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Mechanical Properties of Ni_xTi_{1-x} Alloy for Medical Application

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Abstract

The effect of Ni:Ti ratios in Ni_xTi_{x-1} shape memory alloy at x equal to 0.9, 0.8, 0.7, 0.6, and 0.5 wt% prepared using the solid-state reaction method for medical applications have been studied. The mechanical properties of the alloy included hardness, impact, and Young's modulus which play an important role of issues were examined. The hardness values of 590.16, 670.41, 735.15, 888.03, and 901.17, which correspond to ratios of 90:10, 80:20, 70:30, 60:40 and 50:50 respectively. Besides the impact test recorded the highest value of 9.12 (KJ/m^2) at the ratio of 50:50, and the lowest value of 5.32 (KJ/m^2) for the 90:10 ratio. The Young's modulus of nickel-titanium (Ni-Ti) alloy have the highest value at a 50:50 ratio of nickel to titanium which considered as the optimal ratio depend on all there tested. The reason is that the ideal balance between nickel and titanium in the alloy provides maximum hardness and flexibility, making it particularly suitable for applications that require strong and stable mechanical properties, such as medical applications, which is useful in medical applications compared to other ratios.

Introduction

Nickel-titanium alloy (Ni-Ti) is an alloy composed of 50% nickel and 50% titanium. It is one of the most widely used alloys, especially in modern medical applications, because of its unique properties like shape memory and other mechanical properties in addition to its biocompatibility [1]. The distinguishes these alloys is their ability to restore their original shape after being exposed to external influences and deformation such as heat, tension, etc. This is called the shape memory property [2]. Its shape memory property makes it an ideal alloy for use in many fields, especially in various medical applications such as heart valves, catheter networks, orthodontic wires, and others [3]. In addition, these alloys have high shock resistance and superior hardness [4], this improves their longterm medical use within the human body, as these implanted alloys require that they be biocompatible and not affect the surrounding tissues [5]. The factors that greatly affect the mechanical properties of nickel: titanium (Nitinol) alloys the ratio of Ni to Ti [6]. The balance between the nickel and titanium ratio directly affects mechanical properties such as Young's modulus, impact strength, hardness, etc. [7], which directly affects the performance of alloys used in medical applications. [8]. Several previous studies have shown that a 50:50 nickel to titanium ratio provides the best mechanical properties and provides a balance between hardness and ductility at the same time, making this ratio ideal for applications requiring stability and long service life, especially in the medical field [9]. However, any change in these ratios could lead to significant changes in the mechanical properties, biocompatibility, and other properties of these alloys, which would allow for further study to determine the optimal ratios for each type of application, especially medical applications [10].

This study aims to investigate the effect of Ni to Ti ratios in nitinol alloys on mechanical properties, with emphasis on medical applications [11]. The effect of varying nickel to titanium ratios on the performance of these alloys and their suitability for medical applications, such as hardness, impact resistance, and flexibility, will be investigated to determine the optimal ratios that provide the highest efficiency in these applications [12]. This study has provided valuable information for improving more suitable and safe smart medical materials (mechanical properties and biocompatibility), which contributes to the development of the quality of medical devices made from these materials.

Experimental

2.1 Materials

Nickel powder have a particle size of approximately 74 microns and a purity of 99.8%, as well as titanium powder with a particle size of approximately 44 microns and a purity of 99.8% was Provided. These powders were bought from local markets to manufacture Ni:Ti shape memory alloys with various ratio as shown in Table (1). These alloys are used in several fields, especially medical devices, as the nickel to titanium ratio affects their performance in terms of mechanical properties and biocompatibility. This paper focuses on investigating the effect of changing these ratios on alloy properties.

Table 1 Materials used in this research, purity, particle sizes and Manufacture source.

Powder	Purity (%)	Particle Size (μm)	place of manufacture
Ni	99.8	74	China
Ti	99.8	44	China

Method

A sensitive balance was used to weigh 3 grams for each sample: nickel (Ni) and titanium (Ti) powder in different ratios by increasing the Ni powder value from 50% to 90% and decreasing the Ti percentage from 50% to 10% (Ni50Ti50, Ni60Ti40, Ni70Ti30, Ni80Ti20, Ni90,Ti10 wt %. In order to obtain homogeneous distribution of powders and thorough mixing of sample components, the powders were mixed by mortar in the specified ratios. by a hydraulic press to ensure a homogeneous distribution of the material and also to reduce the pores and gaps within the sample and make it more cohesive. A steel mold with a diameter of 12.5 mm was used for this purpose, so the thickness of the sample became about 1.5 mm, as in Figure (1). After that, the resulting pellet was placed in a German-made furnace at 950°C for four hours to sinter the samples, then the temperature was reduced to 250°C for half an hour to dry.

The mechanical properties of the samples were tested: hardness test to determine their resistance to surface deformation, a basic indicator of a material's strength. Impact testing was also conducted to measure the samples' ability to withstand sudden shocks, which contributes to assessing their durability under high stress conditions especially in medical applications in the human body. Finally, the flexibility of the alloys was studied using the Young's modulus test, which indicates their ability to withstand stress and regain their original shape after the external influence is removed, without being subjected to permanent deformation to achieve shape memory.

These mechanical tests are considered essential for understanding the behavior of alloys in medical applications, as they help determine their suitability for uses that require high resistance and flexibility under operating conditions cruel.

Figure 1: pellet of Ni:Ti alloys

Result and Discussion

The hardness of all samples was measured as an average of 10 readings, and the results are presented graphically in Figure 2. The results showed that the hardness for the equal proportion of 50:50 with heat treatment at 950 degrees Celsius for 4 hours have the highest values of (901.17HV) and then the hardness values decreased which make this ratio optimal. In addition, for the comparison with this value the sample with ratio of 50:50 without heat treatment have hardness value of 251.63 HV which maybe occurred in the microstructure of the material during heat treatment improving the mechanical properties of the material to be suitable for applications that require high durability, especially medical applications.

Heat treatment contributes to the rearrangement of atoms within the crystal lattice, resulting in the formation of more stable and dense crystal structures. This improvement in the crystal structure increases the material's ability to resist loads and pressures, enhancing its durability and strength. Table 2 represents the hardness values of NiTi alloy and the corresponding different ratios of nickel-titanium alloy components.

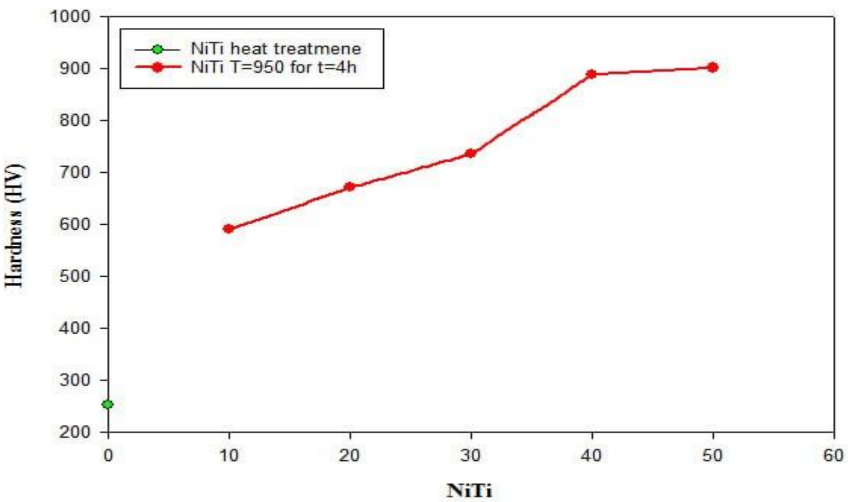

Figure 2: The hardness of NiTi alloy for different ratios

Table 2 hardness values of NiTi alloy for various percentages

NiTi	Hardness (HV)
$Ni_{90}Ti_{10}$	590.16
$Ni_{80}Ti_{20}$	670.41
$Ni_{70}Ti_{30}$	735.15
$Ni_{60}Ti_{40}$	888.03
$Ni_{50}Ti_{50}$	901.17

Impact testing (Charpy) was performed on samples of nickel-titanium alloys with different nickel-titanium ratios, after subjecting them to heat treatment at 950 °C for 4 hours. Figure 3 shows the results of the impact strength test for these alloys (NiTi) in various proportions. The horizontal axis (x) represents the proportions of nickel and titanium in different alloys, while the vertical axis (y) represents the impact force (KJ/m²). The proportions studied include: Ni90Ti10 (90% nickel and 10% titanium), Ni80Ti20 (80% nickel and 20% titanium), Ni70Ti30 (70% nickel and 30% titanium), Ni60Ti40 (60% nickel and 40% titanium), and Ni50Ti50 (50% nickel and 50% titanium). % titanium). Table 3 shows the impact test values for different percentages of each alloy. The results indicate that a change in the nickel-titanium ratio directly affects impact strength, illustrating how to improve the alloy's mechanical properties by controlling its composition (nickel to titanium ratio) and heat treatment, which is important for improving performance in applications requiring high impact resistance. Especially medical applications.

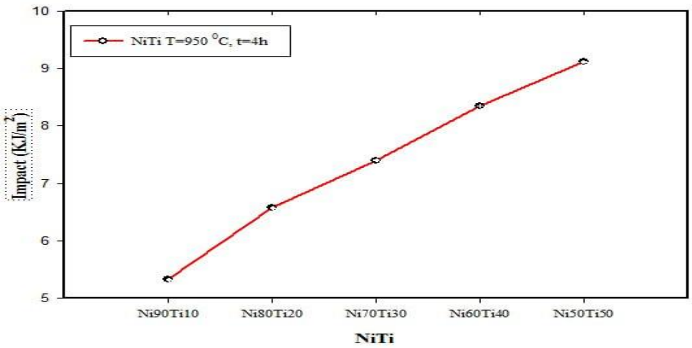

Figure 3: Impact values of NiTi alloy for samples with different ratios

Increasing the percentage of titanium from 10% to 50% in the nickel-titanium alloy, subjecting it to heat treatment at 950°C for 4 hours, results in a significant improvement in the impact strength of the alloy. The graph shows that the impact strength gradually increases from 5.8 kJ/m² to 9.2 kJ/m² with the increase of titanium content, which indicates that titanium enhances the hardness of the alloy and makes it more resistant to impacts. The equal proportion of nickel and titanium (50% each) gives the alloy the best mechanical properties, making it ideal for applications requiring high impact resistance. Heat treatment helps improve element distribution and increase toughness, which contributes to enhancing the mechanical performance of the alloy.

Table 3 Impact test values and the corresponding different percentages for NiTi alloy

NiTi	Impact (KJ/m^2)
$Ni_{90}Ti_{10}$	5.32
$Ni_{80}Ti_{20}$	6.57
$Ni_{70}Ti_{30}$	7.40
$Ni_{60}Ti_{40}$	8.35
$Ni_{50}Ti_{50}$	9.12

NiTi alloys were examined under tensile and strain tests, and the results showed that samples with equal proportions of nickel and titanium provided the best mechanical performance, as shown in Figure 4. The delamination initiation stress was approximately 214 MPa, indicating that the alloy is essentially elastic under this stress. When the disassembly initiation stress is exceeded, the process of disassembly of martensite variants occurs, which involves significant energy dissipation via relative motions between the variant interfaces during their reorientation and growth. In polycrystalline alloys, the delamination process can be seen in two stages, indicating the complexity and overlap of the mechanical processes that occur when the alloy is subjected to high stresses. The importance of equal proportions in the composition of nickel and titanium alloy lies in achieving the optimal balance between flexibility and hardness. These optimal ratios contribute to improving the mechanical performance of the alloy under high stress conditions. The balance in the proportion of materials produces an equal and homogeneous distribution of atoms within the crystal structure of the alloy, which in turn leads to improving the alloy's properties, especially mechanical ones, in a way that is compatible with medical applications that require these properties. The properties of alloys, particularly their mechanical properties, can be improved by two important factors: precise control of the proportions of the constituent materials and the formation of the appropriate crystal structure. Heat treatments directly affect the particle distribution in the crystal structure and reshape it, thereby impacting the mechanical performance of the alloys, making them suitable for the targeted applications as a result of improved mechanical properties. NiTi alloys have been obtained that are suitable for medical applications due to their mechanical properties that are similar to some parts of the body such as bones. These alloys are characterized by their high flexibility and ability to return to their original shape after the removal of the external influence and to a certain desired limit, i.e. they achieve shape memory, thus becoming ideal for use in the medical field such as stents, catheter networks, artificial heart, prosthetic limbs, and other applications. Its flexibility allows it to withstand mechanical stresses that occur in the human body, while its ability to restore shape helps stabilize and improve the function of implanted medical parts. Hence, NiTi alloys offer a unique combination of mechanical properties and ductility, making them an excellent choice for use in a variety of applications especially medical applications.

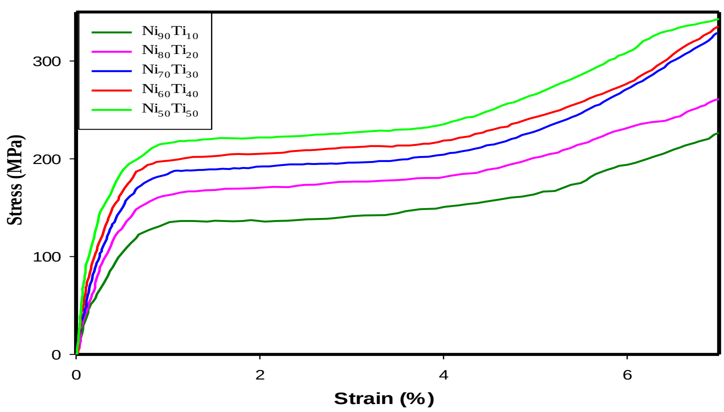

Figure 4: The stress-strain curve of a NiTi alloy

Conclusion

nickel-titanium (NiTi) alloys have been successfully prepared using solid state reaction method. The percentage of nickel is a critical factor in determining the transition temperature of the alloy, as increasing the percentage of nickel leads to lowering the temperature at which martensitic transformation occurs, which enhances the performance of the alloy in applications that require superior flexibility at high temperatures. The nickel content in an alloy affects biocompatibility. High nickel content reduces biocompatibility by releasing nickel ions into the human body, which are toxic within certain limits. Increasing the nickel content also increases the alloy's hardness and must be controlled within a certain range. However, it may negatively impact its durability and increase its fragility. Therefore, the optimal ratio for this alloy must be considered, which is when the proportions of both elements are equal. Therefore, balancing the alloy's component ratios is essential to ensuring suitable mechanical properties and compatibility for targeted medical applications. The optimal ratio of alloy components must be carefully achieved to achieve a balance between various mechanical properties: superior elasticity, toughness, and biocompatibility, tailored to each medical application. Controlling the ratio of materials in Ni:Ti (Nitinol) alloys is a vital tool for optimizing alloy properties to suit various medical uses and specific purposes. This leads to the development and manufacture of high-performance smart materials with appropriate specifications, thereby achieving the desired purpose.

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