The Novel Usage of Nitrocellulose as a Propellant of 5.56 mm Bullet

Mohd Najib Abdul Ghani Yolhamid, Farizha Ibrahim,
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Mohd Najib Abdul Ghani Yolhamid[1*] , Farizha Ibrahim[1] , Mohamad Abu Ubaidah Amir[1], Rushdan Ibrahim[2], Sharmiza Adnan[2], Muhd Zu Azhan Yahya[1]

[1]Faculty of Science and Defence Technology, University Pertahanan Nasional Malaysia, MALAYSIA
[2] Forest Research Institute Malaysia (FRIM), Kepong, Selangor Darul Ehsan, MALAYSIA

Abstract
Black powder is predicted to be more expensive in relation to the world oil shortage crisis in future. However, cellulose (generic chemical formula (C6H10O5) is the carbohydrate that makes up the main structure of plants. It seems to be more economical especially for countries with a lot of natural resources and rain forest like Malaysia. The findings of the study reveal the capability of nitrocellulose as gunpowder. In this research, a comparison of the same mass of nitrocellulose and gunpowder is done to find out which propellant is able to produce longer distance and greater impact. From this study, the main objective is to find out the performance and capability of nitrocellulose from various samples such as Rhizophora (Hardwood), Palm Oil Bunches (Empty Fruit Bunches) and Kenaf Bast (Soft Wood) compared to gunpowder in terms of velocity, calorific value of bullets and kinetic energy produced. The result of this study is that the nitrocellulose performs better than gunpowder. The new application of smokeless gunpowder makes troops especially snipers more difficult to be detected by our enemy while at the same time improves our safety and security level.

Keywords:
Gun powder, nitrocellulose, Rhizophora (Hardwood), Palm Oil Bunches (Empty Fruit Bunches,) and Kenaf Bast (Soft Wood)

1. Introduction

In the decrease of natural resources such as petroleum, a new invention must be made to ensure the survival of projection power especially in small arms use. The elements that have been used in producing black powder are showing their shortage recently. The most obvious factor is oil usage worldwide, where the usage has increased but the oil supply can only meet 95% of it [1].

As compared with gunpowder (black powder), modern nitrocellulose explosive is characterised by great increase in power, giving an enormously greater range, flatter trajectory and better penetration to projectile fired from rifles or artillery [2]. The idea of having uniqueness not to produce smoke in firing is to cover up exact position of firing [3].

2. Propellant/ Powder

A propellant or gunpowder is a material that produces pressurised gas that fills the interior of an ammunition cartridge or the chamber of gun cannon, leading to the explosion of a bullet or shell. Propellants are used in forms called grains. The propellant used by the 5.56mm bullet studied in this research is WC844 mixed into composition with nitrocellulose that has been extracted from Rhizophora Apiculata, Palm Oil Bunches (Empty Fruit Bunches) and Kenaf Bast (Soft Wood). The composition of nitrocellulose that is used in this study is determined by weight in relation with WC844 gunpowder.

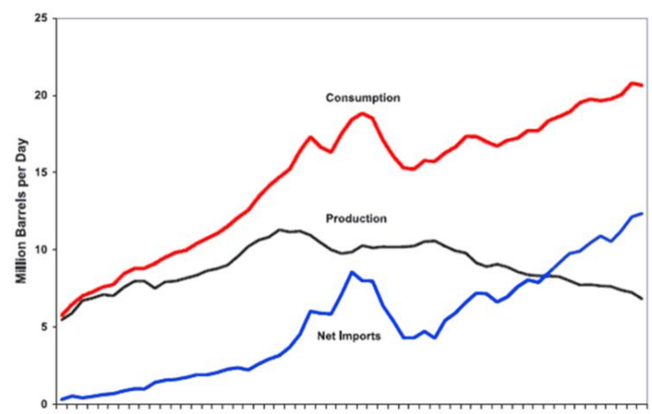

Fig. 1: US Energy Consumption Production and Imports 1949-2005[1]

*Corresponding author. Tel: +60-19-2120576; fax: +60-3-90512549

**E-mail address*: najib@upnm.edu.my

Authors E-mail address: ionmillion@gmail.com, amir.a@upnm.edu.my, rushdan@frim.gov.my, sharmiza@frim.gov.my, mzay@upnm.edu.my

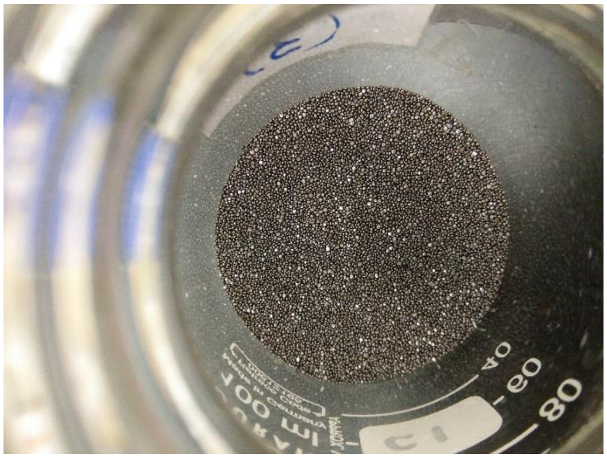

Fig. 2: Ball M193 gunpowder

Smokeless powders are available in two types of composition; Single Base and Double Base. Single Base Powders are made from straight nitro-cellulose composition. Double Base Powders contain both nitrocellulose and percentage of nitro-glycerine and this combination enables it to produce more energy than the Single Base Powders.

Table 1: The propellant classification system employed by the following groups.

Group	Description
Group 1	Single based propellant stabilised with DPA.
Group 2	Single based propellants stabilised with DPA and deterred with EC.
Group 3	Single based propellants manufactured from nitrocellulose at 12.00 ± 0.10 percent nitrogen content and stabilised with EC.
Group 4	Double base 'BALL' propellants stabilised with DPA.
Group 5	Double base propellants stabilised with less than 1.0 % EC.
Group 6	Double or triple base propellants stabilised with 1.5% (nominal) EC.
Group 7	Double base propellants with nitroglycerin content of 20-40% and stabilised with 6% EC (nominal).
Group 8	Triple base propellants stabilised with 3.0% (nominal) EC.
Group 9	Triple base propellants stabilised with 3.6% (nominal) EC.
Group 10	Triple base propellants stabilised at least 7% of EC.

*Nitrocellulose is the propellant from Group 3.It is a single based propellant, which can be manufactured from raw material containing12.00 ± 0.10 percent nitrogen content. Nitrocellulose can be stabilised with EC up to 8% of propellant composition.

The burning rates of spherical shaped powder when it is double based are determined by chemical composition, grain size and deterrent coating. Spherical powder, in general, is harder to ignite than other shapes of powder, therefore magnum primers are recommended in certain loads.

3. Energy

Energy can be defined as the capability to produce force against the basic nature force. In internal ballistic, there are two types of energy involved which are chemical energy produced by the combustion of the propellant, and the kinetic energy of the bullet which results in velocity.
Kinetic Energy

Kinetic energy is the energy which is possessed by an object due to its motion. Kinetic energy of the bullets can be calculated based on its velocity and mass using kinetic energy's general equation which is:

$$ke = \frac{1}{2} mv2$$

Where m is a bullet mass
v is a bullet velocity

The kinetic energy of bullet is produced when the pressure of the gas (produced during combustion) forces the bullet to go through the barrel.

Energy Distribution

According to [4], the general energy distribution for small firearm is as shown in Table 2.

Table 2: Energy distribution of small firearm cartridge

Item	Percentage
Heat to Cartridge Case	6%
Kinetic Energy to Bullet	29%
Kinetic Energy to Gases	17%
Heat to Barrel	21%
Heat to Gases	18%
Heat to Bullet Friction	9%
Total	**100%**

*Corresponding author. Tel: +60-19-2120576; fax: +60-3-90512549

**E-mail address*: najib@upnm.edu.my

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Based on energy distribution, it seems that only 29% of the combustion chemical energy is converted into the kinetic energy of the bullet. However, the energy distribution as stated above is only 100% applicable for normal charge. As in Hatcher's, 1966, the value of energy for heat to cartridge case and heat to bullet friction are the same for each weapon even with different amount of propellant. So in this study the value of heat to cartridge case and heat to bullet friction is the same for every amount of propellant of 5.56mm round.

4. Nitrocellulose

Nitrocellulose was found by Schönbein in 1846 coincidently. He observed the explosive properties of the nitrocellulose after he had mopped up concentrated nitric acid with a cotton towel and left it to dry above the stove, [5]. The nitrated towel was ignited by the heat of the stove. It ignited almost without the release of smoke [6].

As a result, he found that by applying nitric acid on cotton, which is cellulose, nitrocellulose is formed. Nitrocellulose is produced from cellulose being mixed with a mixture of nitric esters. Because of that, it also can be called as cellulose nitrate. It's the main ingredient of modern gunpowder because of the high flammability of its compound.

5. Methodology

The objective of this experiment is to define the actual kinetic energy from three categories of raw materials for nitrocellulose as a propellant and based on the previous study of other researchers there are two references of experimental method that can be reviewed in order to achieve this objective. The method of performing experiment for stride and Atanov has minor differences such as parameters involved.

In STRIDE manual, the parameters involved are amount of propellant and the velocity of bullet, but in Atanov's experiment, the parameters involved are the type of gas used to propel the bullet and the velocity of the bullet. However, both experiments yielded the result of bullet velocity. As in this study, the experiment method that is implemented is according to STRIDE's manual of experiment because it fulfils all the requirement of the experiment needed such as the experiment for bullet preparation.

By using this type of experiment, the actual value of kinetic energy can be defined. The layout of experiment is shown in Fig. 3. From the layout, it can be seen that the distance between the rifle and the middle of both optical light screens is 2m, so it seems that the distance that the rifle and the first optical light screen is 1m. It can be said that when the bullet has travel 1m from the muzzle, its velocity starts to be measured at first optical light screen at a distance of 1m.

There is a distance between the rifle and the optical light screen because the bullet needs to follow the path and stabilise before its velocity is taken. The function of the target is to prove that all bullets are following the same path which is at the centre of the target.

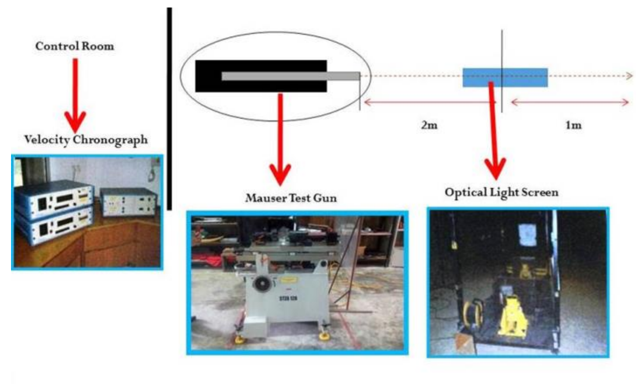

Fig. 3: STRIDE's Experiment Layout

For each experiment, there will be 10 specimens for each cartridge containing 0.6grams of specimen. The experiment uses 8 specimens for each composition because the average value of muzzle velocity will be calculated in order to achieve an accurate and precise result. Based on the value of average muzzle velocity, the kinetic energy of the bullet can be calculated using general equation of kinetic energy.

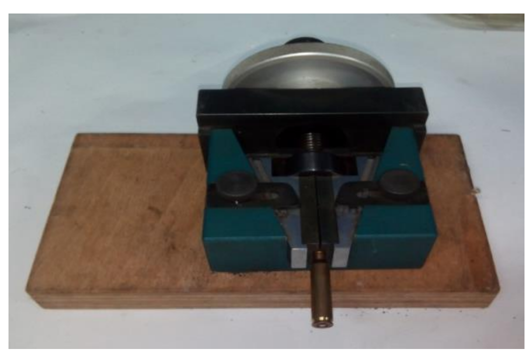

Fig. 4: Bullet Puller

*Corresponding author. Tel: +60-19-2120576; fax: +60-3-90512549

**E-mail address*: najib@upnm.edu.my

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In order to do the preparation for the cartridges as specimens, certain equipment is needed. The first equipment is an impact bullet puller. The image of a bullet puller is shown in Fig. 4. The bullet puller disassembles the round into its component parts (bullet, gunpowder, casing and primer). Pullers use inertia to pull the bullet: they are shaped like hammers, and the case is locked in place inside. A sharp blow on a hard surface will suddenly stop the case, and the inertia of the heavy bullet will pull it free of the case in a few blows, trapping the powder and bullet in the body of the puller.

The second equipment is a precision balance. Precision balance shown in Fig. 5 is used to weigh the mass of the propellant in order to prepare the cartridges for four different amounts of propellant. Its accuracy is not affected by gravity. By using this equipment, the mass of propellant can be measured to be filled in the cartridges accordingly.

Fig. 5: Precision Balance

Then, to reassemble back the cartridges, the single stage reloading press as seen in Fig. 6 is used. It will press the case opening to the bullet. The pressure will open the cartridges and hold the bullet. The suitable pressure is different for each type of cartridge. After the cartridges were reassembled back, the cartridges will be ready for firing.


Fig. 6: Reloading Press

4. Analysis and performance measurements

4.1 Firing Test

The firing test conducted in STRIDE as in Fig. 7, 5.56mm cartridge is used using Mauser Test Gun with equal volume of propellant. 0.6 gram of each sample is filled in the cartridge for firing test. For each cartridge fired, the velocity is recorded and kinetic energy calculated.

Muzzle velocity will be measured using optical light screen which is placed 2 metres in front of the Mauser test gun. The velocity is measured in metre/second (m/s).

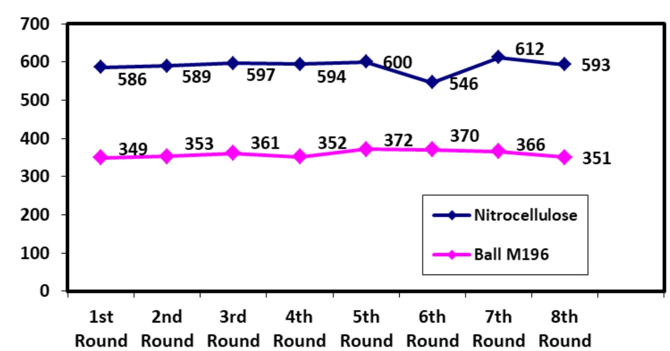

Fig. 7: Velocity of Bullets

*Corresponding author. Tel: +60-19-2120576; fax: +60-3-90512549

**E-mail address*: najib@upnm.edu.my

Authors E-mail address: ionmillion@gmail.com, amir.a@upnm.edu.my, rushdan@frim.gov.my, sharmiza@frim.gov.my, mzay@upnm.edu.my

From table 3 and fig. 8, one can determine that muzzle velocity of nitrocellulose is 230.3m/s higher than gunpowder (64.1%). Although using just 11.4% of nitrogen content, nitrocellulose can produce 64.1% higher muzzle velocity which will improve maximum firing range of the bullets.

Table 3: Mean, highest and lowest of bullets velocity

	Gunpowder	**Nitrocellulose**
Mean	359.3	589.6
Highest	372	617
Lowest	349	593

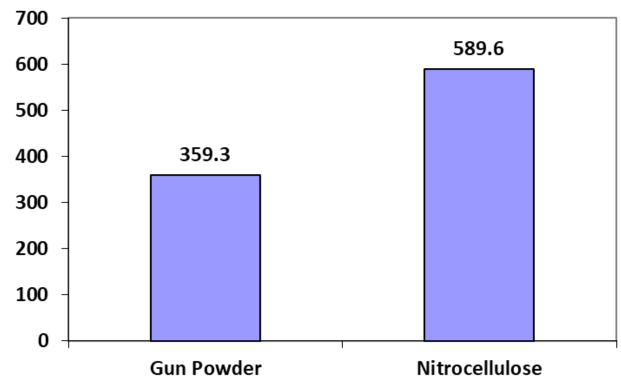

Fig. 8: Mean of Muzzle Velocity (m/s)

Kinetic energy is the energy of the bullet's movement which will influence the projectile of bullets. This energy is measured using the formula below:

K.E : ½mv2

Where:

K.E : Kinetic Energy
m : Mass of bullets (3.63g)
v : Velocity of bullets

K.E Gunpowder : ½ (3.63/1000)(359.3)²

: **234.3 J**

K.ENitrocellulos:½(3.63/1000)(589.6)²

:**630.9J**

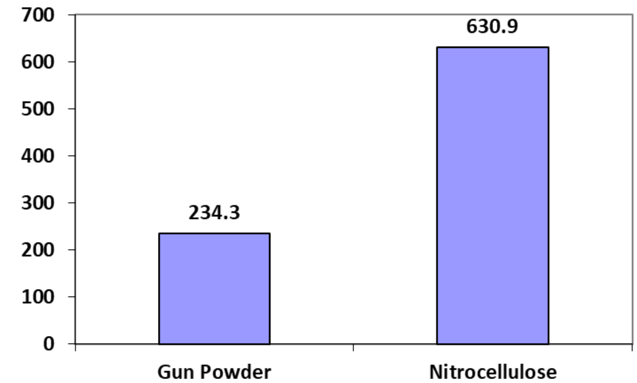

Fig. 9: Kinetic Energy (Joule)

4.2 Calorimetry test

Calorimetry test was also conducted in the Weapon Department of STRIDE, Batu Arang, to measure the gross heat value of the sample. All the data collected uses joules as a unit of measurement.

Table 4: Data obtained from calorimetric test

Categories	**NC Rhizophora**	**Ball M196**
Method	Dynamic	Dynamic
Benzoic Acid (grams)	0.3119	0.5330
EE Value	10,421,220	10,451,900
Weight (grams)	0.312	0.533
Fuse	15	15
Sulfur	Nil	Nil
Initial Temperature (ºC)	26.6028	27.2175
Jacket Temperature (ºC)	29.9758	29.9696
Spike Weight	Nil	Nil
Acid	10	10
Temperature Rise	0.1979	0.2683
Gross Heat J/gm	**6,612,900.29**	**5,260,853.39**

From the data obtained, gross heat produced from nitrocellulose is 6,612,900.29 J/gm and ball M196 5,260,853.39 J/gm as shown in Fig. 10. This shows that the nitrocellulose produced a 1,352,046.9 J/gm (25.7%) greater gross heat than ball M196 gunpowder.

*Corresponding author. Tel: +60-19-2120576; fax: +60-3-90512549

**E-mail address*: najib@upnm.edu.my

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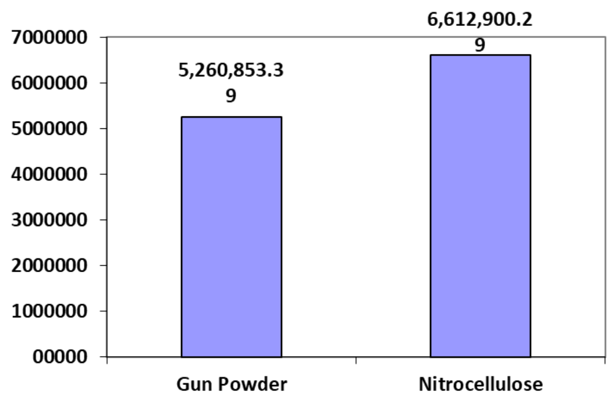

Fig. 10: Gross Heat (J/gm)

4.3 Thermo Gravimetric Analysis (TGA) and Differential Scanning Calorimetric (DSC) TEST

Thermal analysis consist of the analysis; i) Thermo Gravimetric Analysis (TGA) to measure heat absorbed or liberated during heating or cooling and ii) Differential Scanning Calorimetric (DSC) to measure change in weight during heating or cooling.

i. Differential Scanning Calorimetric (DSC) - These technique is to measures the temperatures and heat flows associated with the transitions in materials as a function of time and temperature in a controlled atmosphere. DSC are able to measure glass transition, melting and boiling points, crystallisation time and temperature, heat and fusion reactions, specific heat capacity, oxidative/ thermal stability, reaction kinetics and purity.

ii. Thermo Gravimetric Analysis (TGA) - These measurements provide quantitative and qualitative information about physical and chemical changes that involves endothermic or exothermic process, or changes in heat capacity. In this process, TGA is performed simultaneously with DSC to measures accurately the sample mass

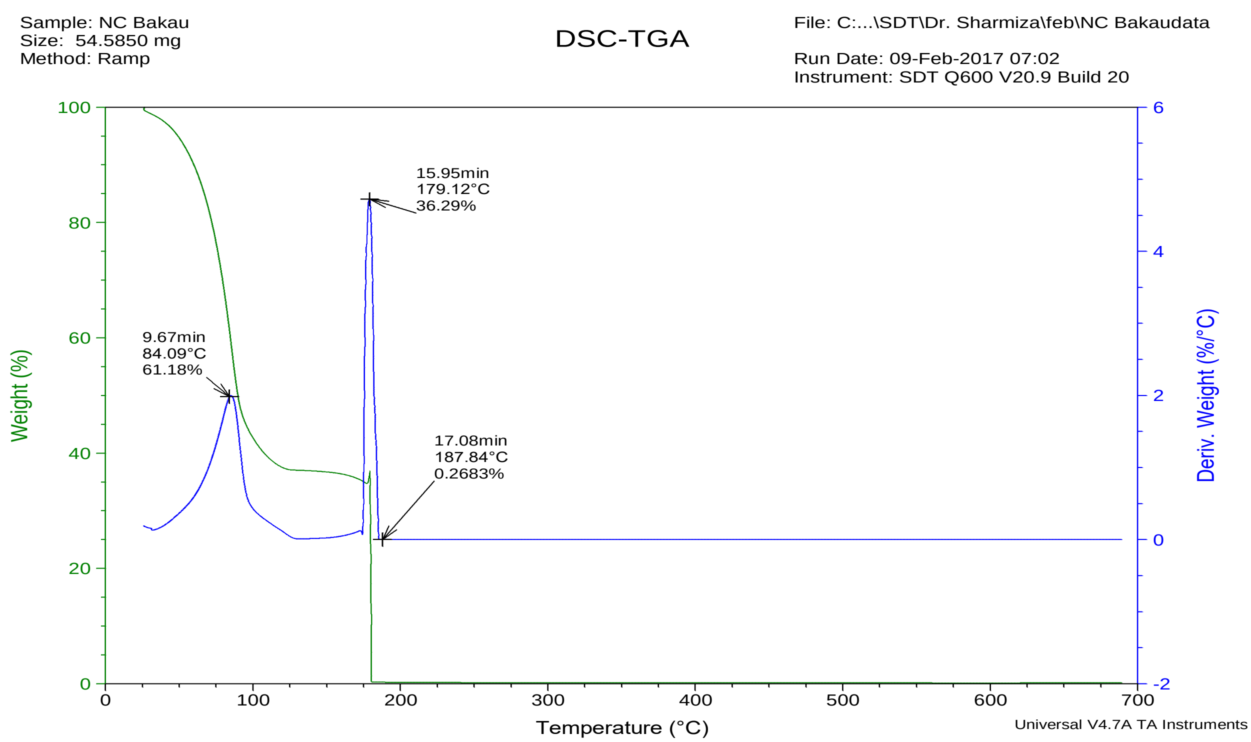

Fig. 11: DSC-TGA for Rhizophora Nitrocellulose

TGA curve (green solid line) shows in Fig. 11. The first heating curve is usually measured from room temperature to the desired final temperature. The curve shows in weight loss caused by chemical reactions

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*Corresponding author. Tel: +60-19-2120576; fax: +60-3-90512549

**E-mail address*: najib@upnm.edu.my

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(decomposition and loss of water crystallization, combustion, reduction of metal oxides) or physical transitions (vaporization, evaporation, drying). The line pattern from beginning up to 175 ºC shows the drying effect of Nitrocellulose. At this point, the moisture (nitrogen) is escape from Nitrocellulose, causing it weight drop until 38%. While at about 180 ºC shows the response of explosive decomposition with recoil effect. After the explosion, the weight is completely zero.

DSC curve (blue solid line) shows in Fig. 11. It is shows from the results that crystallisation response (exothermic process) occurs two times at 84.09 ºC and 179.12 ºC. At 84.09 ºC, the (nitrogen) contents is about 61.18% whilst at 179.12 ºC the (nitrogen) content is about 36.29% before drop to 0.26 % at 187.84 ºC. At this point, derivative weight completely zero. The response pattern shows that there is no melting and/ or glass transition give an indicator that the substance is pure.

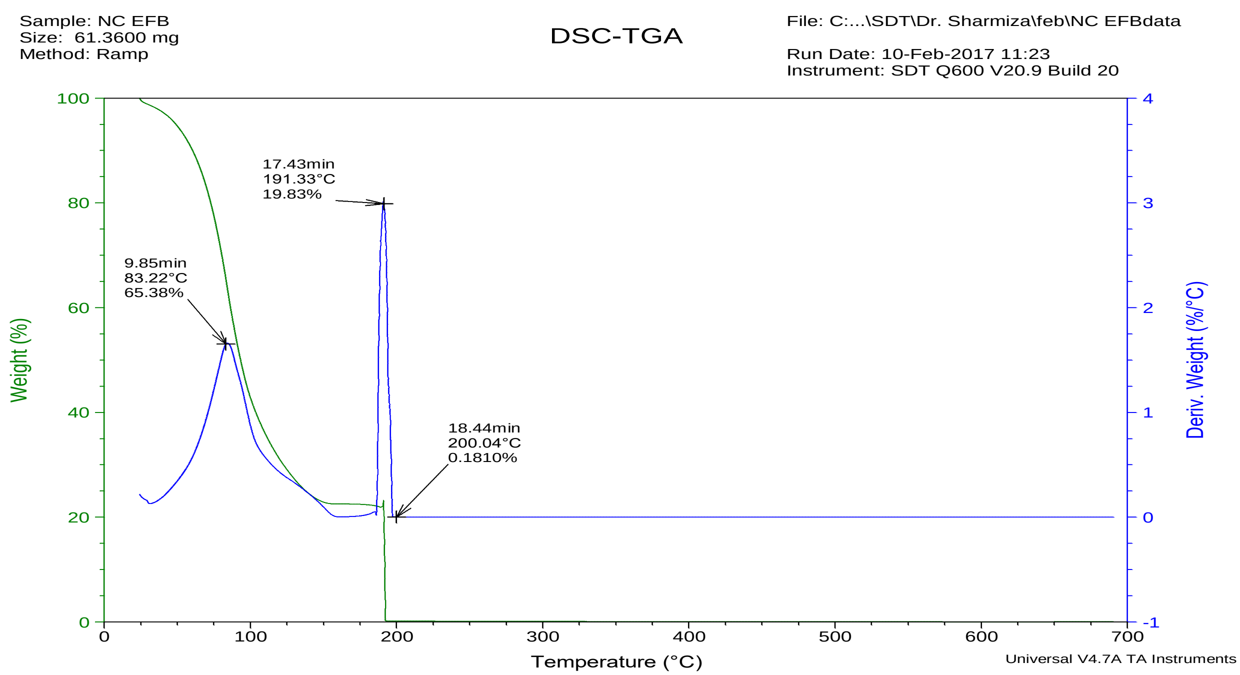

Fig. 12: DSC-TGA for EFB Nitrocellulose

TGA curve (green solid line) shows in Fig. 12. The EFB shows quite similar pattern with Rhizophora Nitrocellulose. The first heating curve is usually measured from room temperature to the desired final temperature. The line pattern from beginning up to 180 oC shows the drying effect of Nitrocellulose. At this point, the moisture (nitrogen) is escape from Nitrocellulose, causing it weight drop until 22%. While at about 190 oC shows the response of explosive decomposition with recoil effect. After the explosion, the weight is completely zero.

DSC curve (blue solid line) shows in Fig. 12. It is shows from the results that crystallisation response (exothermic process) occurs two times at 83.33 oC and 191.33 oC. At 83.33 oC, the (nitrogen) contents is about 65.38% whilst at 179.12 oC the (nitrogen) content is about 19.83% before drop to 0.181 % at 200 oC. At this point, derivative weight completely zero. The response pattern shows that there is no melting and/ or glass transition give an indicator that the substance is pure.

*Corresponding author. Tel: +60-19-2120576; fax: +60-3-90512549

**E-mail address*: najib@upnm.edu.my

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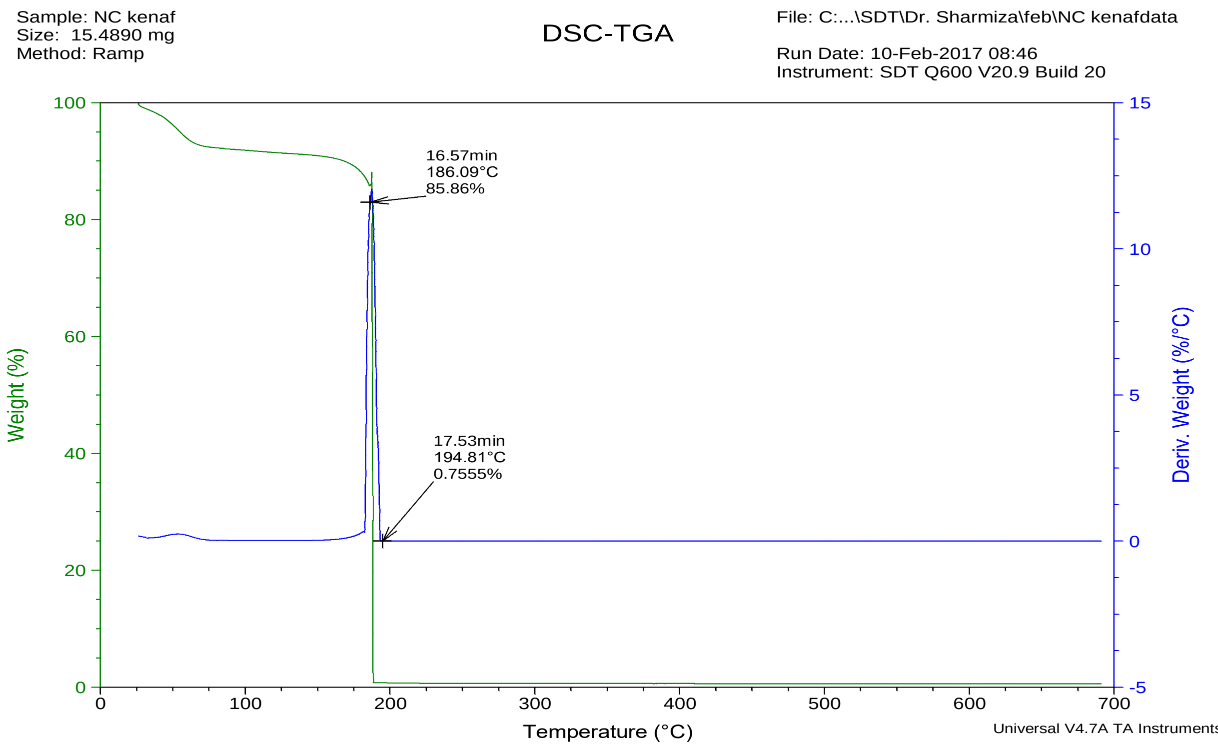

Fig. 13: DSC-TGA for Kenaf Nitrocellulose

TGA curve (green solid line) shows in Fig. 13. The Kenaf shows different pattern with Rhizophora and EFB Nitrocellulose. The line pattern from beginning up to 180 oC shows the slow drying effect of Nitrocellulose. At this point, the moisture (nitrogen) is escape from Nitrocellulose. While at about 190 oC shows the response of explosive decomposition with recoil effect. After the explosion, the weight is completely zero.

DSC curve (blue solid line) shows in Fig. 13. It is shows from the results that crystallisation response (exothermic process) occurs at 186.09 oC, the (nitrogen) contents is about 85.86% before drop to 0.755 % at 180 oC. At this point, derivative weight completely zero. The response pattern shows that there is no melting and/ or glass transition give an indicator that the substance is pure.

6. Conclusions

This paper discussed the capability of nitrocellulose as gunpowder. In this research, a comparison of the same mass of nitrocellulose and gunpowder is done to find out which propellant is able to produce longer distance and greater impact. The conclusion can be describe as:

i. Cartridge was de-assemble and all propellant removed. Only 0.6 gram propellant was filled inside the cartridge as a control to nitrocellulose sample.
ii. 0.6 grams of nitrocellulose was filled into blank cartridge as a comparison to gunpowder and successfully fired.
iii. Calorimetry test using Model of Parr 6200 Calorimeter in STRIDE determined that nitrocellulose produces a greater energy than ball M196 which is the normal gunpowder used in 5.56mm cartridge. Gross heat produced from nitrocellulose is 1579.46 cal/kg and M1961256.53J/kg. This shows that the nitrocellulose produces a 319.93 cal/gm (25.5%) greater gross heat than ball M196 gunpowder.
iv. Nitrocellulose that was produced from local raw material successfully underwent firing test

*Corresponding author. Tel: +60-19-2120576; fax: +60-3-90512549

**E-mail address*: najib@upnm.edu.my

Authors E-mail address: ionmillion@gmail.com, amir.a@upnm.edu.my, rushdan@frim.gov.my, sharmiza@frim.gov.my, mzay@upnm.edu.my

and as a result, it doubled the velocity and kinetic energy compared with gun powder.

v. Pure nitrocellulose is capable of becoming a propellant in the future. If it is produced locally at the same time, it can reduce interdependent to outsource.

vi. It is also found that the nitrogen content must preserve inside the nitrocellulose, thus the heat procedure before put the nitrocellulose into cartridge must be avoided.

Acknowledgements

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*Corresponding author. Tel: +60-19-2120576; fax: +60-3-90512549

**E-mail address*: najib@upnm.edu.my

Authors E-mail address: ionmillion@gmail.com, amir.a@upnm.edu.my, rushdan@frim.gov.my, sharmiza@frim.gov.my, mzay@upnm.edu.my