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Applied Mechanics for Mechanical Engineers: Principles and Applications

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A**bstract---** Shape memory alloys (SMAs) are a collection of clever metallic materials that, due to their remarkable thermo-mechanical behavior, appear to offer a wide range of applications. Their ability to regain their distinctive shape after severe deformations when subjected to an adequate warm cycle sets them apart from conventional metallic materials. By the property of remembering their original shape, SMAs are called "memory" materials. The fundamental reason for such behavior of these alloys is associated to crystallographic stage change actuated by pressure or temperature and a few combinations address this way of behaving. Due to large deformation behavior these alloys are capable for fulfilling functions such as sensors and actuators. SMAs are widely used in domains and direct applications in numerous areas such as biomedical field, aviation industry, aerospace field, atomic nucleation industry. The material's ability to promote the mechanical contribution to non-mechanical results is used in the detecting application. However, these amalgams transform the non-mechanical variety into a mechanical result in activation applications. According to SMA incitation, significant burdens and relocations can be formed in a relatively short amount of time throughout a SMA part's stage shift cycle. Activation energy thickness, often referred to as the accessible work yield per unit volume, and activation recurrence are two of the most important factors that affect the incitation use of a functional material. One should have the highest incitation energy thickness and incitation recurrence in order to work with a superior activator substance. However, in naturally occurring actuators and man-made actuators, shape memory alloys possess the highest actuation energy density and the frequency. Since, shape memory alloys have the function of both actuator as well as a sensor, they are very suitable candidates for miniaturization of actuators such as micro actuators or micromachines or human body implants.

Keywords--- Shape Memory Alloys, Human Body Implants, Artificial Intelligence, Machine Learning.

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I. Introduction

SMAs are an unmistakable type of clever material that exhibits unusual properties, or at the very least, the material can return to its original shape after being twisted, or alternatively, it can recover strain after being warmed. Shape memory impact (SME) is the term used to describe this unusual behavior of SMA (Mishnaevsky Jr et al., 2014). Buehler and Wiley at the US Maritime Law Lab disseminated the first report on SME of shape memory combination material. The first instance of SME influence was observed in NiTi composite (Nitinol). Shape memory combinations with SME properties have a high energy thickness. Additionally, the material experiences a reversible hysteretic change under certain conditions, allowing the material to spread energy for energy-ingestion applications. Because of these characteristics, shape memory combinations present a good challenge for various biomedical applications. In any event, the material's low recurrence reactivity is a drawback that limits its uses. Among different SMAs, NiTi alloy is one of the most widespread and implemented alloy for biomedical application for its two unique properties; shape memory (SM) and super elasticity (SE), in addition with a higher range of biocompatibility, good resistance with corrosion, wear and unique mechanical properties roughly equal to the bone mechanical properties (Ferraris & Spriano, 2016).

In recent years, researchers have been gained interest on the use of shape memory alloy in various field such like aviation, biomedical and so forth. A biomedical literature analysis has been carried out to estimate the research in this field with key word "shape memory alloy" and "nitinol" using PUBMED search engine, which is well known for accessing primarily the MEDLINE database of references and abstracts on biomedical areas; Prevalence of shape memory alloy application in biomedical devices has been increasing from past few decades, because of their special thermomechanical behavior and its biocompatibility. However, there are many biomedical devices which had been developed because of the discovery of shape memory alloy and it was extremely hard to develop from different materials like other grade titanium alloy, stainless steel and so forth (Feng et al., 2015). Although, shape memory alloy is significantly expensive from other materials for the use of medical application, shape memory exhibits a wide use in medical industry. In application of shape memory alloys, It usually falls into one of two categories: aloof application or dynamic application. In a dynamic application, the compound's temperature is regulated to initiate a stage transition that produces the desired thermomechanical conduct between martensite and austenite. However, passive application corresponds to both the shape memory characteristics: shape memory effect and superelasticity. These phenomena allow the shape memory alloy, especially in the form of NiTi to undergo the mechanically induced transformation and then recovery of original shape. A famous and most commercialized application of NiTi shape memory alloy in medical field is self-expanding stents. Actual definition is made from its functionality as, a tiny tube that is placed inside duct or blood vessel, to keep blocked pathway open. Nitinol is used to develop stents which uses its shape memory and superelastic properties passively, to make them self-expanding after inserting into the body. Stents are shape set according to their use. Normally the The shape set form's external diameter is set at 10% bigger from the vessel or duct diameter to guarantee that the stent can't move (Balazic & Kopac, 2007).

II. Problem Statement

Hip joint is one of the most stable joint in human body, its stability originates from the rigid ball and socket joint of femoral head and acetabulum of the pelvis (Teo et al., 2016). The articulating surfaces of femur head and acetabulum makes a stable joint contact for load bearing and provides a range of movement of joint. Hip Joint bones and its mechanical properties.

Hip joint is composed of two bones; femur and pelvis. Bones are a type of rigid connective tissue which has either cortical and cancellous bone or spongy bone. Cortical bone is hard in nature that means the density is high ($\simeq$ 1.8 gm/cm^3), it provides the protective layer of these bony structures. Cancellous bone is spongy in nature and provides support to the cortex, density of cancellous bone is lower than the cortical bone ($\simeq$ 0.9 gm/cm^3), spongier nature of cancellous bone helps to reduce the weight of bony structure. Mechanical properties of bone are highly dependent on age, gender, location and many pathological reasons. Since, the bone is highly anisotropic, means its mechanical properties is considered in two orthogonal directions; longitudinal and transverse. Human bone consists of mainly 35% of organic and 65% of inorganic substances. Organic substances are composed of cells, matrix of collagen fibers composites and ground substances, whereas inorganic are mineral crystals which includes primarily calcium phosphates. Despite of fact, fiber composites are composed two or more different components, so modulus of elasticity of bone can be estimated by using rule of mixture and inverse rule of mixture which gives the value for cortical bone as transversely isotropic and cancellous bone is considered as isotropic substance with υ=0.3 and E=2.13 GPa (Cowin, 1989). These characteristics were obtained from long bones, such as the tibia or femur, because they are easier to evaluate and are uniformly expressed along the bone (Teo et al., 2016).

Total hip surgery (THS) is a surgical procedure to correct the mobility of hip ball-socket joint function by replacing damaged or arthritic bone and cartilage with metal components. Although there isn't a full comprehension of aseptic release in such mindset, it is most likely going to be the result of numerous disappointing circumstances (Grote & Hefazi, 2021). It is necessary to change the small THR level that actually bombs. Additionally, THRs are increasingly carried out on younger, more active patients, who in thus way outlive their embed. Update medical treatments have a variety of underpinnings, none of which are essentially unrelated. Osteolysis and aseptic slackening, separation or unsteadiness, contaminations, and breakage are the four main factors that cause alteration. To illustrate the possible cycles that lead to insert disappointment, developed a framework of disappointment scenarios, which include: collected damage; particle response; bombed ingrowth; stress protection; stress sidestep; and terrible wear. The article has also included high liquid strain and cautious error as possible causes of dissatisfaction.

III. Methodology

It is not possible to portray various calculations and conditions without execution into a mathematical climate using the constitutive model for the peculiarity of shape memory compound materials that is shown. A created code into the Ansys limited Structure (ANSYS® Scholastic Exploration) as a Mechanical APDL Order is used to have the choice to be able to deconstruct difficult situations. This code implements the described constitutive model analytically. The method by which the global APDL solver displays a nonlinear material, such as shape memory composites, using the order line. As can be seen, the model uses the more well-known removal-based restricted component research technique. By addressing the direct problem (versatile solidness framework), the solver begins by guessing the appropriate initial deformity over the space hubs in light of the thermo-mechanical stacking pass. The order takes care of these strains. The computation updates the burdens based on the constitutive model of shape memory amalgams. The neighborhood digression solidity over the material point region is also established, in addition to the updated burdens (Reddy, 2017). Through component-to-component reconciliation, these burdens are used to determine the powers on the components. To satisfy the static balance, the total power applied to all hubs is calculated to be zero. Architecture diagram shown in Figure 1.

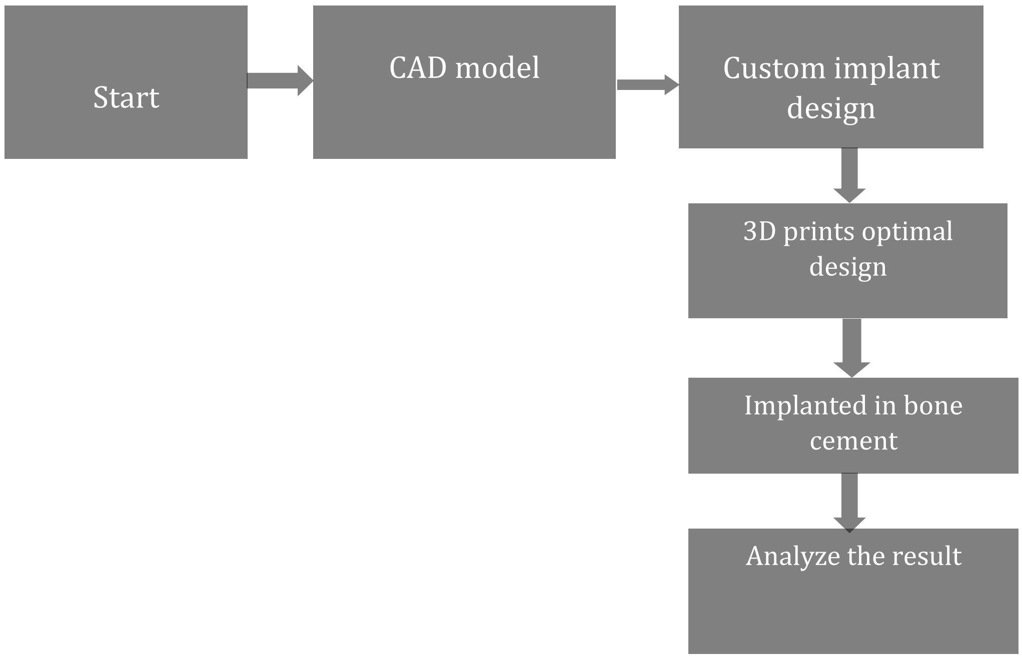

Figure 1: Architecture Diagram

These hubs' remaining powers are calculated, and if the size falls below a certain resistance, the arrangement is valid and the solver advances to the next stacking path. When the extent is large, the Full Newton-Raphson technique is applied to identify new attributes for the misshapenings, where the program's calculated digression solidity connects the remaining power to the newly hypothesized relocations. As previously illustrated, the strain for each hub in the recently developed Ansys APDL software is the result of the Ansys worldwide solver, and the pressure and pressure digression firmness are the outcomes. At the start of each step, the APDL computation anticipates no change (Bird & Ross, 2014; Shahid et al., 2021; Elsayed et al., 2018). In this way, the UMAT can return the result as the hub's pressure in the event that there is a flexible assumption. However, it suggests that change is taking place if the flexible presupposition is violated in relation to the disparity. The change condition contains the required pressure and digression firmness, which can be determined using the return planning formula. In this case, the martensite volume division is increased, and the resulting pressure is calculated based on the constitutive conditions shown. The results will be returned to the global solver each time the change capability is recalculated and whenever the condition is met.

IV. Experiment and Evaluation

The SMA wire-tube assembly will be inserted and fixated into these holes. The wire should activate at above body temperature and it should be in Martensite phase when in body temperature. The tube, made of another composition of nitinol has an activation temperature around body temperature shown in Figure 3. The wire should be inserted into the tube. Then the assembly of wire and tube is wrapped around the base screw and fitted in the circular cut on the surface of the screw. The stem of the wire-tube assembly is welded to the screw for achieving better fixation. The assembly of the wire and tube is depicted in Figure 2.

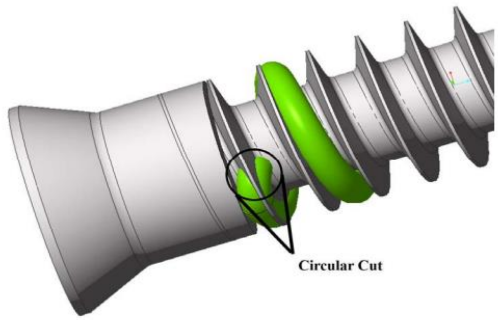

Figure 2: The SMA Helical Insert is Fused to the Holes on the Surface of the Screw

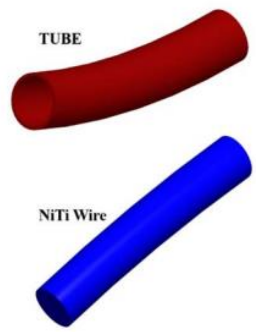

Figure 3: Initial Memorized Shapes of the Nitinol Wire and Tube Assembly

The block's temperature should be lower than the austenite start temperature in order to simulate the shape memory influence. The underlying state is at the austenite stage, and the temperature is set to 253.15 K to achieve this. In vertical bearings, a single 0.35 mm uniaxial relocation stacking pattern is used. The whole process includes tension, unload, compression, and unload. The temperature is then increased to 285.15 K, which is above the austenite finish temperature. Illustration of state of equilibrium shown in Figure 4.

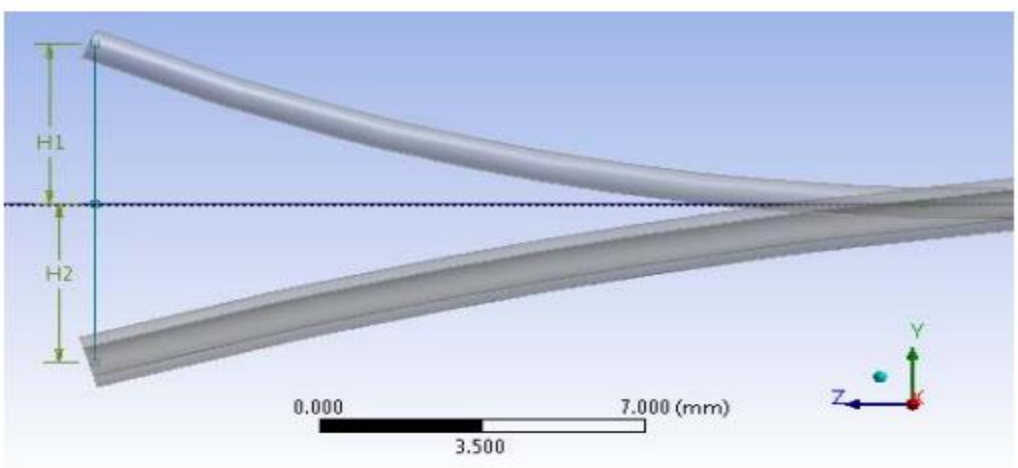

Figure 4: Illustration of State of Equilibrium

The difference in temperature change between the wire and the cylinder is the activity's basis. The wire is form memory and the cylinder is superelastic at a supposedly low temperature (internal heat level 37°C for current biomedical reasons). However, the wire also becomes superelastic at a greater temperature (let's say 52°C). Both the wire and the cylinder survive in an Austenite state beyond this temperature, where their memorized shape remains constant.

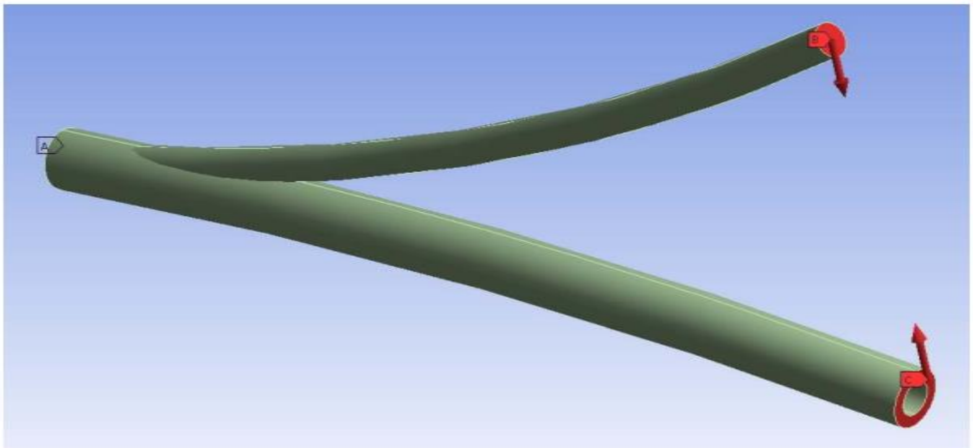

Figure 5: Loading and Boundary Condition of Nitinol Wire Tube Assembly

The wire and the tube are deformed at the 1st stage temperature level under a distributed tip loading. The loading causes Martensite transformation in top and bottom layers of the tube and wire that sustain the highest amount of stress. Therefore, upon unloading, there will be some residual deformation in the structure. The type of loading and boundary conditions (B.C.) used for this model are shown in Figure 5. Based on the above FE simulations and pilot experiment of the novel screw anchored with nitinol elements, it is evident that implementing nitinol in rig will surely give the enhanced pullout strength of the acetabular screw rather than the conventional press-fit acetabular cup. Shape memory alloys are a unique kind of alloys which show a specific thermomechanical behavior. They have the ability to return to a certain predefined shape upon heating after deformation. The second specific property is the ability to tolerate large deformations without undergoing the plastic region. These specific properties along with the biocompatibility of nitinol are the reasons that this alloy has been used in recent years for biomedical devices applications. To better design and analyze the nitinol devices which are used in biomedical applications, a simulation tool is required.

V. Conclusion

To this end, the constitutive modeling of the thermomechanical behavior of the shape memory alloys has been implemented into the Ansys solver. A novel total hip implant design which has been proposed and analyzed in this study. The nitinol clusters that were attached to the acetabular cup and screw were the plan's standout feature. The congregations were constructed from nitinol, which gave the screw the capacity to grow and retract (at particular temperatures). By creating a model with a larger scope and conducting tests, the usefulness of the depicted gathering was evaluated. The result of the hip displacement of the assembly was recorded and reported as the function of temperature variation of the nitinol beam. The FE modeling of nitinol thermo-mechanical behavior in Ansys was also conducted and verified by comparing the results with the experimental ones. Pullout test as the standard method of evaluating the acetabular screws was also modeled in Ansys as the FEA modeling software. In the experiment, the pullout test results of a regular screw were compared to the enhanced screw with nitinol wires. In both experiment and modeling, the screw with nitinol showed much higher pullout force than a regular screw.

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