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Development of shape memory actuated ITU Robot Hand and its mine clearance compatibility

Savas Dilibal*, R. Murat Tabanli, Adnan Dikicioglu

Mechanical Engineering Department, Istanbul Technical University, Turkey

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Abstract

Grippers and general purpose robot hands, which are end effector elements in robot applications, have been used previously in the painting and welding operations. With developing technology, they are employed seriously in various industrial operations such as transferring, assembling, manufacturing. There are various technological actuators of robot hands which give the power for the joint motion. Hydraulic, pneumatic systems and electrical motor systems are very common actuator technologies. However, the actuator systems, which are employed by shape memory alloys, take importance recently, besides traditional actuators. In this study, we have made a change in prototype SMA Robot Hand, which is presented in Army Academy XXth Operation Research and Industrial Engineering Congress in Product Development and Design area. A new prototype, ITUHand, is developed using Ni–Ti shape memory alloy and a set of studies were performed in order to check the compatibility of the system in the mine clearance area.

Keywords: Mines; Dexterious Robot Hand; Shape memory alloys; Ni–Ti alloy

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1. Introduction

The activities regarding detection and cleaning of land-mines, that are thought to be around 110 million all around the world, has been accelerating with the advancement in sensor, programming and actuator technologies. The importance of such activities becomes clear once we consider that at least 7 years are needed to clear only the land-mines in Afghanistan, with the existing technologies [1]. Research about mine cleaning has been directed towards safer mine cleaning systems that have less risk factor.

Mine cleaning systems in general have two tasks. First task is search and detection, the other is destroying and removal [2]. The methods that are used for these tasks can be divided into four main group such as:

- Manual systems, i.e. manpower and detectors are used
- Mine clearing dogs.
- Mechanical mine clearing systems.
- Robotics.

1.1. Manual systems

With the help of recently developed non-metallic mine detectors, operator can detect signals if there are any changes in the conductance or density of the swept ground. These detectors enable the detection of landmines that are metallic or completely non-metallic [3]. However, this method always requires very high caution, it is time consuming and the risk factor elevates if the speed of tracking increases.

1.2. The use of mine clearing dogs

The use of specially trained dogs for mine clearing purposes has generated a much higher sensitive and efficient system with the help of their sensitive sense of smell against vapors of explosives with respect to human made mine detectors [4]. Additionally, mine detection dogs can be used in various field and climates. However, it is difficult to use the dogs in this task for long times. Research on animal with strong sense of smell such as dogs, mice, bees and on artificial biosensors has been developing in the field.

1.3. The use of mechanical mine clearing systems

The popularity of using mechanical mine clearing systems has been increasing since it is one of the least risk factor

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* Corresponding author.
E-mail addresses: dilibal@itu.edu.tr (S. Dilibal), tabanlir@itu.edu.tr (R. Murat Tabanli), dikicioglu@itu.edu.tr (A. Dikicioglu).

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bearing systems. In this research field, various military armoured vehicle prototypes are being tested. In general, mechanical mine clearing equipment provide high pressure on the mine and serve to explode the mine. Application areas are generally flat fields with no rough surface that enable the equipment to maneuver easily.

Disregarding their cost, mechanical mine clearing systems are more reliable and less risky systems compared to manual systems. However considering mechanical systems, one always has to take into account the maintenance and logistics along with high costs.

1.4. The use of robotic systems

The reason that research about robotic mine clearing systems has been accelerating is that the high technology products used in this field have been developing fast and the thought that implementation of such products would give fast results.

Beside remote air-vehicles that are used for discovery and informative purposes, it is pursued to establish less risky advanced technology systems with the use of manless land vehicles and robots. Robots for this purpose have been used by US Army in Afghanistan in August 2002 (Fig. 1).

The sub-systems of a robotic mine clearing system can be divided into four main groups: mobile system, multi functional sensor systems for mine detection, destroying system and a control unit [6]. Advancement in robotics technology has been used in each of these sub-systems. The main purpose is to establish a robotic systems that bears all the subsystems in the optimum dimensions, having less risk and low costs, being reliable and renewable.

The destroying sub system of a robotic mine clearing system consists of an end-effector and a multi purpose gripper. Considering the fact that the multi purpose gripper operates vulnerably in risky environments, the importance of it to be simple, inexpensive and renewable becomes clear.

Fig. 1. Hermes Robot [5].

2. Design of ITU Robot Hand and the subsystems used in it

In general, the hydraulic, pneumatic and electrical motor systems have been used as actuators in the robot hand systems traditionally [7]. Shape memory alloys have put a new approach into the robot hand and other actuator systems. Nowadays, SMA are being used in various applications such as sensor systems in electronics; blood pressure test valves, stents in medicine; radiator fans in automotive industry; multi leg mobile robot systems in robotics. In ITU Robot Hand, one of the most popular SMA, nickel–titanium (NiTi) alloy is used.

SMA are alloys that exhibit the shape memory effect (SME). The SME is related to martensitic phase transformations. In a material capable of undergoing martensitic phase transformations, at zero stress, there is a high temperature phase (austenite) that is stable above some critical temperature (A_f) and a low temperature phase (martensite) that is stable below some critical temperature (M_f). The starting temperatures for austenite to martensite and martensite to austenite transformations are called M_s and A_s, respectively.

To understand the mechanism underlying the shape memory effect, consider a material that has a cubic austenite and is initially in its austenitic state (Fig. 2a). Let us cool this material below M_f temperature such that the austenite phase transforms into martensite, preserving the overall shape of the material (Fig. 2b). Note that the structure in Fig. 2b consists of two different martensite such that the overall macroscopic shape of material is accommodated. If we now apply shear to this material, we encounter a shape change that is shown in Fig. 2b to Fig. 2c. The deformation here is merely due to detwinning of martensite. Further loading changes the shape more and more, and eventually we have the crystal structure shown in Fig. 2d. Note that the structure is still martensitic, however the martensite variant that has favorable orientation to the direction of the applied stress, has outgrown the other variant.

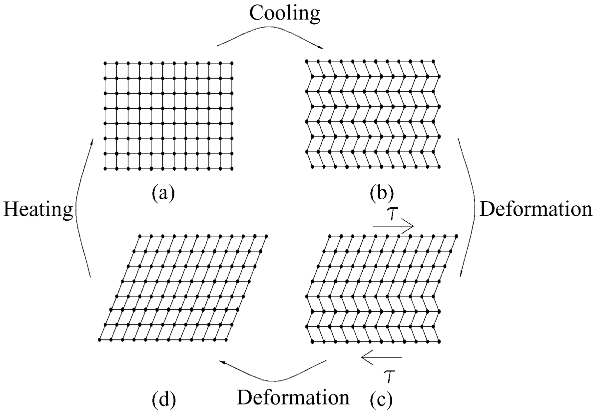


Fig. 2. The mechanism of the shape memory effect.

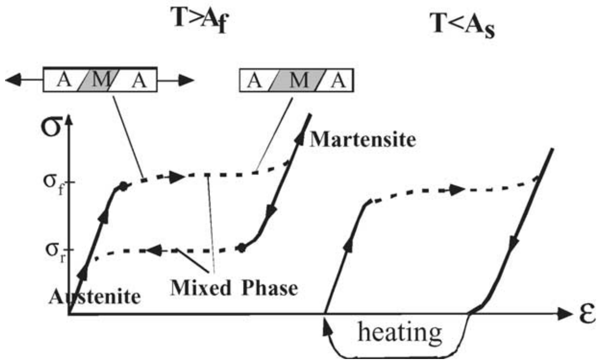


Fig. 3. Stress–strain curves for temperatures $T > \mathrm{A_f}$ and $T < \mathrm{A_s}$.

Now we have applied a macroscopic shape change to the material, which appears to be a permanent deformation. If we take this material and heat it up to its $\mathrm{A_f}$ temperature, then the material has to convert its crystal structure to cubic austenite. However to obtain a cubic crystal structure, the material's only choice is to go to its original state in Fig. 2a. This phenomenon is called shape memory effect and the materials capable of recovering deformation in such a way are called shape memory alloys.

In Fig. 3, stress–strain curve of a shape memory alloy in its martensitic state is shown next to the stress–strain curve at a temperature above $\mathrm{A_f}$ (the figure on the right), which is called the supeelastic curve. Note that the superelastic curve corresponds to test temperature greater than $\mathrm{A_f}$ whereas the curve on the right corresponds to test temperature less than $\mathrm{A_s}$. The material is subjected to a quasistatic stretch, however the complete strain is not recovered after unloading. The material has an apparent plastic deformation upon unloading. If we now heat the material above $\mathrm{A_f}$ temperature, the material recovers the apparent plastic deformation by going back to its original length (shown by arrow in Fig. 3). The term "shape memory effect" refers to the phenomenon where the material recovers an apparent plastic deformation by heating.

The shape memory effect in NiTi alloy was discovered in 1962 by W.J. Buehler at the US Naval Ordnance Laboratory. Commercially known as nitinol (Ni Ti Naval Ordnance Laboratory), this alloy exhibits strong shape memory characteristics depending on the temperature and deformation [8].

Among the actuator systems, applied force/weight ratio is the most important property and naturally, systems with a high force/weight ratio has been preferably used. NiTi shows excellent force/weight characteristics, which makes it very suitable to be used in actuator systems.

ITU Robot Hand system consists of gripping, releasing and control subsystems. Gripping is obtained by heating through passing electricity in the NiTi part, as it had been done in SMA Robot Hand [9].

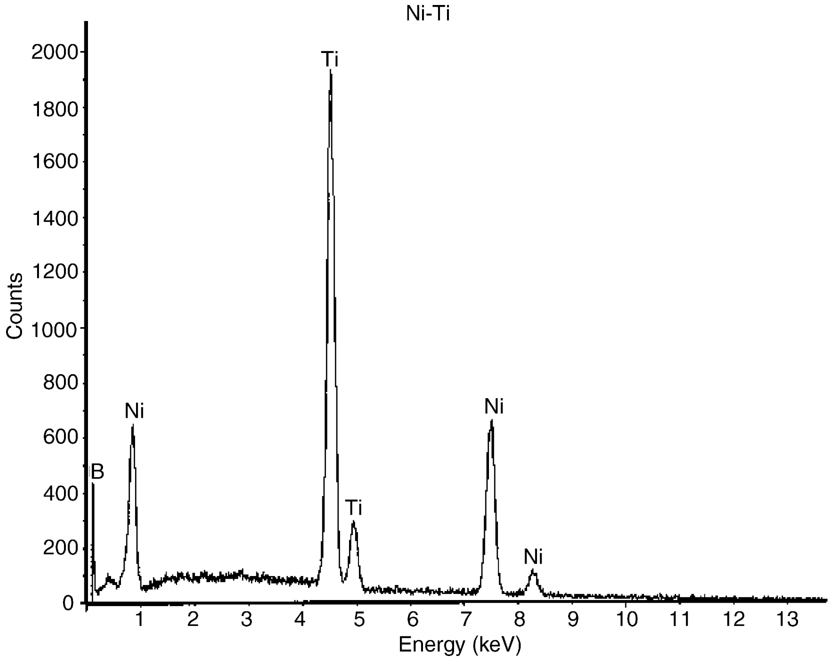
In the control system of the ITU Robot Hand (Fig. 4), force (pressure change) data is used as a control variable. An liquid filled elastic pipe that is linked to the pressure switch in the system, is connected onto the thumb. By closing the finger, the gripped material applies pressure to the pipe and by this pressure, electrical circuit inside the heating sub-system gets cut. This way, heating of the fingers is interrupted and appropriate holding is established. The pressure control that can be adjusted for various pressure values, is a continuous process inside the system. Passing cooling liquid onto the fingers results in releasing process opposite to the gripping direction. The thickness of the alloy used in the system has been reduced such that the gripping and releasing movements became accelerated.

Fig. 4. ITU Robot Hand.

The biggest advantage of the ITU Robot Hand system is that it is a simple and low-cost application. Another advantage is that it function without noise and causes no environmental hazards. The system has the ease to be used in low voltages such as 3 or 12 V. It is preferred that the robot systems that need to work in high risk fields such as mine clearance, explosive and bubby trap systems, would be light-weight, economical and robust. ITUHand bears all these three advantages. The gripping and releasing movements of the robot hand can always be adjusted for special tasks. The only job that needs to be done is the adjustment of the system that would give the necessary finger movements.

3. Performance analysis of ITU Robot Hand

In order to determine the performance of the ITU-Hand a set of experiments were performed. Gripping time of the Ni–Ti fingers according to applied powers and largest/smallest objects that the ITU Robot Hand can grip were examined. The EDS results of the used NiTi alloy is given in Fig. 5 and Table 1 gives the properties of the used NiTi alloy.



Element	Atom %	Element Wt %
Ti	51.02	45.94
Ni	48.98	54.06

Fig. 5. EDS results of the NiTi alloy used in ITU Robot Hand.

3.1. Gripping time of the Ni–Ti fingers according to applied power

Two transformers 100 and 300 W have been used in the experiments, which had been designed for measuring the gripping time of the ITU Robot Hand. The three fingers were in full gripping position in 38 s with the use of the 100 W transformer, while with the 300 W transformer this took 3.76 s.

3.2. Largest and smallest objects that the ITU Robot Hand can grip

In order to determine the range between the largest and smallest object dimensions, the dimensions of a prismatic object in three axes of the Cartesian coordinates are changed step by step. Then the delicate gripping and strong gripping processes of the robot hand are tested within these dimensions. In the delicate gripping process, in gripping with fingertips, gripping action was observed for the objects that were as thin as a paper sheet and as thick as 5.2 cm. In the present design of the ITU Robot Hand, it has been observed that the robot hand can grip the smallest cylindrical object (2.6 cm in diameter) by using the inner face of the fingers (strong gripping). After increasing the object dimension step by step, the largest object diameter, which can be griped by the robot hand, has been determined to be 8.4 cm. In these delicate and strong gripping studies, the gripping range can be increased and decreased by changing the angles of finger roots, at the location where the fingers are fixed to the acrylic frame.

Table 1
The properties of the used NiTi alloy

Martensite finish temperature	48 °C
Martensite start temperature	69 °C
Austenite start temperature	86 °C
Austenite finish temperature	98 °C
Annealing temperature	550 °C
Melting temperature	1310 °C
Density	645 g/cc
Energy conversion efficiency	5%
Max. deformation ratio	8%
Recommended deformation ratio	3–5%

4. Results and suggestions

The wide spread use of the shape memory alloys in technological applications made them suitable candidates to be used in the defense technologies and space research industry. With the ITU Robot Hand prototype, it has been demonstrated that a NiTi actuator system can successfully be used in Robot Hand designs. In the established prototype system, the data coming from the pressure sensor can be digitally processed by a computer so that the control can be made computationally. The remote control capability of the system can be enhanced by placing camera and sensor systems to the fingers.

This system can be used for low risk destroying of active explosive and bubby trapped systems safely and efficiently. The most important advantages of this system is that it is easy to use, light-weight and economic.

Acknowledgements

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