FABRICATION OF CERAMIC NOZZLE MADE FROM CLAY-ALUMINA MIXTURE

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ABSTRACT

Heat transfer from hot gases to the chamber and nozzle walls, can result in weakening the rocket casing. Thus proper and complete insulation is needed to protect the casing material from reaching melting temperature or become damaged at elevated temperature. Typical solution to this problem would be to thicken the casing walls which in effect would increase the total weight. To reduce the total weight, a new material that can withstand high temperature and is lightweight was studied. Ceramic is one of the materials that can withstand high temperature and at the same time is much lighter than normal metal. There are several developments using ceramic as a hot section component. In this study, ceramic was used as a replacement for typical metal component of rocket motor. Traditional clay called Sayong clay and refractories material, namely, alumina were used. A suitable material for rocket motor development would be one that has good mechanical strength, minimum shrinkage and low thermal conductivity. Three different composition sets were prepared and characterized according to shrinkage reduction, compressive strength and thermal conductivity. Composition A which contains only clay mixed with water as a binder shows high degree of shrinkage during drying and firing at temperature ranging from 700 ^{o}C to 1500 ^{o}C. Thus, by introducing alumina to the tune of 30% and 50%, the shrinkage of clay was reduced significantly. Furthermore, high compressive strength was achieved for the mixed composition of 50% alumina-clay (composition C) at firing temperature of 1500 ^{o}C, about 29.2 kN. Thermal conductivity test was conducted on composition C, and it was observed that as the firing temperature increases the value of thermal conductivity, k also increases due to the densification of ceramic particles. To verify the real potential of this ceramic material, Ballistic Research Motor (BRM) test was performed. Since composition C was found to be superior to others, a nozzle made from it was fabricated. The nozzle with throat measuring 30 mm in diameter was loaded into the existing rocket motor with solid propellant and combustion chamber. The firing of BRM took about 5 seconds with average chamber pressure reaching 0.124 Mpa. Calculations showed that the ceramic nozzle produced 42.47 N of thrust. The experiment proved the potential of ceramic as a suitable material for rocket motor design.

ABSTRAK

Pemindahan haba dari gas panas ke dinding kebuk dan muncung boleh melemahkan sarung roket. Oleh demikian, penebat haba yang baik dan menyeluruh diperlukan untuk melindungi bahan sarung dari mencapai suhu cair atau melemahkanya pada suhu tertentu. Kebiasaannya dinding sarung ditebalkan bagi menangani masalah ini seterusnya menyebabkan peningkatan berat. Bahan yang ringan dan mempunyai kebolehan untuk menahan suhu yang tinggi dikaji untuk mengurangkan jumlah berat. Seramik merupakan salah satu bahan yang berkebolehan menahan suhu tinggi dan lebih ringan berbanding logam. Terdapat beberapa pembangunan telah dilakukan ke atas bahan seramik sebagai komponen sektor panas. Di dalam kajian ini, seramik digunakan sebagai pengganti logam yang kebiasaannya digunakan dalam pembuatan komponen roket motor. Tanah liat tradisional yang dinamakan sebagai tanah liat Sayong dan bahan refraktori, alumina digunakan dalam kajian ini. Bahan yang sesuai untuk digunakan dalam pembangunan roket motor mestilah mempunyai kekuatan mekanikal yang baik, pengecutan yang minimum dan kekonduksian terma yang rendah. Tiga set campuran/komposisi disediakan dan dicirikan berdasarkan pengurangan pengecutan, tegasan mampatan dan kekonduksian terma. Komposisi A yang mengandungi hanya tanah liat dicampur bersama air yang bertindak sebagai pengikat mempamerkan jumlah pengecutan yang tinggi semasa proses pengeringan dan pembakaran pada suhu 700 ^{o}C hingga 1500 ^{o}C. Pengecutan tanah liat berjaya dikurangkan dengan cara menambah alumina sebanyak 30% dan 50%. Nilai kekuatan mampatan tertinggi dicapai oleh komposisi C yang mengandungi 50% alumina- tanah liat pada suhu pembakaran 1500 ^{o}C iaitu sebanyak 29.2 kN. Ujian kekonduksian terma dilakukan terhadap komposisi C menunjukkan nilai kekonduksian terma, k meningkat bersama peningkatan suhu pembakaran, disebabkan oleh pemadatan zarah seramik. Untuk menguji kebolehan sebenar seramik ini, ujian balistik roket motor (BRM) dilaksanakan dalam kajian ini. Disebabkan komposisi C menunjukkan ciri-ciri yang baik dan sesuai berbanding komposisi lain, muncung roket direka dan dibina daripada komposisi ini. Muncung yang mempunyai garis pusat tekak 30 mm dimasukkan ke dalam roket motor yang sedia ada bersama-sama bahan dorongan pepejal dan kebuk pembakaran. Pembakaran BRM mengambil masa selama 5 saat menghasilkan purata tekanan kebuk sebanyak 0.124 Mpa. Pengiraan dibuat menunjukkan muncung seramik menghasilkan daya tujah sebanyak 42.47 N. Ini membuktikan bahawa bahan seramik ini mempunyai potensi yang sesuai digunakan dalan rekaan roket motor.

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LIST OF ABBREVIATIONS

AP	-	Ammonium perchlorate
ATR	-	Air Turbo Ramjet
Al	-	Aluminium
Al_2O_3	-	Aluminium Oxide
SiC	-	Silicon Carbide
Si_3N_4	-	Silicon Nitride
k	-	Thermal Conductivity
k_e	-	free electron thermal conductivity
k_l	-	lattice vibration thermal conductivity
A	-	Cross sectional area
V		Velocity
ρ	-	Density of the fluid
K	-	Ratio of specific heat
HP	-	Hot Pressing
HIP	-	Hot Isostatic pressing
DCC	-	Direct coagulation casting
CIP	-	Cold isostatic pressing
PE	-	Polyethylene
UTM	-	Universiti Teknologi Malaysia
BRM	-	Ballistic Research Motor
DAQ	-	Data acquisition
DC	-	Direct current
OEM	-	Original equipment manufacturer
RTV	-	Room Temperature Vulcanizing
$\frac{\Delta T}{L}$	-	Temperature gradient with respect to thickness,L

F_x	-	Force in x direction
V_n	-	Velocity in normal plane
a	-	Speed of sound
$\dot{m}$	-	Mass flow rate
A_e	-	Exit area
A_t	-	Throat area
M_e	-	Mach number at exit
R_o	-	Universal Gas Constant
M_t	-	Mach number at throat
P_c	-	Combustion chamber pressure
P_t	-	Throat pressure

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CHAPTER 1

INTRODUCTION

The world of rocketry has expanded rapidly. According to written history, China was the first country to introduce a rocket system as shown in figure1.1 [1] In the year 1232, during the first recorded battle between Chinese and Mongol true form rockets were utilized. In this battle, an arrow was attached with open ended tube that contained gunpowder. As the gunpowder ignited, the combustion inside the open ended tube produced thrust that sent the arrow flying.

Figure 1.1: Chinese Arrows [1]

From then on, the technology of rocket spread throughout the world. The usage of rocket system has been deployed into various fields such as weapon, space travel, weather modification and more. It is a challenge for scientists and engineers to design and fabricate a rocket system that fulfills the various required specifications. Scientists and engineers often face the problem of selecting suitable materials that are appropriate for the operation or mission of the rocket.

Part of the challenge which must be overcome is choosing suitable material that can withstand the harsh environment in the rocket motor. The material must be able to withstand high mechanical and thermal stresses at high temperature, resist oxidation and corrosion that result from high velocity gases. Furthermore, the material must withstand the chemical reaction with adjacent component, be stable in high and low cycle vibration conditions and have acceptable creep and stress rapture life.

Previously, various type of materials had been proposed and tested in the development of rocket motor and one of them was ceramic material. This material is capable of withstanding high temperature and inert to chemical reaction. However, ceramic materials are brittle and cannot survive certain stresses or impacts. Nevertheless, with the right procedures in fabrication process, these disadvantages can be reduced or even eliminated.

1.1 Problem statement

Heat transfer from hot gases in the combustion to the chamber and nozzle walls can cause the rocket motor casing to be weakened. Insulation is needed to protect the casing material from reaching melting temperature or weaken the material properties. A typical solution would be to thicken the casing wall but this caused the total weight of the rocket motor to increase. Other solutions would be to use new material that can withstand high temperature. Ceramic is one of the materials that can withstand high temperature. However, ceramic has several disadvantages such as being brittle, porous and shrinkable. In this research, ceramic material was chosen as an alternative replacement to typical metal material which has been used currently in solid propellant rocket nozzle. The weakness of ceramic material such as mechanical strength, shrinkage during firing, and thermal conductivity were studied and solution was proposed.

1.2 Objective

To design and fabricate a solid propellant rocket nozzle utilizing clay-alumina mixture.

1.3 Scope of the study

This research study was carried out on the properties of ceramic materials importance in the development of rocket nozzle. An experimental test was conducted to select a suitable material that can be used in the construction of rocket nozzle. After the selection of material, a design and fabrication process were studied and implemented to produce a ceramic rocket nozzle. Finally, the ceramic rocket nozzle was tested using typical Ammonium perchlorate (AP) + Aluminium (Al) propellant [2]. In summary, the scope of this project can be listed as follows:-

- To study the properties of ceramic material.
- To study the characteristic of a solid propellant rocket motor.
- To design and fabricate ceramic rocket nozzle.

- To test the newly developed ceramic rocket nozzle.

1.4 Limitation of Study

Several limitations have to be accepted in this study due to cost and time constraints and availability of materials. These limitations are as follows:

1. The study only focuses on the fabrication of rocket nozzle.
2. The materials used were easily available in local market.
3. Focus only on easy method of fabrication and low end equipment.
4. There was no detailed study on micro or macro structure changes of ceramic material.

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