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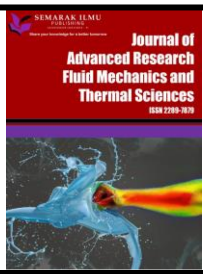

Heating Techniques of Shape Memory Alloy (SMA) - A Review

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Shape Memory Alloy (SMA) possess memory capability to revert its original shape when exposed to load or temperature changes. This unique thermomechanical property occurs during solid state phase transformations which corresponds to functional properties of SMA, shape memory effect (SME) and super elasticity (SE). The significant coupling behaviour of SMA can be utilized as actuator in aerospace, automotive, electrical and civil fields. However, in practical applications, the coupling behaviour of SMA are non-linear and hysteretic. The control mechanism of SMA coupling behaviour is complex. Therefore, in order to achieve good control of thermomechanical properties, a highly controllable and promising heating technique is required. Thus, this paper reviewed the existing heating techniques for the SMA intending to find a controllable heating technique for the SMA. Besides that, this review suggested the promising induction heating for SMA thermomechanical characterization which offer temperature controllability and faster heating capability. However, till date most of research works are purely empirical. The present paper is able to provide an insight on the experimental approaches toward induction heating of SMA. Thus, the main aim of this paper is to provide a better understanding on the heating mechanism of SMA to develop an optimized utilization of SMA as an actuator.

1. Introduction

The technology advancement towards smart and adaptive material with intelligent functions resulted in the manufacture of smart sensors and actuators. This rapid development increases the undesirable weight and volume of application components. Therefore, advanced technology is inclined to employ smart materials such as Shape Memory Alloys (SMA) due its capability to provide high power-to-weight ratio and compact actuation [1].

SMAs are active and multifunctional materials that are popularly utilized in various commercial engineering applications such as aerospace, automotive, electrical, medical and civil industry. SMA is

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kind of temperature-sensitive smart material with unique functional properties including super elasticity (SE) and shape memory effect (SME). The changes in temperature or load enable the SMAs strain recovery up to 10 percent [2]. Ölander [3] is the first physicist who discovered SMA in 1932 through solid phase transformation whereas, in 1938, Greninger first observed the memory effect in SMAs which was further described by Vernon in 1941 as shape memory. However, the commercialization of SMAs received much popular recognition in 1962 when Buehler *et al.,* [4] discovered SME in Nickel Titanium (NiTi) also known as nitinol. NiTi is most famous utilized SMA in many design and engineering applications due to its commercial availability, stability, better mechanical and thermomechanical properties.

The thermomechanical properties of SMA are controlled through the material temperature which exhibit non-linear and intrinsic hysteresis effect [5]. This coupling behavior led to complexity in controlling the temperature of SMA. Therefore, a precise heating technique is required in order to control the SMA temperature. Various heating techniques had been used by researchers to control the temperature of SMA in attaining the full manipulation of SMA thermomechanical behavior [6]. Reliable SME must be trained by applying right heat activation mechanism through appropriate application of stress and temperature. Consequently, desired actuation with stable hysteresis can be achieved.

This paper presents existing heating techniques for the SMA intending to find a controllable heating technique for the SMA. The paper starts with a brief discussion on the characteristics of SMA, then followed by a discussion on the existing heating techniques of SMA. Besides that, this this paper also suggested the promising induction heating for SMA thermomechanical characterization. Application of SMA as actuators are also discussed in brief.

1.1 SMA Cooling Mechanism

Conductive SMA alloy possess a low resistance thus allow large current to flow through the material. The principle of Ohm's law is applied on the voltage distribution of SMA alloy in which the current is directly proportional to the input voltage and inversely proportional to resistance [5,7]. Due to this, the heat generation by the current is greater. Therefore, the pulse width modulation is used to control the heat generation as well as the current and indirectly the temperature of the SMA alloy can be controlled [1,7]. Few researchers have used this method to control the temperature of SMA. Through the pulse width modulation signal, the current is control by using the power driver circuit [8]. In this method, a simple controllable heating element is required and only applicable for heating [9]. However, natural cooling method which is uncontrollable though, can be used if the speed is not a concern [10]. Otherwise, an active cooling us preferable for controlled cooling mechanism [11,12].

There are many different approaches used for cooling system for SMA material including natural air cooling, active air cooling and active liquid cooling. The natural air-cooling system decreases temperature by using heat convection principle to remove the heat generation [13]. It relays on the surrounding temperature of the environment including the room temperature and SMA temperature. However, since natural air-cooling system is subjected to environmental conditions, thus it is not controlled and consistent [14]. Therefore, this method is preferable for laboratory condition as preliminary test [15,16]. In addition, when SMA is used as an actuator, this method is become less effective as the cooling process required more time [16]. On the other hand, an active air-cooling system is using circulation of airflow around the SMA at faster rate. This method can be achieved by using an electrical fan to blow the air directly to SMA or a tube carrying forced air with high velocity air flow which is channelled through tube to cool down the SMA material [10]. Apart from that, high pressure air can be channelled through a jet nozzle to cool the SMA material [17]. However, the disadvantages of this method are that the cooling process is uncontrollable and the air speed is very high, thus reducing the efficiency of the energy system [17]. Active liquid cooling uses water to increase the speed of cooling liquid to enhance the cooling process. Generally, water is injected into SMA wire which is encased in a flexible tube to cool down the SMA wire [18]. The flexible tube can be fabricated according to the form of SMA [17,18], whereas the cooling rate in controlled through the water flow rate during heat generation [18,19]. However, the temperature of the cooling water is fixed thus shocks the SMA during cooling process [19].

1.2 SMA Heating Mechanism

Heating process of SMA is also very important when comes to assessment of SMA thermomechanical behaviour. There are two types of heating process that are commonly applied for SMA material which are the liquid heating and cooling, and laser heating. Generally, heating process comes together with cooling process in order to balance the heat generation surround the SMA material. Thermoelectric module (TEM) is one of the techniques which offers both heating and cooling process [20,21]. This technique utilizes the Peltier effect known as heat pump in which can control the location of heating region as well as the cooling region by the changing the power supply polarity [20,21]. In addition, in order to improve the heat convection, surround the SMA material, thermal paste can be applied on the SMA material [21]. However, TEM technique has limitation in terms of the geometrical constraints as it only can accommodate SMA wire.

Since TEM has limitation in terms of the geometrical constraints, liquid heating and cooling can supply heat to SMA through tubing externally. The design of technique includes encapsulation of SMA material in a containment made of flexible material and filled with liquid to ensure the SMA wire in contact with the liquid. This method can be observed from the research work conducted by Ishikawa and Nakada [22] on artificial muscle, in which they use a contractable rolled film to encapsulate the SMA wire to provide a barrier for the liquid. This is to prevent the mixing of SMA with the liquid surround it. The rolled film tube is sued to submerged the SMA in the liquid and to control the SMA temperature by channelling the how and cold water. On contrary, Park *et al.,* [23] sealed the bundle of spring shaped SMA wire with a flexible silicon tube which channelled the liquid with a controlled temperature to the SMA wire. The temperature is controlled by using a two-way mixing valve to blend the hot and cold water to ensure the desired temperature is attained before it is channelled through the silicon tube [23]. By using the similar mixing valve, Hegana *et al.,* [24] fixed the SMA with hard tube to channel the liquid with an opened top end for SMA actuators.

Another heating process that is uncommon for SMA material especially for large actuators is the laser heating. This is due to the dimension of SMA material which is like human muscles and requires larger source of laser to cover the large SMA actuator [25]. Therefore, laser heating is preferable for small dimension SMA actuator as the intensity of laser is controllable and precise [25]. However, the cooling process is absent on laser heating process yet the heat generation can be compensated due the small size of SMA [25]. In short, the rate of heating and cooling of small SMA actuator is fast and reliable.

2. Characteristics of SMA

SMA are alloy that are capable of memorizing the process between two difficult transformation phases. It can reinstate its original shape or form when changes in temperature or load is applied. The fundamental mechanism of SMA is very simple. The material is readily deformed when the external force is applied and when the material is heated beyond a certain temperature, it restores or recover its original shape or form. Technically, SMA exist in two different phases which are austenite and martensite with three different crystal structure including twinned martensite, detwinned martensite and austenite [26]. Austenite is a stable high temperature parent phase, whereas martensite is a stable low temperature parent phase [26]. Figure 1 depicts the SMA phases and the associated crystal structures. Two key functional properties of SMA are exhibited due to the reversible solid-to-solid phase transformation between martensite and austenite phase. These unique functional properties of SMA are discussed in the next section.

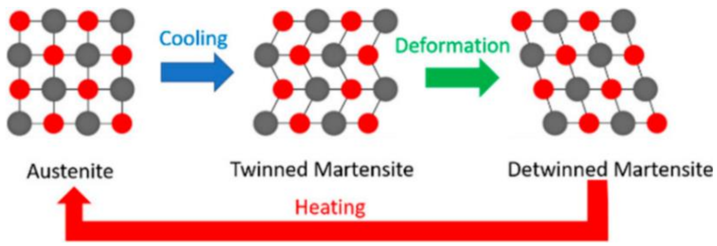

Fig. 1. SMA phases and the associated crystal structure [27]

2.1 Shape Memory Effect (SME)

SME occurs at temperature below martensite finish temperature, M_f in which the SMA is stressed under loading and the structure changes from twinned to detwinned martensite [27]. Upon unloading, the residual strain is exhibited. However, the strain can be recovered when the SMA is heated above the austenite finish temperature, A_f in which it restores its original shape or form. Figure 2 illustrates the SME of SMA. In short, SME can be defined as recovery of shape of SMA after heat is applied.

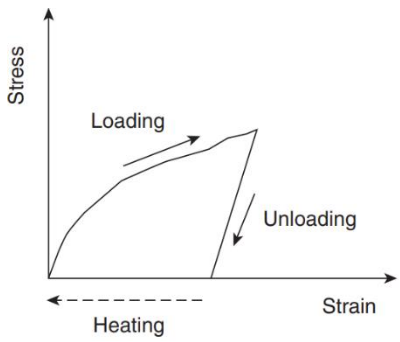

Fig. 2. SME of SMA [28]

2.2 Super-elasticity (SE)

On contrary to SME, SE occurs at temperature above austenite finish temperature, A_f in which SMA is stressed under loading [27]. However, upon unloading, the induced strain can be recovered quickly and completely. Figure 3 illustrates the SE of SMA. In short, SE develops hysteric behavior and shows the response of transition temperature between heating and cooling when loaded at high temperature.

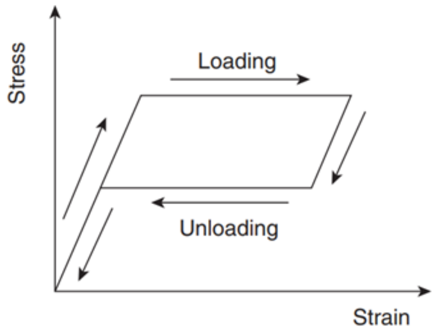

Fig. 3. SE of SMA [28]

3. SMA Heating Techniques

Commercially, the most common form of SMA actuator is wire as it possesses high actuation strength and significant strain recovery which is up to 4% [29]. The small size of wire gives more advantage to be used in muscle-like robotic applications. However, the practical challenges have hindered the use of SMA wire as actuators. Direct heating of SMA wire with the aid of electric current may lead to low efficiency and may induce thermos-coupling interaction with the surrounding. Therefore, an uneven distribution of surface temperature will be created thus lead to fractional distribution of temperature within the SMA wire [30]. This phenomenon will influence the thermomechanical behavior of SMA material.

The characteristics of SMA as discussed in the above section implies that SMA wire are very sensitive to the change in temperature. Therefore, the actuation rate and frequency of SMA wire are limited by the rate of heat transfer into and out of the SMA component [31]. In addition, the size and shape of SMA material are also plays an important role in the selection of appropriate heating techniques for SMA characterization [30,31]. Coupled-thermomechanical interaction of SMA with the surrounding environment directly affects the forward and reverse phase transformation process of SMA material [31]. The difference in phase transformation affects the hysteresis and the energy dissipation of SMA material, thus directly influencing and compromising the SMA key functional properties, SME and SE [31].

To date, various heating techniques has been developed and implemented by researchers to manipulate the SMA thermomechanical behavior in order to achieve the desired application. An appropriate heat activation time and cooling rate are required to achieve good SME of SMA material. The following section provides a brief review on the existing heating techniques of SMA and the associated response of SMA.

3.1 Direct Resistive

Direct resistive heating is defined as the transfer of electrical power due to resistive heating, *P*, directly proportional to the function of the wire resistance, *R*, and electric current, *I*, as expressed in Eq. (1). Ohm's Law provide current and resistance relationship in Eq. (2), whereas for a uniform material with constant current flow, the resistance is given in Eq. (3). It has to be noted that ρ is the strength of opposing flow of electric current and l is the length of wire.

$$P = I^2 R \quad (1)$$

$$I = {}^{V}\!/_{R} \quad (2)$$

$$R = \frac{\rho l}{A} \tag{3}$$

The wire temperature is predicted from the specific heat capacity, *c*, in Eq. (4) by ignoring the losses to the surrounding environment. *Q* is defined as the thermal energy; *m* is the mass of the object and *T* is the temperature. The temperature can be predicted in Eq. (5) by assuming that all the electrical power transfer due to the resistive heating is converted to heat. The final derivation of Eq. (6) is the predicted temperature which is independent of SMA material length [31]. Eq. (6) consist of the associated constant, material parameters and external properties of SMA material.

$$c = \frac{\Delta Q}{m\Delta T} \tag{4}$$

$$\Delta T = \frac{\Delta Q}{mc} = \frac{P\Delta T}{mc} = \frac{16I^2\rho\Delta t}{\rho_0\pi^2\, d^4c} \tag{5}$$

$$\Delta T = \left(\frac{16}{\pi^2}\right)\left(\frac{\rho}{\rho_0} d_c^4\right)(I_\Delta^2 T) \tag{6}$$

Huang *et al.,* [32] investigated the response time of SMA by using resistive heating technique to optimize the transient heat transfer. This work has proved that the resistive heating time is shorter thus reduces the lagging of cooling time. However, selection of the appropriate design variables such as ambient temperature, lagging parameters and heat convection effects are crucial in the development commercial development of the actuators. The resistive heating technique is faster than direct heat transfer to the environment thus activates SMA material's heating response in shorter time than the cooling response. This method enhanced the thermal heat transfer efficiency.

3.2 Capacitance-assisted Resistive

Capacitance-assisted resistive is defined as power rate, *P*, and expressed in Eq. (7) in which, *R,* is the resistance of the actuator and *I,* is the electrical current. The electric circuit design for the actuator heating is illustrated in Figure 4. The circuit consist of three parts of *R* that are associated with actuation, R_1, capacitors, R_2, and connecting cable, R_3, respectively and expressed in Eq. (8). It has to be noted that the determination of the total capacitor's resistance is based on the number and connection of capacitors while, the configuration of the circuit determines the resistance for connecting cables [33].

$$P_a = R_1 I^2 = \frac{V}{R_1} \tag{7}$$

$$R = R_1 + R_2 + R_3 \tag{8}$$

$$P_a = \frac{R_1}{R} P \tag{9}$$

$$I = \frac{v_0 e^{-\frac{t}{RC}}}{R} \tag{10}$$

$$\tau = -\frac{1}{2} RC \log\left(1 - \frac{2RE_t}{R_1 C V_0^2}\right) \tag{11}$$

On the other hand, the total power of capacitor, P, and power consumed on actuator is expressed in Eq. (9) which is determined by the actuator response time. Here the R_2 and R_3 are kept as small as possible to increase the efficiency of heating, thus decrease the response time due to smaller total resistance. The electric current as expressed in Eq. (10), decays exponentially when the capacitors discharged across the actuator. The variable t is defined as time, V_o is the capacitor's charged voltage at initial, and C is the total capacitance of capacitors. At given values of R, C and V, by integrating Eq. (10) the time of required energy E_t is obtained and expressed in Eq. (11). This equation provides the time for a complete phase transformation which also depicts the time taken for the actuator at maximum recovery displacement [33].

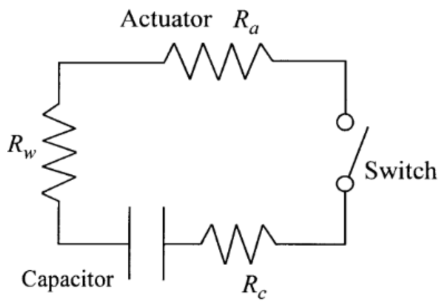

Fig. 4. The electric circuit design for the actuator heating [33]

Qiu *et al.,* [33] in his research work has designed capacitance-assisted resistive heating technique for high-speed SMA actuator and found that the response time of the actuator is shorter. On contrary, the response time for recovering force is longer. In short, it can be concluded by controlling the total resistance, capacitance-assisted resistive heating technique are able to provide the shorter response time which is dependent only on the heating process [33].

3.3 Heat Transfer Mechanism

Practically, the response time of SMA includes the heating time to reach austenite phase transformation, the time to initiate phase transformation and the cooling time of SMA material [31]. The conventional heating technique for SMA produce relatively slow expansion rate attributed by heat transfer through convection to the surrounding environment. This convection mechanism slows down the cooling time and reduces SMA actuation frequency. It can be noted that SMA actuator response is dependent and dominated by the cooling time of SMA after heat activation [31].

In order to reduce the overheating and increases SMA material cooling rate, utilization of heat transfer mechanism in heating techniques need to be assessed precisely for efficient heat transfer. Manipulation of heat transfer mechanism such as conduction, convection and radiation efficiently enable the development of practical and cost-effective actuator. Heat transfer mechanism using refrigerant also provides a significant effect on the efficiency of heat transfer [35]. However, for the application of SMA actuator, this paper focused on the heat transfer mechanism such as conduction, convection and radiation. Conduction is heat transfer that occurs in solid state particles by a direct contact, whereas, convection is heat transfer that occurs within a fluid, movable particles [34,36]. Heat transfer in radiation occurs by electromagnetic waves without a direct contact of the particles [34]. Figure 5 illustrates the fundamental mechanism of conduction, convection and radiation.

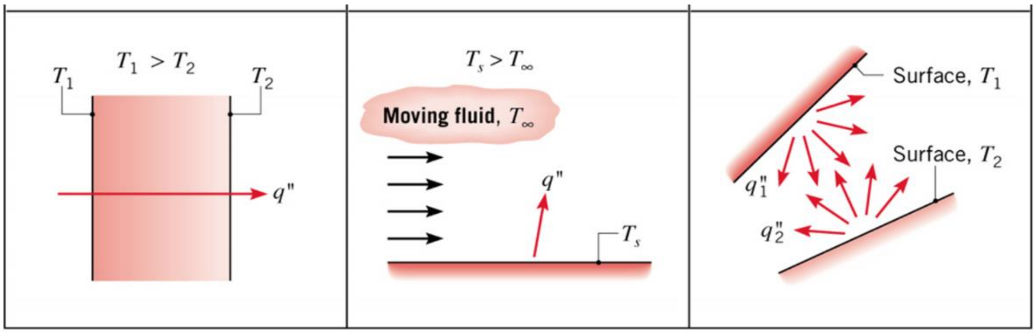

Fig. 5. The fundamental mechanism of conduction, convection and radiation [34]

When the SMA material is enveloped by moving fluid condition, the convection heating takes place and radiation is ignored due to its negligible values. The convection heat transfer between SMA material and the ambient temperature can be expressed as in Eq. (12). The variables, P is defined as the transmitted power, h is the convective heat coefficient, A is defined as the contact surface and ΔT is the temperature difference between material surface temperature and fixed surrounding temperature [31]. This empirical correlation is able to enhance the actuation frequency with a minimal power usage in the system utilizing SMA material. In order to mitigate, the slow response of SMA material, changing the geometry of SMA material intending to increase surface area can lead to optimal heat transfer rate. On contrary to convection, in a condition where the enveloped fluid is static around the SMA material, the convective heating takes place. This heat transfer mechanism is more effective and rapid compared to convection as it allows greater actuation frequency.

$$P = h \cdot A\Delta T \tag{12}$$

In short, the development of effective and optimal SMA actuator need manipulation of heating technique through appropriate selection of heat transfer mechanism. Manipulation of heating techniques is vital in anticipating the behavior of actuator utilizing the SMA material, and thereby, determining the suitability of SMA material for desired applications.

4. Promising Induction Heating Technique for SMA Thermomechanical Characterization

Practically, SMA components possess greater actuation rate and frequency, however it is limited to heat transfer rate in which how quickly the heat is added and removed from SMA components. In the previous section, some of existing heating techniques utilizing SMA materials in design system are briefly discussed. Apart from the speed of heat transfer, other factors contribute to the selection of heating techniques of SMA is the size and shape of SMA [37]. Therefore, induction heating then becomes promising option to heat SMA material regardless the geometry in a short time.

Inductive heating is a contactless heating method that can heat any electrically conductive material in effective way. The induction heating system consist of workpiece which is the element to be heated, and the inductor coil. The workpiece is usually placed inside the coil to induce coupling effect and can be in any geometry. The principle of induction heating is based on Faraday's Law in which the current is induced by electromagnetic field whereby the magnetic field generated inside the coil induces a voltage in the workpiece thus resulting in the alternating current as an input to a coil [37]. Figure 6 illustrates the model of inductor-workpiece. The induced alternating current and the workpiece current tin the vicinity of the coil have same frequency with opposing current flow. Induction heating utilizes high frequency approximately up to 104-106Hz [38]. Eddy current is the resultant induced current which is attributed by localized Joule heating in the workpiece and the most important mechanism in terms of energy dissipation [38]. This energy dissipation can be expressed as volume power density and can be calculated using the Eq. (13). The variables κ is defined as spectrum electrical conductivity, E is the electrical field strength and J is current density.

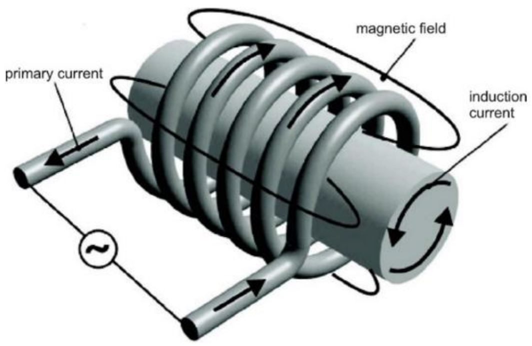

Fig. 6. The model of inductor-workpiece [38]

$$p(t) = \kappa \cdot E^2(t) = \frac{1}{\kappa} \cdot J^2(t) \left[\frac{W}{m}\right] \quad (13)$$

$$\delta = \sqrt{\frac{\rho}{\pi f \mu}} \quad (14)$$

The induced current distribution within the cross-sectional are spatially non-uniform. It is depending on the parameters such as workpiece proximity with the coil, properties of electromagnetic field, the frequency of eddy current and the presence of electrically conductive object in the surrounding induction heating system [37,38]. Eddy current induced in the workpiece create a magnetic field which opposes to the original magnetic field, thus cancel of each other. Due to the weak resultant magnetic field, the eddy currents start to circulate near the surface of the workpiece, known as skin effect [38]. The combination these parameters affects the depth of penetration, also known as skin depth and can be calculated using the Eq. (14), where δ is the skin depth, ρ is the spectrum electrical resistance, f is the frequency and μ is the permeability. Both the volume power density and skin depth are very important in design of induction heating system as it directly affecting the transfer of heat energy from the coil to workpiece which contributes to the overall efficiency of the system.

In practical condition, induction heating is preferrable option to heat large SMA components. Various research works have implemented induction heating techniques in experimental characterization of SMA behavior for intended material applications. Mohr *et al.,* [39] implemented induction heating technique to train shape memory polymers embedded with magnetic nanoparticles in short time thus able to produce faster actuation. On the other hand, in SMA manufacturing industry, inductive heating technique is used as heat treatment in order to achieve the desired mechanical properties of nickel pellets and titanium rods [40]. This technique quickens the vacuum arc melting process and the produce homogenous SMA materials. In medical field, Tanaka *et al.,* [41] have implemented inductive heating method to heat contactless SMA device in artificial urethra valve driven by SMA actuator. Besides that, induction heating techniques is also used investigate several properties of SMA material including to test NiTi SMA crystal specimen strength by heating the grips, to actuate SMA actuator through a control debonding applications and to train noise attenuation SMA actuator to control adaptable gas turbine exhaust [42-44].

Based on the research works mentioned here, it can be noted that induction heating techniques recently has been a popular choice to heat SMA. Although it requires additional hardware such as inductor coil for heating, compared to other heating method, this contactless induction heating provide one of the most effective ways to heat SMA materials. The SMA material to be heated is not contaminated as it is non-contact to the heating element. It also provides a clean heating in any atmosphere as there is no presence of smoke, noise, no production of by products or dust during heating. Besides that, the inductive heating mechanism is efficient as the heat is generated within the workpiece thus, able to provide exact temperature distribution in the material. This heating mechanism is also providing an option for selective and localized heating process if the application of SMA material required. Apart from that, by using inductive heating technique, researchers are able to control the temperature and monitor the heat transfer between the workpiece. Moreover, an automatic temperature control also can be achieved with the integration of feedback controller in the inductive heating system. In comparison to other heating techniques of SMA, the inductive heating is energy saving method as no involvement of warm up or cool down cycle as well as ease of turning off and restarting the system.

However, when come to investigation utilizing SMA wire, the thermal conductivity becomes a hinderance to implement inductive heating for SMA characterization. Due to very small diameter and size of wire, the heating rate for wire becomes extremely slow due to the skin effect mention in the previous section. The inductance of wire is negligible due to larger size of inductor coil compared to the size of wire to produce electromagnetic field. This problem can be overcome by using selective inductor coil size which suits the size of workpiece to be heated.

In conclusion, induction heating technique is a promising method to characterize the thermomechanical behavior of SMA material regardless the material size and shape. Inductive heating technique approaches to change the mechanical and thermal properties of SMA material within the application field. It is a short heating process with reduced heat impact on the surrounding environment. With the optimized parameters, the inductive heating will provide an efficient heat transfer rate.

5. Applications of SMA as an Actuator

Adaptation of smart, adaptive and intelligent materials such as SMA in different engineering fields has resulted in enhancement of performances of many technological devices and infrastructures. SMA material received monumental attention as a prospective material in many application fields. SMA applications can be divided based on their functional property including SME and SE. SME can be utilized for generation of both motion or force, whereas, SE can be utilized for energy storage [45]. In this section, application of SMA particularly in biomedical, aerospace, robotic and automotive fields are briefly discussed.

In biomedical applications, SMA is generally used as artificial materials to replace human body parts or to enhance the performances of body parts [45]. SMA materials are biologically reliable, corrosion resistance and free toxicity [46,47], thus enable the ease of utilization in human tissues. The utilizations of SMA materials ranges from small dental arch wire to the stents in damaged blood vessels which covers various areas in including cardiology, neurology, dentistry, and orthopaedics [46,47]. Yamada *et al.,* [48] has developed SMA fibre to assist heart disease patients in order to improve mechanical circulation.

In aerospace applications, SMA has been used in F-14 fighter jets as a hydraulic line coupling around 1970s, thus received tremendous attention for solving the structural engineering issues related to aerospace material [49,50]. Following it, agencies and companies such as Boeing, Advanced Research Projects Agency (DARPA), Smart Aircraft and Marine Propulsion System Demonstration (SAMPSON), National Aerospace and Space Agency (NASA) carried out numerous research to integrate the use of SMA material in wings and jet engines [51]. The Boeing company has developed smart SMA device integrated in a variable geometry chevron on a 77-300 ER which is able to reduce the noise of with GE90-115B jet engine during take-off [52].

SMA application in robotic field has emerged since 1980s and can be classified in terms of movement techniques such as walker, crawler and biomimetic robotic hand [53,54]. However, in recent years, the application has shift into humanoid robots to solve problems that are challenging for human [54]. These problems are including to find pertinent information from space, underwater, air and land which are complex for human beings [53,54]. Therefore, by using SMA functional properties, sever flying robot which imitates the dragonfly, has been developed to control the overall movement in all direction thus accessing the required information from the environments [55].

Looking into automotive field, utilization of SMA particularly as sensors and actuators in modern vehicles have received popular attention due to the demand for safety and comfort performances [56]. The utilization of SMA in automobile parts can be seen in various components including radiators, engine mounted fan clutch, engine controls, transmission controls, brakes, door and locking mechanisms and rear-view mirror. Recently, Fiat Research Center has adapted SMA actuator with different method such as pantograph and design mechanism for electrical actuation of antiglare rear-view (EAGLE) mirror to detect a glare condition for drivers especially at night. This design is able to prevent distraction for driver and also working in a silent operation [57]. Besides that, other applications of SMA actuators are including pop-up bonnet, micro scanner systems, flaps actuator and adaptive grab handles [58]. However, the practical applications of SMA have limitation due to the limited range of operating temperature of SMA material [59]. Therefore, NiTi SMA materials are preferable for automotive industry as its standard range of operational temperature meets the standard environmental temperature, ranges from -50 degree Celsius to +110 degree Celsius, similar of the passenger vehicles during driving service [60].

6. Conclusions

SMA is a multifunctional smart and active material which possess various potential applications. However, all the potential applications may be hindered if the limitation related to the heating techniques and heat transfer mechanism are not dealt with. Therefore, in order to overcome such a limitation, a thorough understanding of SMA material behaviors with associated heating techniques and heat transfer must be developed. An effective SMA design system can be developed by manipulating the heat transfer rate through efficient heating techniques. In this paper, the feasibility of contactless induction heating provides a conservative thermal transition mechanism thus optimizes the SMA actuator for the use of desired application. Besides that, this induction heating also offers the possibility to change or to train the thermomechanical properties of SMA material according to the design applications. The mathematical and empirical correlation given in this paper guide the designer to predict accurately the associated thermal coefficient and power efficiency for any systems that are utilizing the SMA material.

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