ANALYSIS OF CHARACTERIZATION AND PERFORMANCE OF MATERIAL FOR SMALL ARMS BARREL

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ABSTRACT

There are some aspects to be considered in the ideal of designing a modern gun barrel. One of the main factors is the right chosen of materials to make the barrel. Gun barrel operates under very stored energy either which is more than 450 MPa compressing the gas and explosion of the high-pressure environment. During the process of firing, the gun barrel incapable to withstand of high pressure it may occur to fail. In this research, an experiments are work is conducted to determine the mechanical, physical, and chemical properties of Unknown Material. The results of the experiment are then compared to the mechanical, physical and chemical properties of the common material used for making small arms gun barrel namely AISI 4340 and AISI 4140. It can be seem that there minor difference value in term of Young’s modulus, yield strength, and ultimate tensile strength, for these three materials. By using the experiment of data the 3D model of the gun barrel will perform static analysis using ANSYS to observe either it fails or not. This thesis deals with the analysis of the gun barrel for the given boundary condition.

ABSTRAK

Terdapat beberapa aspek yang harus dipertimbangkan dalam memperolehi reka bentuk laras senjata kecil moden yang optimum. Salah satu faktor utama adalah pemilihan bahan yang betul untuk membuat laras senjata kecil. Laras senjata kecil biasanya beroperasi di bawah tenaga yang sangat tersimpan sama lebih daripada 450 MPa, terhasil daripada gas yang termampat dan letupan persekitaran tekanan tinggi, atau letupan propellant. Semasa proses menembak jika laras senjata kecil ini tidak dapat menahan tekanan tinggi, ia mungkin akan gagal. Dalam penyelidikan ini, eksperimen lengkap untuk menentukan sifat-sifat mekanik, fizikal dan komposisi kimia bagi bahan yang tidak diketahui. Kemudian, hasil eksperimen akan dibandingkan dengan sifat mekanikal, fizikal dan komposisi kimia bahan biasa yang digunakan untuk membuat laras senjata kecil seperti AISI 4340 dan AISI 4140. Menggunakan lengkung tekanan strain terukur dan sifat mekanik yang diperolehi, termasuk modulus Young, dan kekuatan tegangan muktamad, akan dibuat perbandingan antara tiga bahan ini. Dengan menggunakan data eksperimen, akan dijalankan analisis statik terhadap model 3D laras senjata kecil dengan menggunakan ANSYS untuk memerhatikan sama ada ia gagal atau tidak. Dalam analisa statik ini terdapat had sempadan yang telah ditetapkan bagi membolehkan analisa dilaksanakan dengan jayannya.

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APPROVAL SHEET

This thesis was submitted to the Faculty of Engineering, Universiti Pertahanan Nasional Malaysia and has been accepted as partial fulfillment of the requirement for the Degree of Bachelor of Mechanical Engineering. The members of the Supervisory Committee were as follows.

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TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION

AISI	American Iron and Steel Institute
ANSYS	Analysis Systems
ASTM	American Society for Testing and Materials
BMG	Browning Machine Gun
CAD	Computer-aided design
EDX	Energy Dispersive X-Ray Analysis
FEA	Finite Element Analysis
FEM	Finite Element Method
SAE	Society of Automotive Engineering
UNS	Unified Numbering System
UTS	Ultimate Tensile Strength

CHAPTER 1

INTRODUCTION

1.1 Background

The first primitive weapons developed in China in the 10th century, it starts with bamboo barrels having gunpowder, and tablet projectiles were mounted on spears in a single-person fire lance, which was later used as a shock weapon in the Siege of Dean in 1132. The Chinese invented the metal-barreled cannon in the 13th century, widely regarded as the true ancestor of all weapons. Know day's firearms are categories by two-term, small arms, and a light weapon. Practically, a small weapon is a weapon designed for personal use, and a light weapon is a weapon designed for use by several crew members (Jenzen-Jones & Schroeder, 2018).

The phrase "small arms" refers to any kinetic-projectile weapon that is small and light enough to be carried and handled by a single infantry soldier. Small arms are also generally classified as weapons with a millimeter bore or a caliber below 20 mm (Jenzen-Jones & Schroeder, 2018). According to D F Allsop & Toomey (2004), small arms include handguns which are common caliber is 9 mm, and rifles which usually use barrel caliber from 5.56 mm up to 12.7 mm. Other than that, shotguns with smoothbore 12 gauge and machine guns such as submachine gun, light machinegun, and heavy machinegun with a caliber from 5.56 mm up to 12.7 mm are categorized as a small arm.

The small arm can be described depending on the type of action used (muzzle revolver, loader, pump, brake loader, lever, bolt, semi-automatic, fully automatic) together with the usual means of deportation (hand-held or mechanical mounting). Some more classification may describe the type of barrel used (rifled) and to the length of the barrel (24 inches), to the firing mechanism, to the design's main desired use, or the commonly accepted name for a specific variation. Although small arms can be described with a lot of variety, however, they have similar three components: a 'barrel', the 'action, and a 'stock' (pistol grip)' which refers to gun operating components.

What is the best material for a barrel of a gun? The response is "it depends," before that, it is important to understand the challenges faced by barrel makers. Until 1880, alloys of brass or iron were widely used to make barrels of ammunition. Nevertheless, these metals proved to be unsuitable for the modern smokeless propellers introduced after 1885. New metal alloys had developed to work safely with smokeless propellers.

The barrel of a gun is the core of any kind of weapon that can fire any kind of material with the aid of stored energy, either by compressing the gas and explosion of the propellers or by some other means. During the process of shooting a bullet or a projectile, the barrel is exposed to several forms of loads that create stress in the barrel. Gun barrel works under a very high-pressure condition more the 360 MPa and it is the most common part or component to fail (Calik, Sahin, & Ucar, 2009). So that the design of the barrel must be use material which is strong enough to withstand the heavy pressure loads.

Manufacture of firearm barrels has been offering special ordnance-grade steel alloys by steel manufacturers. Ordnance-grade steel alloys are subject to special handling, rigorous analysis, and careful heat treatment to guarantee consistency and quality. Small arms are fitted with either monolithic or composite barrels. Monolithic barrels are formed of one piece of material, while composite barrels are formed of a monolithic barrel with an element fitted with other material to shield the breach from wear. It should be noted here that either monolithic or composite use different rifling methods used by barrel makers also work best with similar steel alloys and hardness levels. Most gun barrels have a hardness of about 25 to 32 on the Rockwell C scale (Calik et al., 2009).

D F Allsop & Toomey (2004) state that the barrel has a major effect on the construction of the whole weapon. The basic requirements that must consider are:

1. Required strength at maximum operating load.
2. High rigidity to minimize vibrations.
3. Maximum straightness.
4. Concentricity between inner and outer diameters.
5. Adequate service life.
6. Optimum mass for strength and stiffness.

7. Low manufacturing costs.

The gun tube designer is intended to find a structure with minimum weight, which typically corresponds to the smallest radial dimension, aligned with the safe firing of a projectile. They also are generally interested in determining the minimum weight of the projectile structure necessary to meet reliability, safety, and, in particular, efficiency requirements. They must be aware of the high pressure at the base of the moving projectile during its time in the tube, known as the single base maximum pressure. The designer could move on to other aspects once this single pressure-induced pressure is accommodated. On the other side, as the projectile transits the tube, the tube builder must know the maximum pressure exerted on the tube at any axial position in the bore. They are regarded as the high-pressure station in the design of the tunnel. We use the combination of projectile and charge that adds the most stress to the firearm (usually the heaviest projectile and the biggest charge is this). With each shot fired, these pressures are continuously applied as the tube is cycled, contributing to the need to account for and anticipate the design's fatigue failure.

1.2 Problem Statement

The gun barrel is the most important part of the weapon that holds the bullet shell during the breech loading. It is the most important part of the gun, and it is quite common that sometimes it failed during the process of firing the bullet. It is because barrel works under very stored energy both by compressing the gas and by blowing off the high-pressure condition more than 360 MPa (Dixit, Singh, & Rajora, 2016).

Another major consideration in gun barrel design is the degradation of material strength with temperature. The repetitive firing of a weapon with propellants burning in the chamber and in the bore generates a large amount of heat. In the gun barrel of small arm, the temperatures developed can become high enough from 250 ^{o}C to 320 ^{o}C.

Because of that reason, the gun barrel designer must be consider this two criteria to unsure that the gun barrel are not fail. Therefore, this project aims to analysis the characteristic and performance of Unknown Material as gun barrel material.

In this research are focus to study the strength and ductility of Unknown Material and its ability to withstand the high-pressure temperature more than 360 MPa and 250 ^{o}C. Other than that, this research will make comparison of mechanical and chemical properties of Unknown Material between two common material used for making small arms barrel, AISI (American Iron and Steel Institute) 4140 and AISI 4340. The comparison will figure out either Unknown Material suitable to use as material for gun barrel 12.7mm.

1.3 Objective of the Research

The main objectives of this research works are:

a. To determine the mechanical properties and chemical composition of Unknown Material.

b. To analyze the performance of the 3D Model of the barrel by using different material under internal pressure with steady-state thermal by using ANSYS.

1.4 Scope of Work and Limitation

The scope of this study is to focus on the findings of mechanical properties and chemical composition of Unknown Material. FEA (Finite Element Analysis) is just to apply internal pressure and heat transient to the 3D model. The 3D model of the gun barrel is basis on the Barrett M95 12.7 mm anti-material sniper rifle that has been used by Special Force Regiment and Royal Malay Regiment.

There is some limitation that had been stated in this study, which is the limitation is:

a. Material

The material that will be used in this study is Unknown Material (subject to study) and AISI 4140 and AISI 4340 (as a comparison) or with other material that tables up in AISI-SAE Standard Steel Designation and Associated Chemistries

Table. Two specimens will use for each ASTM E18 Standard Test Methods for Tensile Test and EDX Test.

b. Parameter

The 3D model develops by using software Autodesk Inventor 18 and while FEA is using ANSYS. The limitation for FEA is the boundary condition of internal pressure and heat transient condition inside the gun barrel, which is it will apply high-pressure condition 450 MPa with heat up to 300 ^{o}C. This project is limited to the study of the selected material of the gun barrel. These are the analyses which are to be carried out:

a. Static Structural analysis.

b. Steady-State Thermal analysis.

1.5 Thesis Outline

There are five chapters in this thesis. Chapter 1 discusses a general overview of the research, the problem statement, and the general solution to the problem. This chapter also includes the research objectives, research scope, and limitations during this research study.

Chapter 2 describes the material of the gun barrel, mechanical properties, and chemical compound of material and interior pressure inside the gun barrel in this works. The chapter was presently connected with the research progress from the non-destructive and destructive experiment to 3D gun barrel modeling solving using ANSYS. The majority of all-significant references, including journals, web pages, books, chapters in the book, etc., combined in this part. This segment also addresses the important findings of other scholars.

Chapter 3 presents the comprehensive methods used to accomplish good results. Thus, includes EDX Test, Tensile Test then identifies material of Unknown Material base on AISI steel table, develop a 3D model of the gun barrel, and FEA on to 3D model were described specifically in this chapter.

Chapter 4 addressed the outcome of the experiment run. The first part provides information on the process to get on mechanical property and chemical compound of Unknown Material, after that the process follows by investigation of the internal pressure and heat transient condition by using ANSYS. This chapter investigates in-depth the findings, patterns, relevant explanations that meet the discussion.

Chapter 5 presents the conclusion of the main findings of the work and suggestions for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Physic of Firearms – Ballistic

From physics (dynamics, to be precise), as with most firearms, a firearm is a device for delivering maximum destructive energy to the target with minimal energy delivery to the shooter (Deng, Sun, & Chiu, 2012). The science that deals with the propulsion, flight, and effect of gun projectiles are ballistics. There are three phases listed in detail: interior ballistics, exterior ballistics, and terminal ballistics. The propulsion of the projectile within the gun system is internal ballistics. The flight of the projectile through the atmosphere is exterior ballistics. The effect and penetration of the projectile into the target is terminal ballistics (Junior, 1978).

2.1.1 Internal Ballistics in the Gun Barrel

Internal Ballistics is the applied physics needed to inform motion within a gun tube to a projectile (Junior, 1978). The internal ballistics are for the period from the ignition of the propeller to the exit of the gun barrel of the projectile in the guns (see Figure 2.1). For manufacturers and consumers of weapons of all forms, from small rifles and handguns to high-tech artillery, the study of internal ballistics is important.

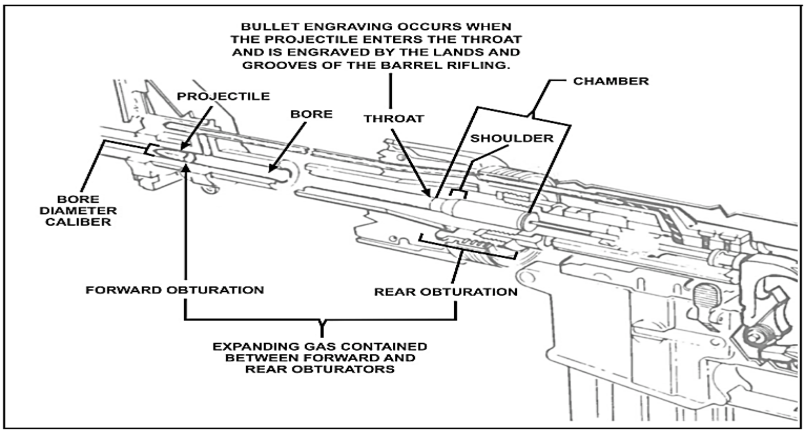

Figure 2.1 Internal Ballistic Terms (MCoE, 2016)

2.1.2 Theory of Blast in Barrel

The blast in barrel (ideal gas law) is exchanging a propellant's stored chemical energy into the projectile's kinetic energy through the gas generation and the resulting increase in pressure. The suitable law of gas is a mixture of multiple relationships. The law of Charles notes that the volume of the gas is directly dependent upon temperature. The Avogadro principle notes that the volume of the gas is dependent on the number of moles of the gas present. Boyle’s law states that volume is inversely proportional to pressure (Carlucci & Jacobson, 2018).

The combination of these three relationships are present at the famous ideal gas law, which states in extensive form as below, known as Noble Able equation.

$$pv = RT \tag{2.1}$$

Which is p is the pressure of the gas; v is the specific volume, R is the specific gas constant, unique to each gas; and T is again the absolute temperature (Johnston, 2005).

2.1.3 High-Pressure Value in Gun Barrel

The tube builder must be aware of the maximum tube pressure on each axial position in the bore, as the projectile moves through the tube. In tube architecture, these are known as the station maximum pressures. It uses the combination of projectile and charge that adds the most stress to the firearm (usually the heaviest projectile and the biggest charge is this). These pressures are continuously applied as the tube is cycled with each shot fired, leading to the need to account for the design fatigue failure and anticipate it.

a. Pressure in Gun Barrel. A lot of research has been done to study the process of internal pressure in a gun barrel and the various pressure value are been apply to the various caliber in their study. The summary of the pressure value that been applied by the various researcher are shown in the table below:

Table 2.1 Summary of Pressure Value that used in the Experiment

Authors	**Gun Barrel Caliber**	**Pressure**
(Babaei, Malakzadeh, & Asgari, 2015)	7.62 mm	450 MPa
(Li, Wang, Zang, Guan, & Qin, 2019)	12.7 mm	465 MPa
(Xavier, 2011)	20 mm	350 MPa