DESIGN AND FABRICATION OF SHAPE MEMORY ALLOY HEAT ENGINE

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DESIGN AND FABRICATION OF SHAPE MEMORY ALLOY HEAT ENGINE

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LIST OF SYMBOLS

Ms	Martensite start temperature
Mf	Martensite finish temperature
As	Austenite start temperature
Af	Austenite finish temperature
Min	Minute
g	Gram
°C	Degree Celsius
ℓ	Litre
⌀	Diameter

LIST OF ABBREVIATIONS

SMA	Shape Memory Alloy
SME	Shape Memory Effect
SE	Superelasticity
Ni	Nitrogen
NiTi	Nickel Titanium
SIMT	Stress Induced Martensite Transformation
DSC	Differential Scanning Calorimetry
UTM	Universal Testing Machine
CAD	Computer Aided Design
Pb	Lead
ID	Inner Diameter
OD	Outer Diameter
PTE	Polyethylene Terephthalate
ABS	Acrylonitrile Butadiene Styrene
PLA	Polylactic Acid
WR	Weight Reduction

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ABSTRAK

Enjin haba NiTi merupakan peranti ringkas yang menukarkan tenaga haba dari sumber haba kepada tenaga mekanikal. Penukaran tenaga ini berlaku kerana sifat unik NiTi iaitu kesan memori bentuk. Kesan memori bentuk adalah fenomena yang di mana NiTi dapat berubah bentuk secara elastik ke dalam bentuk atau geometri apa pun dan perubahan bentuk tersebut dapat dibatalkan sepenuhnya dengan menerapkan haba dengan suhu di atas suhu peralihan NiTi. Terdapat dua jenis kesan memori bentuk iaitu kesan memori bentuk satu hala dan kesan memori bentuk dua hala. Projek ini memfokuskan pada mereka bentuk dan fabrikasi enjin haba NiTi yang menggunakan aloi memori bentuk serta dapat menunjukkan demonstrasi enjin haba aloi memori bentuk yang berfungsi dengan baik. Bahan SMA yang dipilih adalah wayar NiTi 0.5 mm with dengan suhu peralihan 80 °C. Penyelidikan ini membincangkan mengenai proses fabrikasi enjin haba NiTi sepenuhnya termasuk kaedah menggabungkan wayar NiTi untuk membentuk gelung bulat NiTi dan menghasilkan roda takal. Setelah selesai proses fabrikasi, prototaip diuji untuk mendapatkan kelajuan maksimum yang dapat dicapai. Perbincangan mengenai kemungkinan parameter seperti suhu tangkungan air yang mempengaruhi prestasi enjin panas NiTi. Secara amnya, putaran mesin haba NiTi lebih lama apabila dicelupkan ke dalam tangkungan air panas dengan suhu yang lebih tinggi.

ABSTRACT

NiTi heat engine is a simple device that converts heat energy from the heat source into mechanical energy. This conversion of energy happens due to the unique property of NiTi which shape memory effect (SME). SME is a phenomenon where NiTi can be deformed elastically into any shapes or geometry and the deformation can be completely undo by applying heat with temperature above transition temperature of NiTi. There are two types of SME which are One-way SME and Two-way SME. This project focuses on designing and fabricating NiTi heat engine that uses shape memory alloy (SMA) material as well as being able to demonstrate a properly-function SMA heat engine. The selected SMA material is a 0.5 mm ⌀ NiTi wire with a transition temperature of 80°C. This research discusses on the process of fabrication of the NiTi heat engine entirely including the methods of joining the NiTi wire to form a circular loop of NiTi and producing the pulley wheels. After the completion of fabrication process, the prototype is tested to obtain the maximum speed that be achieved. Discussion on the possible parameters such as temperature of water bath that influences the performance of the NiTi heat engine. Generally, the rotation of the NiTi heat engine is longer when being dipped in a hot water bath with higher temperature.

CHAPTER 1

INTRODUCTION

1.1 Project Overview

There have been numerous amounts of interests are shown by many researchers in various fields towards shape memory alloy (SMA) in past couple decades until now. The most used and researched shape memory alloy is Nickel-Titanium (NiTi). Usage of NiTi is well verse and sought after in many field applications such as medical[1], actuators[2], civil engineering as active control systems and many more[3][4]. This is due to their good thermomechanical properties, corrosion resistance, low elastic modulus, low-cost application and their own unique characteristics such as superelasticity also termed as pseudoelasticity and shape memory effect (SME)[5].

Shape memory alloys are known for unique properties due to their reversible changes in their crystal structure. Shape memory alloys have two distinguished phases which are called martensite for the high temperature and austenite on the low temperature region. Both phases have different crystal structure and properties. SMAs have been widely researched and used in many variations of applications in different fields and industries. For this project, a shape memory alloy heat engine will be designed and fabricated to exhibit its unique properties to the communities.

Shape memory alloy products available around us and they are basically hidden as people are unaware of them. SMAs are available in household appliances such as coffee maker and in people mouth which is the dental braces to align and strengthen our teeth[6][7].

Besides, SMAs are also used in optometry which is that some spectacle frames are very flexible and can reform back to its original shape after force is released. SMAs are unique and very versatile material. Towards the advancement in technology, the manufacturing process for SMA also improved and the shape memory materials are also available in form of polymers. By creating this shape memory alloy heat engine, it can promote education towards community who lacked in knowledge of advance material and give more valuable information about this shape memory alloy as well contributing to research in shape memory alloy field.

1.2 Project Background

To create this SMA heat engine, a solid fundamental understanding regarding the shape memory alloy need to be developed. The SMA heat engine will be designed according to the steps obtained from previous design course. Initial components for this heat engine will be draw using CAD software such as Solidworks. Usually, the size of engine will depend on the power aimed for the heat engine to produce.

After finalizing the components design and its drive system, some components can either be fabricate or order from outside source as it depends on the type of materials will be used for the components and its availability. The assembly of the engine will be done after all the components are available and the heat engine can be put into the test. The power generate from this SMA heat engine will be test as well as its reliability.

After all performance and reliability test have been performed on the designed SMA heat engine together with some comments from supervisor will be used. This will help to acknowledge the limitations of this SMA heat engine, and some modifications can be done to improve its overall performance.

1.3 Problem Statement

Shape memory alloy (SMA) is a unique material which is an alloy that can be deformed and returns to its remembered shape upon heating. NiTi based SMA is commonly used due to its high recoverable property from massive strain or forces. Shape memory effect happened due to temperature-induced phase transformation, and it got two common effects such one-way and two-way shape memory effect (SME). This effect can be exploited to design new products by having more knowledge on its gradient geometrical and behaviour. The compositions of Nickel and Titanium are crucial to design properly functioning product as different composition will be triggered at different temperature while exhibiting SME. The design process of shape memory alloy product is quite challenging but can be done.

1.4 Objectives

For this project, there are two main objectives:

i. To design and fabricate heat engine that utilize shape memory alloy

ii. To demonstrate a working shape memory alloy heat engine.

1.5 Scope of Project

This research project focuses on designing and fabricating a shape memory alloy heat engine that can work due the temperature difference of hot side temperature and cold side temperature. The hot side is the section where the heating medium is placed such as boiling water and the cold side is the section of cooling medium like air at room temperature. Several testings on the selected shape memory alloy wire are conducted as Differential Scanning Calorimeter (DSC) in order to know the properties and behaviour of the SMA wire. Then, the process of building a prototype is conducted and working test is performed on the prototype to make sure the prototype is working properly. After, the testing of prototype gives excellent result, the process of building the final product of the SMA heat engine is fabricated.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

On this chapter, it presents the latest and relevant research activities that have been performed in this field of advanced materials. Most of the journals and papers discussed in this literature review is from collection of literatures from the year of 2004-2020. The literature reviews are done starting from shape memory alloy itself, the unique properties of the SMA, important factor to considered when designing a SMA product. It also covers the essential testing of SMA material such DSC test, different manufacturing process led to different application of NiTi as well as the design concepts of the SMA heat engine.

2.2 Shape Memory Alloy (SMA)

By having abundance of information and knowledge as well as the advancement of technology, shape memory material is already synonym with the technology development of material. Shape memory materials are unique as they can transform from one shape to another by exposing them to a certain environmental stimulus such as magnetism, electricity, heat, light, pH, water and even moisture[8][9][10]. The most used shape memory material in engineering industry is the shape memory alloys (SMA). This is due to their sought-after capabilities which are the superelasticity and the shape memory effect (SME). SMA can be deformed plastically at low temperature relatively and can return to its original shape after being stimulated by anymore type of stimulus mentioned above and more specifically is electricity and heat. This phenomenon which people often said that SMA can remember its original shape when induced with suitable stimulus.

A short history on SMA that involve NiTi. Based on this paper [11], the special effect of the SME that is found in an equiatomic NiTi was first discovered by Buehler et al in 1963. The NiTi alloy gained its popularity partly due to the world-wide publicity of the Naval Ordinance Laboratory. The Naval Ordinance Laboratory found the good quality of mechanical properties of this type of SMA. Even for the popularity obtained, the industry of NiTi did not grow rapidly despite the discovering of the understanding of the NiTi itself. This is since NiTi is rather a complicated system of material. Until today, NiTi is known and called as Nitinol. The word "Nitinol" is derived from the alloy composition and the founder of the alloy.

2.3 Shape Memory Alloy Unique Properties & Behaviour

Shape memory alloy are unique type of materials which make them to be considered as smart materials by many researchers and engineers. Products that are made from shape memory alloy are lightweight and become as an alternative for conventional actuators in modern system. Besides, SMA is well-known for the special characteristic such shape memory effect and superelasticity or sometimes called as pseudoelasticity.

2.3.1 Shape Memory Effect (SME)

The shape memory effect (SME) has two different types of effects which are one-way shape memory effect and two-way shape memory effect. For one-way SME, at low temperature and the SMA goes through process of loading and unloading, the residual strain is remained. As the temperature rises, the remaining residual strain is completely gone and the SMA finally return to its original shape.

Two-way SME is known as the reversible process of shape shifting during process of heating and cooling[12] and due to reversible phase transformations observed without any external force application. This type of effect is not an intrinsic feature of SMA, as SMA can only developed this unique effect through proper termed training of the material itself. Even though there are many kinds of SMA training methods have been created, but the physical origin of this two-way SME is remained unfold.

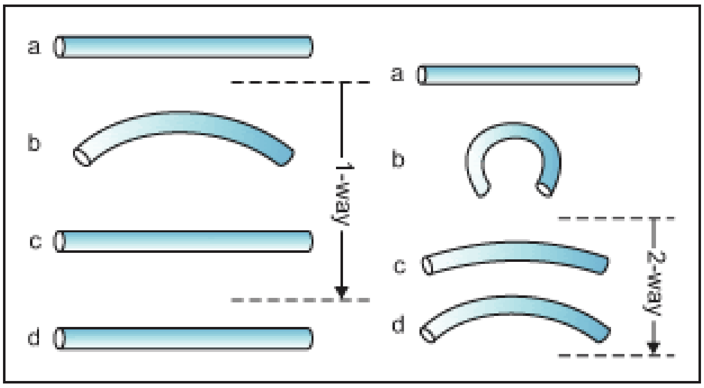

Figure 2.1: Illustration of One-Way and Two-Way SME

2.3.2 Superelasticity (Pseudoelasticity)

Besides having shape memory effect, SMA also exhibits pseudoelasticity properties. Pseudoelasticity is when the atomic bonds between atoms of SMA are extremely stretched without showing any sign of plastic deformation. There are three types of pseudoelasticity exhibits by SMA which are stress-induced phase transformation, pseudo-twin formation and rubber-like behaviour. Formation of pseudo-twin and rubber-like behaviour are the two least research type of pseudoelasticity. This is because short range of order. The most studied pseudoelasticity of SMA is the stress-induced phase transformation as martensitic transformation characteristic is a shear-like mechanism where the stress assists the martensitic transformation.

Possibility of stress-induced martensite to occur on temperature above Ms is higher. As the SMA reaches the martensitic stress, the austenite phase changes to martensite and become detwinned. Figure 2.2 shows the difference between stress-strain curve for SME and Superelasticity.

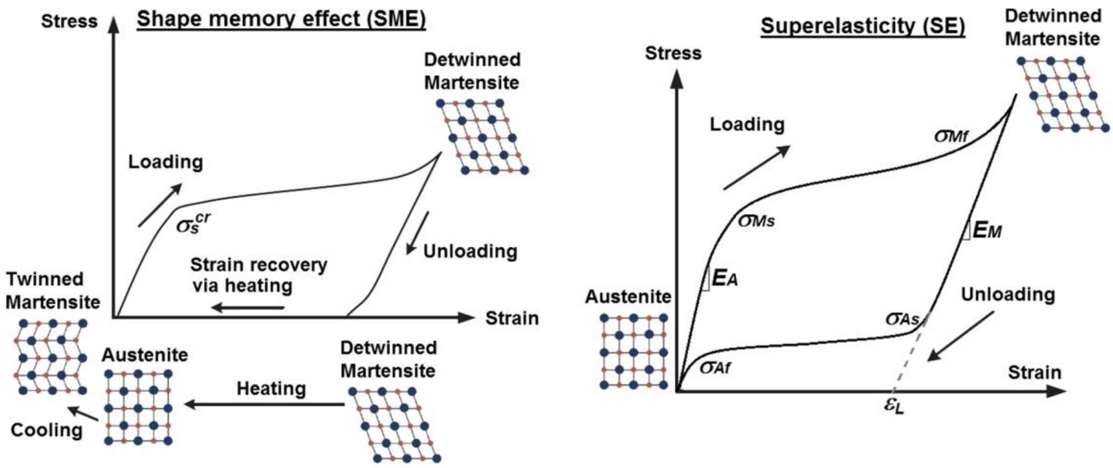

Figure 2.2: Basic stress-strain responses of SMA exhibiting SE or SME [13]

2.4 Important Factor to be Considered when designing SMA Products

When it comes to design and fabricate process, it will require the usage of materials. Every material has their own design considerations that are needed to be taken to account. The logic is also applied to shape memory alloy. Temperature or stress input, composition of shape memory alloy and heat treatment applied to them are the considerations that need to careful[14]. Temperature or stress input is critical factor when designing SMA products. SMAs are sensitive towards temperature and the stress applied. Determining the stress applied and operating temperature is the first step to be taken. Composition of SMA is crucial as different composition will lead to different behaviour at different working conditions.

For example, NiTi, composition of Nickel and Titanium will be triggered at different temperature even the composition is slightly different by 0.1%. The heat treatment applied on the shape memory alloy is important to maintain its life under repetitive stress applied such as cyclic stress.

2.5 Differential Scanning Calorimetry (DSC)

The initial testings on SMA product are crucial in order the exact specifications and the thermal behaviour of SMA. Besides tensile test performed to study deformation behaviour of the SMA wire, thermal phase transformation behaviour analysis is also performed. This type of thermo-analytical method is done in order to the study and understand the characteristic of the shape memory alloy. This type of analysis is also called differential scanning calorimetry (DSC). DSC test measures the heat required to increase the temperature sample based on function of time and temperature[9]. From the DSC, there are four important transition temperatures can be determined which are M_s, M_f, A_s, and A_f. These temperatures are where the microstructure of the SMA experience transformation whether from martensite to austenite or vice versa. Figure 2.3 illustrates the common DSC graph for Nickel-Titantium.

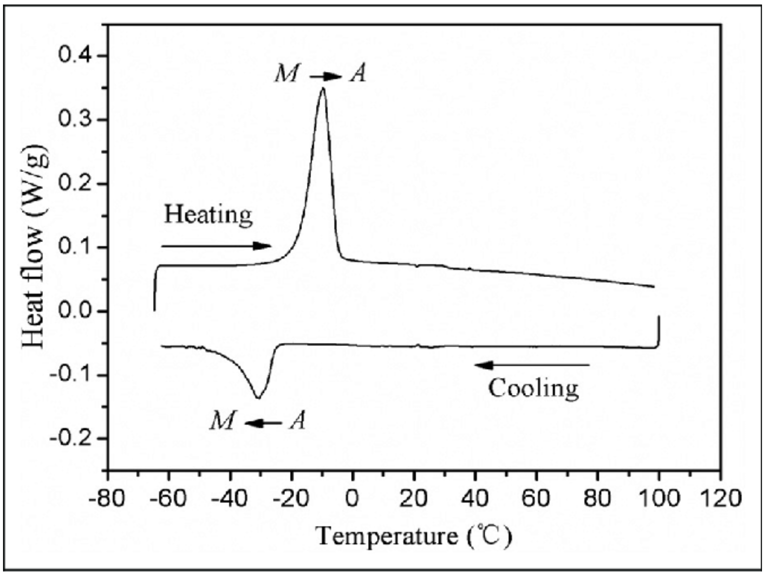

Figure 2.3: Typical DSC Curve for NiTi alloys

The critical temperatures of the phase transformation occurred on shape memory alloys are shown in Table 2.1.

Table 2.1: Critical temperatures of martensitic transformation of SMA

Critical temperatures	Explanation
A_s	Temperature where martensite phase starts to change to austenite
A_f	Temperature where the material becomes fully in form of austenite
M_s	Temperature where austenite phase starts to change to martensite
M_f	Temperature where the material becomes fully in form of martensite

Transition of phase from Austenite to Martensite phase is often called as forward transformation which is usually occurred from high temperature to low temperature which is cooling process. While it is known as reverse transformation when Martensite to Austenite which occurred on heating process of the material. These four critical temperatures are crucial to be identified. As their location relative to environmental of working condition for example at room temperature, determines whether the material exhibit SE or SME or not for both properties [13]. Important notes are that SMA will exhibit SE when the temperature is above A_f while it will exhibit SME when the temperature is under M_f.

2.6 Different NiTi Manufacturing Process Led to Different Applications

In order to manufacture NiTi, there are two most common processes which are liquid metallurgy and powder metallurgy. As for higher accuracy and precision application, additive manufacturing process is more suitable. Most NiTi shape memory alloy is used in form of wire[7]. For medical purposes, such as stents and orthodontic arch wires, powder metallurgy process is preferable due availability of porous on the manufactured NiTi. The porous will made the manufactured NiTi to have lower density [15] and porous. This characteristics are considered as property that are crucial for biocompatibility of NiTi in biomedical uses [16]. For other industrial application, thermo-mechanical processes are being used to manufacture NiTi with the sequence of casting and followed by any necessary heat treatment [17]. The raw materials are usually produced via liquid metallurgy routes to produce any desired forms that can be used such as wire drawing processes.

Heat treatment is crucial after the drawing process in order to release the stress developed during fabrication. This also will promote homogeneity of NiTi. Besides, Ni-rich phase is more prefer in industrial application while Ti-rich phase is more suitable for application of biomedical industry, due to leaching of Nickel can bring toxic effect internally to human body [7]. The latest technology when comes to manufacturing shape memory alloy is the additive manufacturing. This process also uses powder to produce the final product like powder metallurgy process, but the benefit of additive manufacturing is that it requires significantly less post-processing.

In additive manufacturing of SMA, it melts the powder using process of scan raster. Same as any additive manufacturing for other types of materials are that the product can be designed much sooner by utilizing any CAD software. Conventional processes and rapid manufacturing processes is the two major classifications specific techniques that can be used in production of NiTi alloys.

2.7 Design Concepts of SMA Heat Engine

Based on this particular paper[16], it shows multiple design concepts of SMA heat engines that are already be patented and the prototype of the SMA engines already exist. Generally, SMA heat engines utilize shape memory effect via temperature difference to convert heat energy into mechanical energy. From the paper, there are total of six concepts of heat engine that are classified according to their own individual driving mechanism.

2.7.1 Crank Engine

Crank engine usually is a form of engine that driven by a crank mechanism which consists of crankshaft. This type of engine converts reciprocating linear motion of SMA actuator to rotary motion continuously instead of linear motion of pistons and rotary motion of crankshaft. This is done via eccentrically connecting the actuator to the output shaft. Design concept for crank engine is shown on Figure 2.4.

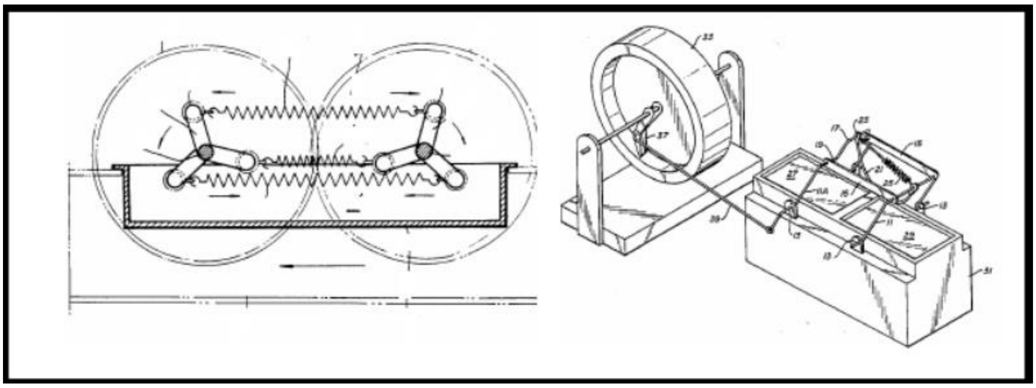

Figure 2.4: Crank Engine Illustration

2.7.2 Pulley Engine and Field Engine

Pulley engine uses belts or wires of SMA as the driving mechanism for this system[18]. The number of SMA wires are not restricted as it depends on the number of powers aim to be generated. The pulley engine can be synchronized or unsynchronized. Figure 2.5 illustrates the pulley engine conceptual design.

Figure 2.5: Concept of Pulley Engine

This engine utilizes a recovering force, such as a magnetic field and gravitational force. The design concept for this field engine is complicated as it involves lots of assembly and many components. The conceptual design of SMA field heat engine is shown on Figure 2.6.

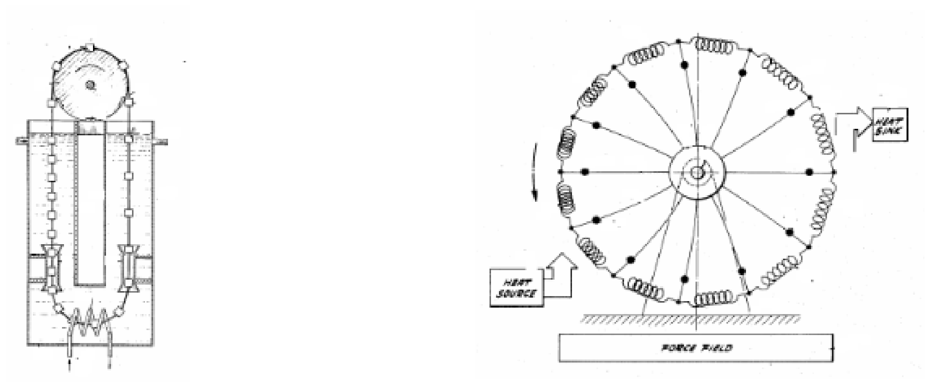

Figure 2.6: Field Engine Concept SMA Heat Engine

2.7.3 Swash Plate Engine

This type of engine is similar with the crank engine in term of the design, but the significant difference between them is the axis of rotation of the swashplate engine in unevenly parallel with the direction of the applied force. The direction of driven force is perpendicular instead for the crank engine. Figure 2.7 shows the swash plate engine concept

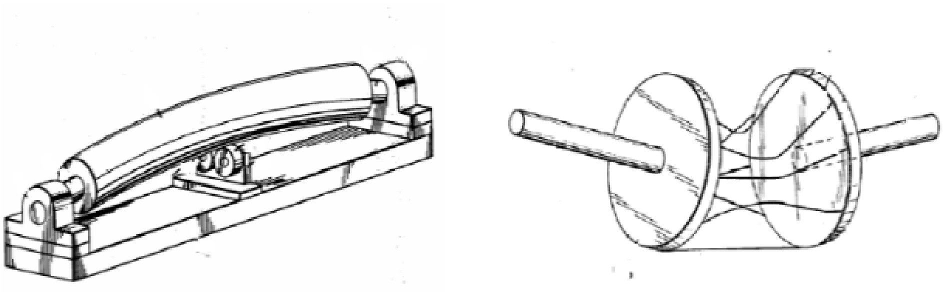

Figure 2.7: Concept of Swash Plate Engine

2.7.4 Reciprocating Engine

As for reciprocating engine, the driving mechanism is linear and in the manner of forward and backward motion. For the reciprocating engine, it differs in motion path as it is in cyclic approach. As for shape memory alloy, it is best suited for axial strain and regaining. Figure 2.8 is conceptual design of SMA reciprocating engine.

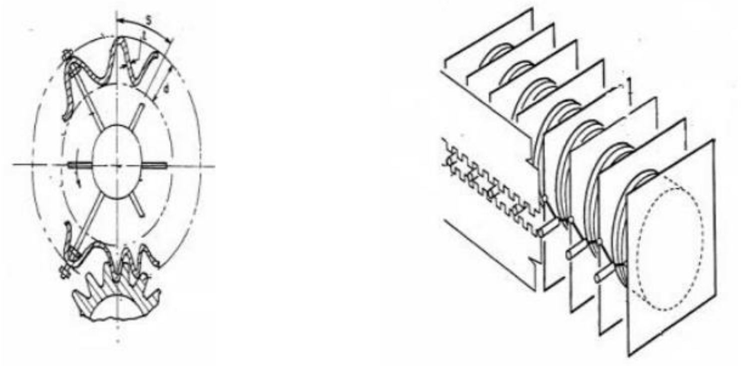

Figure 2.8: Reciprocating Engine Concept

2.7.5 Sequential Engine

This engine moves with lesser steps of motion but even more powerful, which is due to the considerable number of displacements. The mechanism of the sequential engine is that the motion produced is like inchworm, by spreading the front part by a lesser step and then pulling the back part along. With the integration of adjacent back part, front part of the engine can spread again. Figure 2.9 below shown is hollow and tubular gear made of SMA.

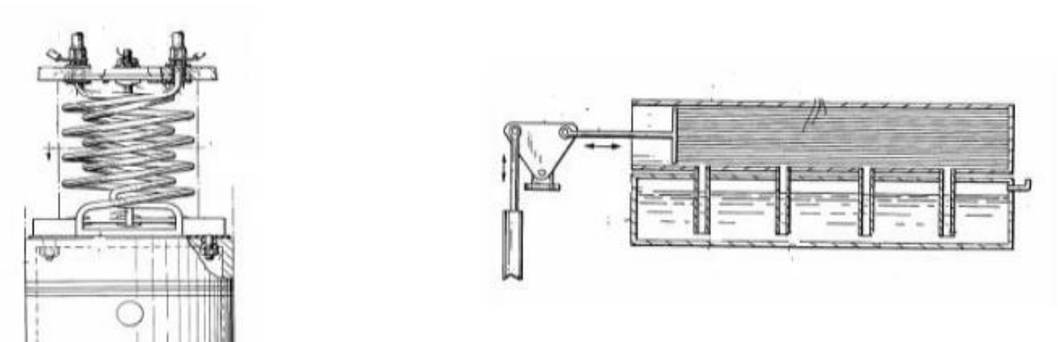

Figure 2.9: Conceptual Design Hollow Gear Engine (Left) and Tubular Gear Engine (Right)

2.8 SMA Pulley Heat Engine Working Principle

For this project, the design concept that will be used is the pulley engine. This is because the design of the engine itself is simple and the number of components is relatively minimum. The main components of this pulley engine are set of pulley wheels, body or support, shafts, ball bearings and the SMA itself that powers the entire system. The SMA can be in form of round wire or spring. The SMA will be formed into circular loop to make them as a belt like in pulley system.

The SMA that will be used is NiTi. The power of this type of engine is derived from the NiTi wire loop and runs in between the large and small pulley wheels. At the large wheel is the cool side while at the small wheel is the hot side and the NiTi wire will react to temperature difference between both wheels. The small wheel is partially immersed into the hot water bath. The memory given to NiTi circular loop wire is straight shape at austenite phase [19]. Therefore, as the NiTi wire come contact with high temperature above the A_f temperature (transition temperature) of the wire, it tries to straighten itself. Working Principle for NiTi Pulley Heat Engine is illustrated on Figure 2.10.

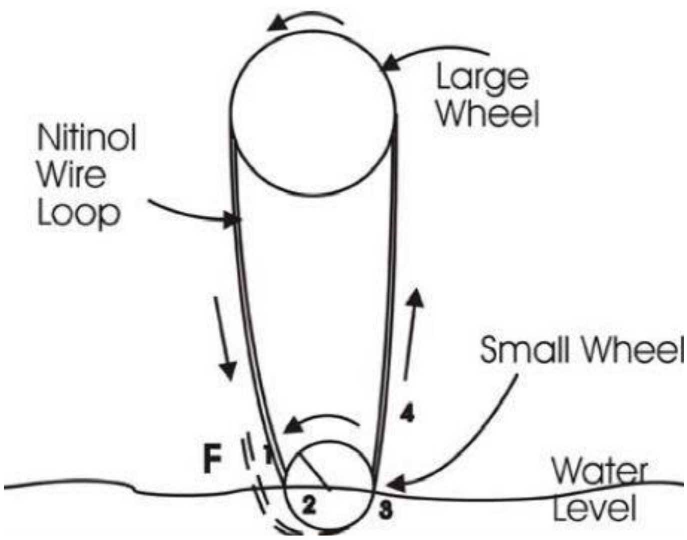

Figure 2.10: Working Principle of Pulley Type NiTi Heat Engine [19]

By referring to Figure 2.10, at point 1, the NiTi is cool and straight. Moving from point 2 to point 3, The straight NiTi is bent according to the shape of the small wheel, also contact with the hot boiling water bath which temperature is above the transition temperature, and it tries to straighten out and exert the force that rotate the small wheel. The force is called as tugging force. From point 3 to point 4, the NiTi come into account with the ambient temperature which is the cool side and continue to travel to large wheel. The wire temperature decreases, and the austenite phase converts to martensite phase as the NiTi wire has sufficient time to cool while moving the large wheel to prepare for another cycle of rotation.

The concept of this engine stated that this engine is unique as it does not have a specific operating rotational direction. It is necessary to jump start the NiTi heat engine to set the direction of rotational motion. Basically, the hot side will stiffen the NiTi loop and the cool side, the loop is relaxed and cool that creates a mechanical force to drive the engine. To improve the output of NiTi heat engine, there several recommendations given which are increase the length of NiTi wire and radius of large pulley wheel, reduce the radius of small pulley wheel and the moment of inertia for pulley wheel [20][21].

2.9 Summary

This section will summarize all the information and studies obtained from the literature reviews. SMA are used due to their unique properties which are SME and Superelasticity. Several tests such as tensile test and DSC are done to study in-depth about the NiTi alloys. To build the NiTi heat engine, the design concept of pulley engine will be used for this project due to its simplicity in design and working principle. The working principle of the heat engine is that it converts heat energy into mechanical energy. It uses SME to produce mechanical motion from heat bath which it remembers its straight shape at high temperature. The loop of NiTi will straighten itself when travels into the hot water bath.

CHAPTER 3

METHODOLOGY

3.1 Overview

This chapter covers on the methodologies applied in the research project. By utilizing the differential scanning behaviour (DSC), the thermal martensite phase transformation behaviour of the NiTi can be determined. The tensile test was performed by using the universal testing machine (UTM). This test was done in order to obtain the shape memory behaviours and material properties of the NiTi wire. A custom testing was done on NiTi wire in a custom setup in order to determine the force exert by the NiTi wire during heating above A temperature. Detailed steps on the fabrication of prototype as well as its testing were documented. For the NiTi wire, the specifications given from the manufacturer is listed on Table 3.1

Table 3.1: Specifications of SMA wire

Specifications	**Details**
Type of Alloy	NiTi
Wire Size(mm)	0.5
Transition Temperature(°C)	80
Manufacturer	Kellog’s Research Lab, USA
Composition of Alloy (%) • Nickel • Titanium • Carbon • Oxygen • Nitrogen • Hydrogen	 55.7 44.2405 0.016 0.04 0.003 0.0005

3.2 Analysis of Thermal Phase Transformation Behaviour

Temperature transformation behaviour of the 0.5mm NiTi wire was analysed by using a TA Q20 differential scanning calorimeter (DSC). The instrument used liquid nitrogen as the cooling agent. For the sample preparation, the NiTi wire was cut into 2-3mm segment in length. The weight of the sample needed to be in range of 5-20mg. The DSC Method set in the software was illustrated in Figure 3.1:

Figure 3.1: DSC Method

For rapid heating process, the specimen was heated at high hating rate below 1 min from 40°C to 150°C. The cooling process was done to cool the specimen from 150°C to -100°C at rate of 10.000°C/min. Then, again heating process was done on the specimen to 150°C at the same rate as before. The purge gas used was pure Ni gas and the purge flow set on the DSC test machine was 50mℓ/min. Figure 3.2 shows the TA Q20 DSC and Liquid Nitrogen Tank.

Figure 3.2: TA Q20 DSC and Liquid Nitrogen Tank

3.3 Tensile Test at Room Temperature

The tensile test was conducted by using UTM and the model of the UTM is Instron Model 3367 (Figure 3.4). This UTM is equipped with 30kN load cell. For the preparation of the sample, the NiTi wire is cut to overall length of 50mm. The gauge length set for the tensile test is 20mm. The crosshead speed set on the Bluehill software was 1mm/min. During the tensile test conducted, the NiTi wire was elongated until the wires start to deform plastically and then compressed back to obtain zero strain. The test was carried out at room temperature of 27.9 °C. The tensile test setup is shown on Figure 3.3.

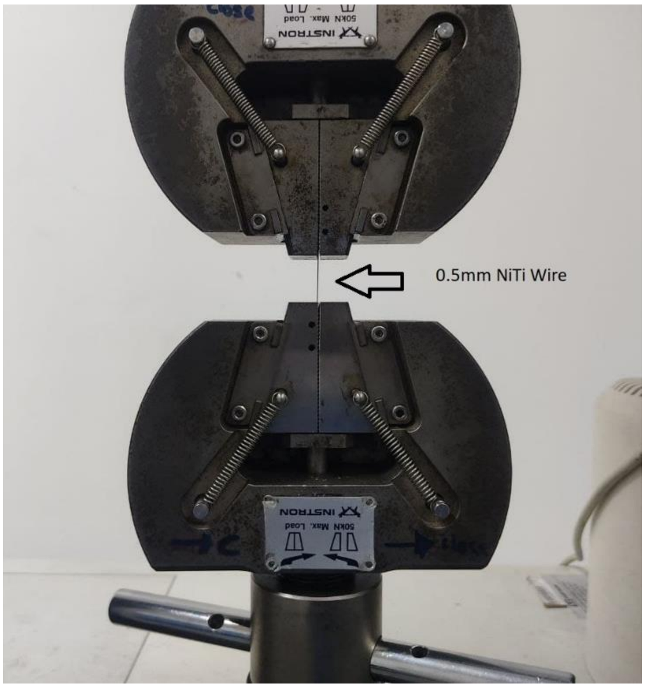

Figure 3.3:Setup of Tensile Test

3.4 Spring-shaped NiTi Loaded Heating Test

This test was done to determine the recovery or reverse transformation force exerted by the NiTi wire as the wire was heated above the A_f temperature. The test was a non-standard test as it did not follow any standard of testing. It required the NiTi wire to set its shape to become spring by using process of shape setting. Then, the NiTi spring was loaded and stretched to its full length. NiTi spring was heated above the transition temperature and observed the NiTi spring to return its initial shape.

3.4.1 Shape Setting Process

By setting the parameter of the spring, mandrel size was 6mm and the pitch arrangement was tight. Both ends of the spring have 2 circular loops and the length is 15mm before the circular loops at both ends. A jig was prepared by using a 6mm mild steel rod with length of 15cm. Two 2mm holes were drilled with spacing of 2 cm in order to secure the NiTi wire from returning to its original shape at high temperature via carbon steel nail. The jig with the NiTi was placed into furnace for 5 min at 500 °C

Figure 3.4: NiTi Wire Was Secured on The Jig and the Vectstars Furnace

Figure 3.5: After Shape Setting Process

3.4.2 Experimental Procedure

The room temperature measured was 29.1°C. One end of the NiTi spring-shaped wire is attached on the jig that was tied together with retort stand clamp. The initial length of the NiTi spring was 1.5 cm. The other end was hooked with the load. The load starts from 10g and gradually increase with the increment of 10g of load. After placing the load, the NiTi spring was stretched to deform the wire. Then, heat was applied onto the NiTi spring by using hair dryer. The hair dryer produced hot air with temperature ranging from 70-85°C. Repeat the steps above until NiTi spring cannot pull the load upward.

Figure 3.6: Experiment Setup and Close-up View of Attachment of NiTi Spring

3.5 Fabrication of NiTi Heat Engine

3.5.1 Overall Design

The overall design and the dimension used is to duplicate the existing NiTi heat engine on the market. Based on this research [19], the dimension of the pulley is stated which are 70mm diameter for the large pulley where as for the small pulley, the diameter is 40mm. The centre length between both pulley wheels is 110mm. The aim of the experiment of this research is to determine the variation of speed of nitinol engine with respect to decrement of temperature of bath. For this project, two types of prototypes were built which were the prototype and final product.

3.5.2 Conceptual Design

The prototype was created in simple manner as the aim was to test the NiTi loop of wire whether it can rotate as intended or not. While for the final product, the aim was to demonstrate a small scale working NiTi heat engine and all its features. Figure 3.7 below is the sketch of conceptual design of the testing prototype for the NiTi heat engine and Figure 3.8 is the sketch of the final prototype.

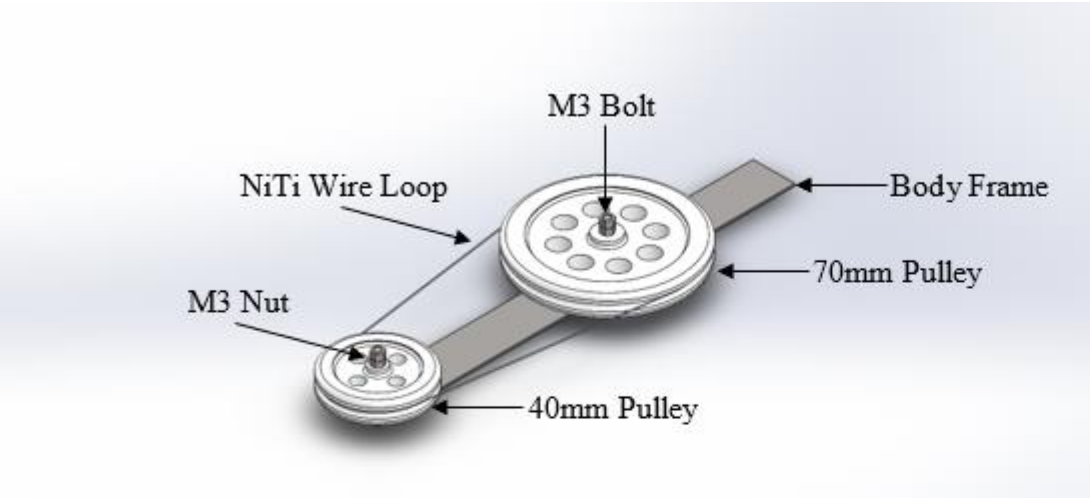

Figure 3.7: Assembly of the Testing Prototype