d) The muzzle region after 100 rounds shoot



(a) **(b)** **(c)** **(d)**

Figure (2-6): Thermal Flow on Gun Tube

(a) The maximum chamber-pressure region after 50 rounds shoot

(b) The muzzle region after 50 rounds shoot

(c) The maximum chamber-pressure region after 100 rounds shoot

(d) The muzzle region after 100 rounds shoot.(Xu Cheng and Yonghaiwu, 2014)

2-8 Type of heat treatment:

1- Annealing
2- Normalizing
3- Hardening
4- Carburizing
5- Tempering

2-8-1 Annealing:

Any annealing process consists of three stages:

1. Heating to the desired temperature.

2. Holding or “soaking” at that temperature.

3. Slowly cooling, usually to room temperature.

Steel is annealed to reduce the hardness, improve machine ability, facilitate cold-working, and produce a desired microstructure. Full annealing is the process of softening steel by a heating and cooling cycle, so that it may be bent or cut easily. In annealing, steel is heated above the transformation temperature to form austenite, and cooled very slowly, usually in the furnace.

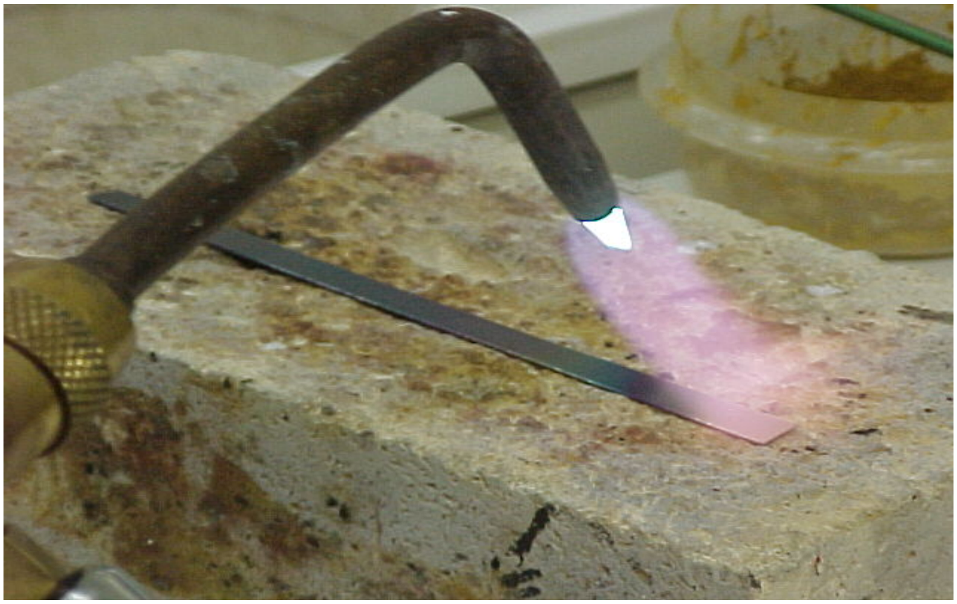


Figure (2-7): Annealing Process

There are several types of annealing like black annealing, blue annealing, box annealing, bright annealing, flame annealing, intermediate annealing, isothermal annealing, process annealing, recrystallization annealing, soft annealing, finish annealing and spheroidizing. These are practiced according to their different final product properties in the industry

This heat treatment is commonly applied in the sheet and wire industries, and the temperatures generally used are from 1020 to 1200 ^{0}F (550 to 650 ^{0}C). Full annealing, where steel is heated 50 to 100 ^{0}F (90 to 180 ^{0}C)

2-8-2 Normalizing:

In normalizing steel is also heated above austenitizing temperature, but cooling is accomplished by still air cooling in a furnace. Steel is normalized to refine grain size, make its structure more uniform, or to improve mach inability. When steel is heated to a high temperature, the carbon can readily diffuse throughout, and the result is a reasonably uniform composition from one area to the next. The steel is then more homogeneous and will respond to the heat treatment in a more uniform way.

The process might be more accurately described as a homogenizing or grain-refining treatment. Within any piece of steel, the composition is usually not uniform throughout. That is, one area may have more carbon than the area adjacent to it. These corn positional differences affect the way in which the steel will respond to heat treatment. Because of characteristics inherent in cast steel, the normalizing treatment is more frequently applied to ingots prior to working, and to steel castings and forgings prior to hardening.

2-8-3 Hardening:

Hardening is carried out by quenching steel, which is cooling it rapidly from a temperature above the transformation temperature. Steel is quenched in water or brine for the most rapid cooling, in oil for some alloy steels, and in air for certain higher alloy steels. The spaceman used first method cooling by water, With this fast cooling rate, the transformation from austenite to pearlite cannot occur and the new phase obtained by quenching is called martensite. Martesite is a supersaturated metastable phase and have body centered tetragonal lattice (bct) instead of bcc. after steel is quenched, it is usually very hard and strong but brittle. Martensite looks needle-like under microscope due to its fine lamellar structure.

2-8-3-1Case Hardening:

Case Hardening is a process of hardening ferrous alloys so that the surface layer or case is made substantially harder than the interior or core. The chemical composition of the surface layer is altered during the treatment by the addition of carbon, nitrogen, or both.

2-8-4 Carburizing:

Carburizing is a process used to harden low carbon steels that normally would not respond to quenching and tempering. This is done for economic reasons (utilizing less expensive steel) or design considerations to provide a tough part with good wear characteristics

Carburizing introduces carbon into a solid ferrous alloy by heating the metal in contact with a carbonaceous material to a temperature above the transformation range and holding at that temperature

2-8-5 Tempering:

Tempering (formerly called drawing), consists of reheating a quenched steel to a suitable temperature below the transformation temperature for an appropriate time and cooling back to room temperature. freshly quenched marten site is hard but not ductile. Tempering is needed to impart ductility to marten site usually at a small sacrifice in strength. The effect of tempering may be illustrated as follows. If the head of a hammer were quenched to a fully martensitic structure, it probably would crack after the first few blows. Tempering during manufacture of the hammer imparts shock resistance with only a slight decrease in hardness. Tempering is accomplished by heating a quenched part to some point below the transformation temperature, and holding it at this temperature for an hour or more, depending on its size. The micro structural changes accompanying tempering include loss of acicular marten site pattern and the precipitation of tiny carbide particles. this micro structural is referred to as tempered marten site.{Samuel J. Rosenberg, and Glenn-1996}

A lot of research has been done to study the process of heat transfer in a gun barrel and the various phenomena occurring when in operation.

Ercanet al (2012), formulated a thermo chemical approach in order to obtain the heat transfer coefficient. the author has used variable burning speed, fluctuating pressure along with wave speed and density of the combustion gases to calculate the Reynolds and Prandtl numbers along the barrel axis. Using these dimensionless numbers further Nussle number is calculated and finally the varying heat transfer coefficient along the length of the barrel is found out.

Mehmet et al(2014), studied the unsteady heat transfer problem taking place in the gun barrel. The transient heat transfer coefficient obtained from the interior ballistic theory was used as inputs to calculate the temperature distribution of the machine gun barrel. Later on Finite Difference method was used to find the numerical solution of the governing differential equation of heat transfer.

YujiaSunetal (2015), investigated the time varying heat transfer nature of a circular pipe subjected to an internally expanding cyclic heat source. The motion of the heat source from inside to outside takes place in a matter of few mille seconds, during which forced heating due to convection takes place. After exiting the pipe natural convective cooling takes place. Using Finite volume approach the varying heat transfer to the pipe is studied during these cyclic thermal loading conditions. The output of the investigation is the temperature response and distributions along with heat flux response have been found out.

Hawetal (2009), considered the interlayer thermal contact resistance between the steel barrel and the chrome coating layer and used the conjugate gradient method based on an inverse algorithm for calculating the heat flux at the inner surface.

Wu Yong-hai (2009), using a material model related to temperature, they calculated the transient temperature field of the gun tube subjected to the action of frequent periodic thermal and pressure pulse. The influence of both these pulses on the temperature distribution in he gun barrel has been found out.

Haw-Long et al(2009), simulated the multilayer gun barrel and estimated the heat flux and thermal stresses along with thermal contact resistance.

S. Procházkaetal (2012), analytical and finite element calculations were done to calculate elastic bore displacement, elastic tangential surface strain and powder gas pressure. The propellant gases and thermal load were considered together. The analysis was done in software ANSYS Workbench. The calculations were carried out for 30mm ballistic barrel.

Ahmed et al (2004), presented the interior ballistics simulations in 9 mm small chamber conducted by implementing the process into the mixture multiphase model.

2-9 AISI/SAE Steel - Numbering System

AISI/SAE steel numbers are indicated below

Example AISI/SAE No. 1020

- the first digit indicates that this is plain carbon steel.
- the second digit indicates there are no alloying elements
- the last two digits indicates that the steel contains approximately 0.20 percent carbon

Example AISI/SAE No. 4340

- the first two digits indicates a Nickel-Chromium-Molybdenum alloy steel
- the last two digits indicates carbon content roughly 0.4 percent

Table 2.4: Steel Numbering System

10XX	Carbon steels	Plain carbon, Mn 1.00% max
11XX		Resulfurized free machining
12XX		Resulfurized / rephosphorized free machining
15XX		Plain carbon, Mn 1.00-1.65%
13XX	Manganese steel	Mn 1.75%
23XX	Nickel steels	Ni 3.50%
25XX		Ni 5.00%
31XX	Nickel-chromium steels	Ni 1.25%, Cr 0.65-0.80%
32XX		Ni 1.75%, Cr 1.07%
33XX		Ni 3.50%, Cr 1.50-1.57%
34XX		Ni 3.00%, Cr 0.77%
40XX	Molybdenum steels	Mo 0.20-0.25%
44XX		Mo 0.40-0.52%
41XX	Chromium-molybdenum steels	Cr 0.50-0.95%, Mo 0.12-0.30%

43XX	Nickel-chromium-molybdenum steels	Ni 1.82%, Cr 0.50-0.80%, Mo 0.25%
47XX		Ni 1.05%, Cr 0.45%, Mo 0.20-0.35%
46XX	Nickel-molybdenum steels	Ni 0.85-1.82%, Mo 0.20-0.25%
48XX		Ni 3.50%, Mo 0.25%
50XX	Chromium steels	Cr 0.27-0.65%
51XX		Cr 0.80-1.05%
50XXX		Cr 0.50%, C 1.00% min
51XXX		Cr 1.02%, C 1.00% min
52XXX		Cr 1.45%, C 1.00% min
61XX	Chromium-vanadium steels	Cr 0.60-0.95%, V 0.10-0.15%
72XX	Tungsten-chromium steels	W 1.75%, Cr 0.75%
81XX	Nickel-chromium-molybdenum steels	Ni .30%, Cr 0.40%, Mo 0.12%
86XX		Ni .55%, Cr 0.50%, Mo 0.20%
87XX		Ni .55%, Cr 0.50%, Mo 0.25%
88XX		Ni .55%, Cr 0.50%, Mo 0.35%
92XX	Silicon-manganese steels	Si 1.40-2.00%, Mn 0.65-0.85%, Cr 0-0.65%
93XX	Nickel-chromium-molybdenum steels	Ni 3.25%, Cr 1.20%, Mo 0.12%
94XX		Ni 0.45%, Cr 0.40%, Mo 0.12%
97XX		Ni 0.55%, Cr 0.20%, Mo 0.20%
98XX		Ni 1.00%, Cr 0.80%, Mo 0.25%

2.10 Heat treatment of metallic alloys

The type of heat treatment to utilize depends on what abilities one wants the treated material to exhibit. processes such as hardening and quenching increases material hardness, while tempering increases ductility (ASM International, 2006). It is worth noting that while several industrial metalworking processes generate heat, the term *heat treatment* is reserved for those processes that intentionally heat and cool materials in order to alter its properties. This section only covers heat treatment processes relevant for S165M, i.e. forging, hardening and quenching, and tempering.

Forging

Forging is a manufacturing process, and is utilized for metallic materials. In the forging process, the material is shaped using localized compressive forces. The material may be forged in a hot or cold state, and is thus classified as hot- or cold-forged, respectively. Iron and steel are almost exclusively hot-forged. Forging is a process that has existed for millennia, and was traditionally used for kitchenware, tools and blade weapons. During the Industrial Revolution, it became more common to utilize forging when manufacturing components or mechanisms that needed a high level of strength.

The main advantage of forging is the production of a component that is stronger than when compared to an equivalent cast or machined part. When a part is forged, the internal grain structure deforms. The new grain structure becomes continuous, and follows the general shape of the part. Due to this continuous structure, the component normally exhibits improved material characteristics and strength. This continuous flow is not present in cast and/or machined parts (Callister & Rethwisch, 2011). See Figure (…..) for an illustration of the grain structure in differently manufactured components.

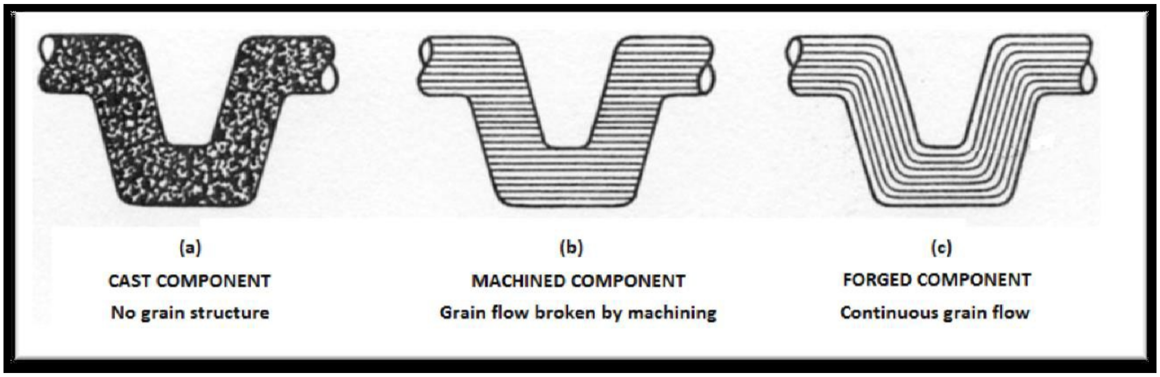


Figure (2-8) – Grain flow in (a) cast component; (b) machined component; and (c) forged component, courtesy of (SIFCO, 2012)

The material utilized in this thesis is hot-forged. Hot-forging is normally chosen for steels, as it diminishes – or completely eliminates – the presence of work-hardening that may arise in the cold-forging process. Most forging operations use metal-forming dies, which must fulfill a great number of characteristics. This includes being able to withstand the forging temperature, and changes to its shape due to the received residual thermal energy from the forged material.

Hardening and quenching

Hardening is a physical-chemical process where the intention is to increase the hardness of a material. Other mechanical properties, such as yield strength/tensile strength are normally increased as well. The general process of hardening consists of two primary phases (ASM International, 2006):

1. The material is slowly heated above its critical temperature, normally causing austenitizing of the steel. Said material is normally held for a sufficient amount of time, allowing precipitations to dissolve

2. The material temperature is rapidly lowered, usually by quenching it in water and/or oil.

The rapid temperature decrease causes carbon atoms to be locked in interstitial positions in the lattice structure. As previously shown, this process causes martensite to form. The hardness – i.e. the material's ability to resist plastic deformation – increases during this process (Bhadeshia & Honeycombe, 2006). Pure hardened steels are – while very hard – normally too brittle. Therefore, hardened steels are normally tempered before used for commercial purposes. See section 2.5.3 for a general introduction to the tempering process.

Tempering of martensite

martensite in steels can be very hard, but at the same time very brittle. It is therefore often necessary to temper the martensite, in order improve its usability in structural and mechanical components. Tempered martensite provides one of the best combinations of strength and toughness obtainable in low carbon steels. The tempering process allows the microstructure to move incrementally towards an equilibrium, under the influence of thermal activation. Thus, the tempering ability of a material depends on the distance the microstructure has from its equilibrium state.

Certain structures contain higher levers of stored free energy than others do. For example, for a typical alloy steel with a composition of Fe-0.2C-1.5Mn wt %, the reference (zero energy) state contains an equilibrium mix of ferrite, graphite and cementite. With a very miniscule increase in stored energy (70 J mol-1), the graphite is no longer present. The alloy steel has a phase mixture consisting of supersaturated ferrite at 1414 J mol-1, and pure martensite at 1714 J mol-1. Tempering a pure martensitic steel with said alloy composition can thus eventually alter the microstructure by releasing the free energy stored in it (Bhadeshia & Honeycombe, 2006).

For pure martensitic steels, the tempering of martensite normally includes the diffusion of interstitially locked carbon. However, the substitutional solutes do not diffuse during this stage. If held at the tempering temperature for a sufficient amount of time, the structure can evolve into a dispersion of coarse carbides in a ferritic matrix, which bears little resemblance to the original martensitic structure. For martensitic ferritic steels, however, the quenching process yields a fully martensitic/ferritic structure. There is no indication that tempering induces the development of further ferritic content, or cementite. If tempering at temperatures above 550 °C, one can expect to see a development of austenite, finely dispersed in the martensitic structure (Song, Rong, & Li, 2011).

This austenite is commonly referred to as reversed austenite, as it reverts to its pre-quenched form due to the reception of thermal energy. The effect this reversed austenite has on mechanical properties is proportional with ΔT (where ΔT is the difference in temperature between 550 °C and the actual temperature used in the tempering process).

CHAPTER THREE

METHODOLOGY

CHAPTER THREE

3-1 Preface

In this project compare between steel alloys (medium carbon steel)that used in barrel of DSHK and MORTAR, with AISI 4140 its stander material used in different heavy machine gun tube, make some process and test to gun tube material

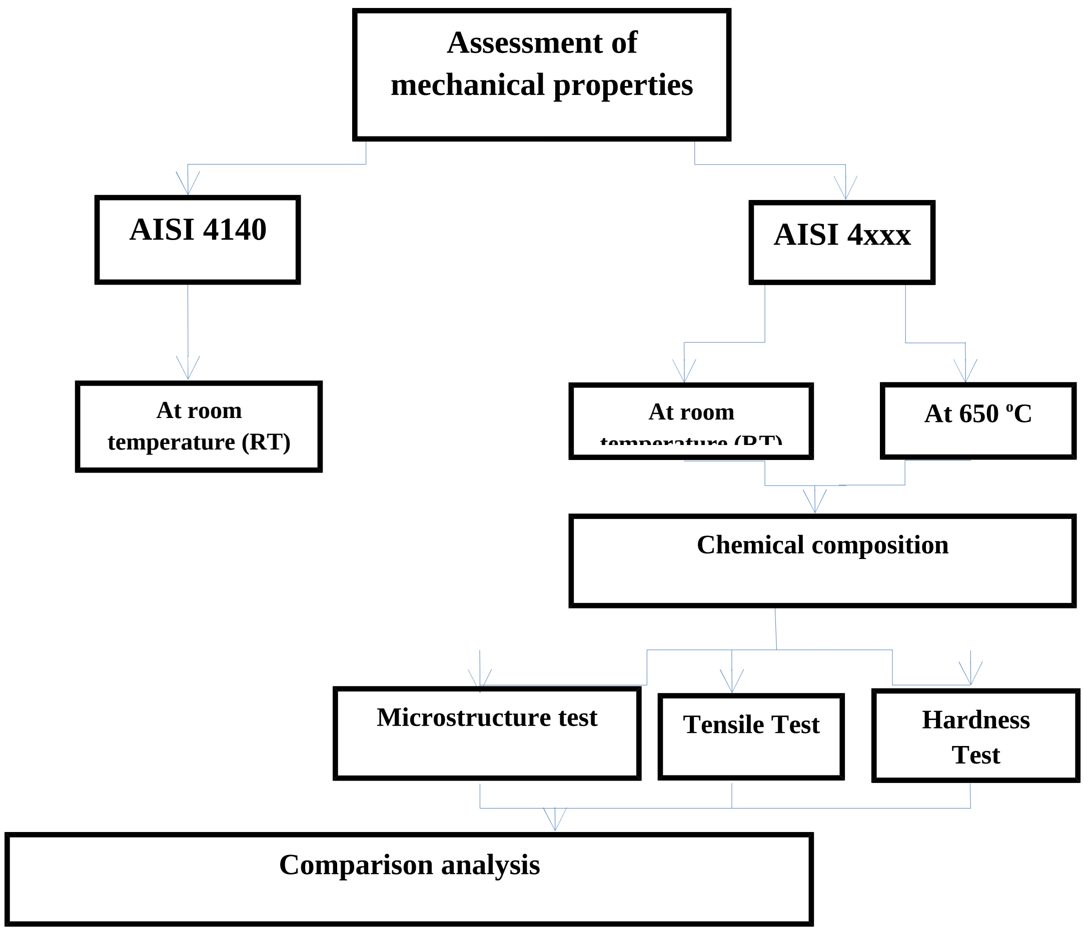


Figure (3-1): overall project Flow chart

3-2 Chemical composition:

Chemical composition analysis was done for AISI (4140) and AISI (4xxx) using SPARK EMISSIONS SPECTROMETR (SES) according to stander ASTM E716-16.

For good accuracy provided spacemen D=25, L=60 prepared with high surface finish as shown in figure (3-2).

AISI (4xxx) used for chemical composition test to know the element contain and it is amount to compare with steel AISI4140.

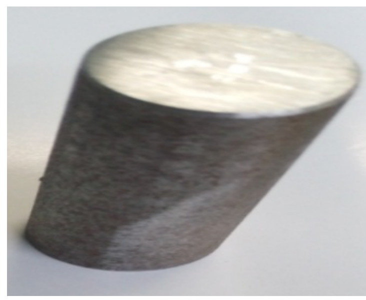


Figure (3-2): Chemical composition Spaceman

3-3 tensile test:

Using UNIVERSALTENSILE TESTING Machine for tensile test according to stander ISO(6892-1and6892-2)room temperature and under heat , ASTME8 the specimen dimension is shown in figure (3-3), device 5 sample 3pc in room temperature and 2 under 650c rebate test to fine the mean value to compare with steel AISI4140

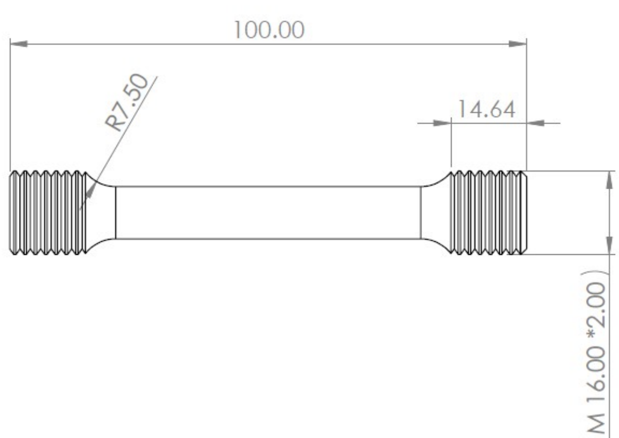


Figure (3-3): tensile specimen

Material Properties:

Table (3-1): stander material properties

Material Name	UNS S41600	AISI 4140	Structural Steel	Units
Density	7800	7850	7850	Kg/m3
Elastic modulus	200	190-210	200	GPa
Yield strength	795	415	255	MPa
Elongation	13	17	22	%
Tensile strength	1000	655	410	MPa
Hardness	321	275	262	Hb

3-4 Microstructure and mechanical test:

Microstructure test to investigate microstructure grain size and phase percentage, provide 6 samples for testing according to stander (ASTME112-12) using Scanning Electron Microscope(SEM)

Optical micrograph of the AISI 4140 steel microstructure consisting of ferrite and pearlite constituents shown in figure (3-4)

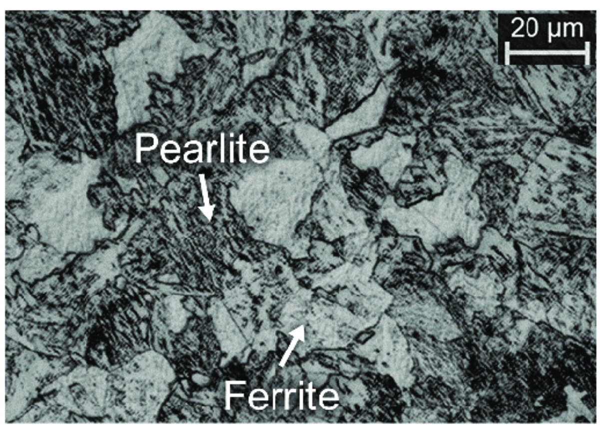


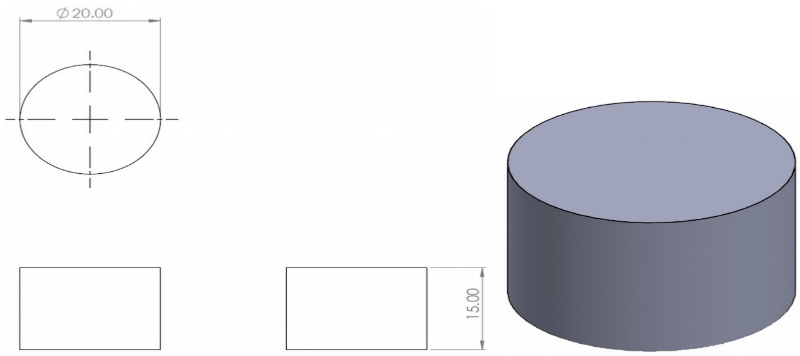
Figure (3-4): microstructure AISI4140

3-5 Hardness test:

Using TIME TH160 hardness tester

Specimen Preparation

The dimension of specimen 16 mm diameter rod is cut into required dimensions i.e., 16x25 mm and is faced to get a fine surface finish shown in figure (3-5)



Dimension specimen (A) picture (B)

Figure (3-5) Hardness specimen

Table (3-2): AISI4140 properties

Properties	AISI-1040	AISI-4140
Density (g/cm^3)	7.845	7.85
Hardness (Rockwell C)	13	30[a]
Ultimate tensile strength (MPa)	620	1020
Yield tensile strength (MPa)	415	655
Modulus of elasticity (GPa)	200	205
Shear Modulus (GPa)	80	80
Poisons ratio	0.29	0.29

[a] Hardness was taken as 1000 MPa in wear calculations by Archard's wear law [5].

CHAPTER FOUR

RESULT AND DISCUSSION

CHAPTER FOUR

4-1 Preface:

During the process of firing a bullet or projectile the barrel undergoes many types of loads which produce stresses in it. So that the design of the barrel must be strong enough to withstand the heavy pressure loads. Due to the absence of the design data a simple design of the gun barrel was made using cad software.

4-2 Chemical Compositions Analysis:

Chemical composition analysis was done for AISI4140 and AISI (4xxx) using SPARK EMISSIONS SPECTROMETR (SES) machine. Results shows that the carbon present in medium carbon steel in both material more than 0.3% and less than 0.6% as in table (4.1). (Chromium and molybdenum family) is more added for the alloy to improve its corrosion resistance.

Table (4-1) chemical composition for steel AISI (4xxx)& steel AISI (4140)

component	Fe	C	Si	Mn	Ni	Cr	MO	AL
AISI4140	96.8%	0.38%	0.21%	0.91%	0.23 %	1.04%	0.23 %	-
AISI4xxx	98.41	0.448	0.059	0.591	0.059	0.092	0.013	0.029

The amount of manganese and chromium in AISI (4140) more than AISI (4xxx)this two element increase hardness and resistance impact and corrosion AISI4140 include aluminum (corrosion resistance).

4-3 Tensile Test

The performance and strength data measured by tensile testers are important in the selection of design and materials, purchase and sale of products, development of new products, quality control, and safety of equipment. during the research stage of product development, tensile testing is crucial in choosing the most appropriate materials. A tensile test machine can verify whether candidate materials pass the required strength and elongation requirements for a certain product.

Tensile testing provides an opportunity to discover new alloys, their qualities, and the possible uses they might have. This can lead to improved materials, which are beneficial to both manufacturers and end users.

Table(4-2): Mechanical properties for steel AISI (4xxx) in room temperature and under heat &4140

	Proof stress ($y_{0.2}$) MPa	**Tensile strength (MPa)**	**Maximum force KN**	**Elongation %**
AISI4xxx At (RT)	340.6	607.3	52.58	18.7
AISI4xxx at 650^{o}c	102.6	175.7	14.07	14.5
AISI4140 At (RT)	415	655	-	17

Table(4-2) shows mechanical properties of AISI (4xxx) at room temperature and at high temperature of 650^{o}Ccompared with the properties of material AISI4140.

From the table(4-2) the deferent in tensile strength between AISI (4xxx) and AISI (4140) about 47MPa but when applied high temperature for steel 4150 make drub to strength and yield stress from 655MPa to 607.3MPa for tensile and from 340.6 to 102.6 for yield stress.

The result in figure 4-1 shows clear drop in stress at high temperature from 607.3 MPa to 175.7 MPa.

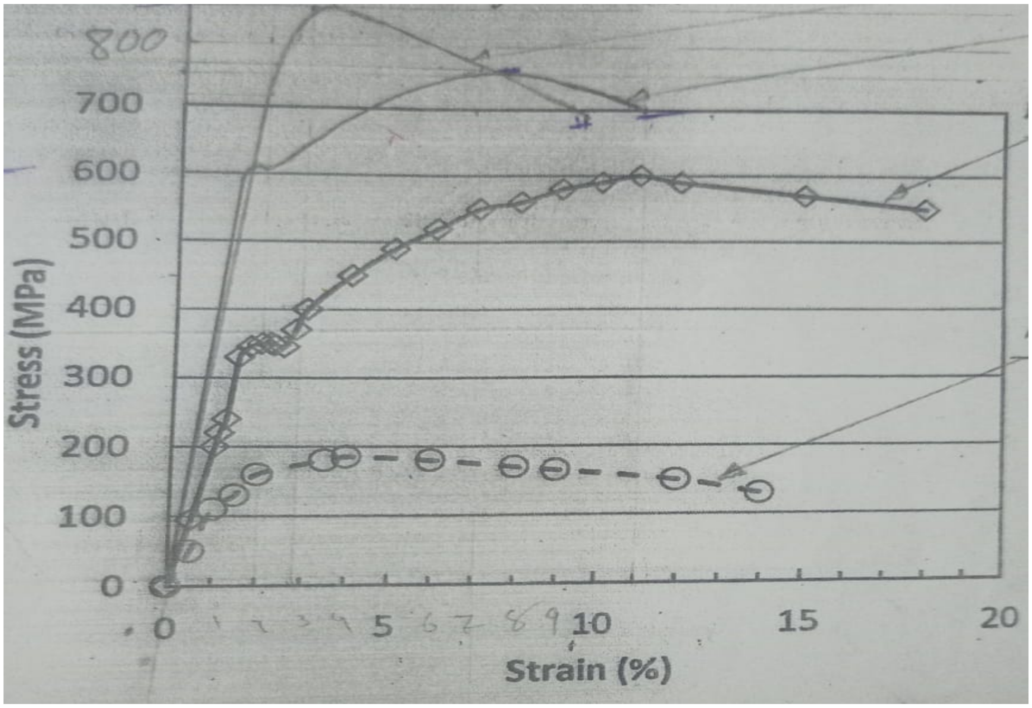


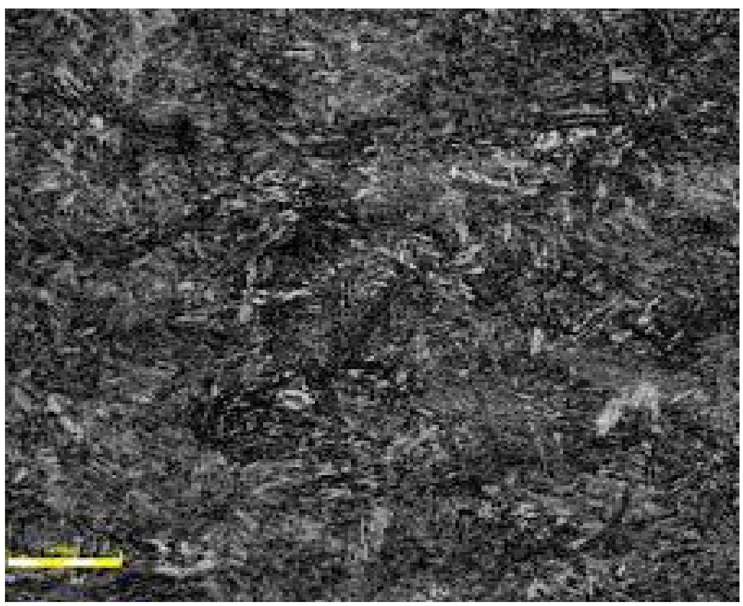
Figure (4-1) stress and strain diagram for AISI4xxx at RT and at high temperature 650^{o}c

4-4 Microstructure Analysis

The properties of an alloy depend not only on properties of the phase but also on how they are arranged structurally at the microscope level.

AISI (4xxx) contain 57% pearlite and 43%firrite shown in figure (4-2)ferrite is white color and pearlite is dark color. The zoom size of picture not same but it's clearly AISI (4xxx)&(4140) shown in figure (4-2) and(4-3) contain ferrite and pearlite, AISI (4140) contain more pearlite and cementitethan AISI (4xxx) that means` AISI4140 more hardness and brittle AISI 4140 high strength and more resistance to deformation.

Figure (4-2): microstructure of steel (4xxx)



Figure(4-3): microstructure for steel (4140)

4-5 Harness test results:

BERNAL HARDNESS test were conducted on steel AISI (4xxx). Average of five points were taken and compared with the hardness of AISI 4140. The result shows that AISI 4140 has a higher hardness of 197 compared with 174 for AISI 4xxx table 4.3. This can be due to the higher percent of pearlite.

Table (4-3) shown Bernal hardness AISI (4xxx)& AISI (4140)

Test	1	2	3	4	5	Average
Steel4xxx HB	214	147	126	177	217	174
steel4140 HB			197			197

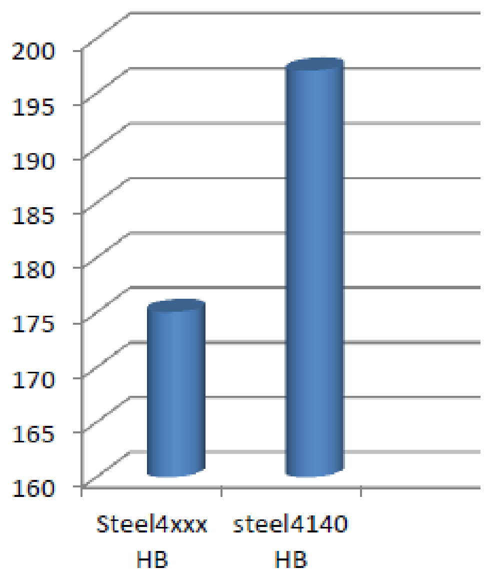


Figure: (4-4)Steel(4xxx)&(4140) Hardness test diagram

The average of hardness test results of steel (4xxx) 74BH cumbering with hardness of steel AISI (4140) its lower than because steel (4140) has more Mo, Cr, Si .

Molybdenum increase hardness penetration of steel ,increase toughness an silicon increase the strength of ferrite used with alloy to increase toughness and hardness. AISI (4140) have more pearlite and cementite that lead to improve hardness.

4.6 Quantitative method for selecting and optimum solution:

A quantitative method was used to select the best material from different alternatives. The criteria used are the strength of the material at room temperature as well as at high temperature in addition to the hardness and the cost of the material. Different weight is given for each criterion according to their importance. Scale of one to five (one =poor up to five =excellent) is used to rate the criteria for each material. Table 4.3 shows the quantitative analysis for different types of steel alloy. The result shows that.

From the table (3-4) found steel alloy AISI4150&4142have high rating weight secondly AISI 4140 & 4xxx.

Steel alloy AISI4150 and 4142 used in heavy gun tube like Mortar, AISI 4140 and 4xxx used in Degtyaryov Shpagina krupnok aliberny (DSHKA) from table (4-3) AISI4140 first choice and AISI 4xxx second one in DSHKA gun tub

Table (4-3) Comparison between deferent materials used in gun tube

Criteria	**Weight**	**Steel41xx**		**Steel4140**		**Steel4150**		**Steel4142**		**Steel 4118**	
		Ratings	**weight rating**	**Ratings**	**weight rating**	**Ratings**	**weight rating**	**Ratings**	**weigh t rating**	**Ratings**	**weight rating**
Strength at RT	0.6	3	1.8	3	3.6	4	2.4	4	2.4	2	1.2
Strength at 650c	0.8	1	0.8	2	1.6	3	2.4	3	2.4	2	1.6
Hardness	0.4	2	0.8	3	1.2	3	1.2	4	1.6	1	0.4
Cost	0.3	4	1.2	4	1.2	1	0.3	3	0.9	4	1.2
Total	**Score**	4.6		5.8		6.3		7.3		4.4	
Rank		fours		Third		Second		First (optimum)		Lastly	

(Rating: 5 = excellent, 4 = very good, 3 = good, 2 = fair, 1=poor)

CHAPTER FIVE

CONCLUSION & RECOMMENDATION

CHAPTER FIVE

5-1 Conclusion:

- AISI (4140) has more tensile strength and yield stress 655MPa tensile for steel (4140) and 607.3MPa for steel (4xxx).
- High temperature in AISI (4xxx) decreases the amount of tensile strength from 607.3MPa to 175.7MPa.
- AISI4140 ha 1.04% Chromium and 0.29 Silicon that lead to become high hardness than AISI (4xxx).
- Brindle harness in steel (4140) 197 bigger than AISI (4xxx) is 174BH.

5-2 Recommendations:

The following are recommended:

People work in this area must improve the steel alloy by change or additional the element that effect in tensile strength and hardness like Cr, Si and Mo can improve the amount of this element and casting alloy to get good properties for steel alloy.

Apply heat treatment to improve mechanical properties and use of computer software programs to make simulation for it.

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