

# Analysing and Comparing the Behaviours of Cylindrical Fatigue Specimens Made of Ni-Ti Shape Memory Alloy and Steel

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**Abstract** - The frequency and the dynamic harmonic behaviours were analysed by using the cylindrical fatigue specimen. The two types of materials were used in the cylindrical fatigue specimens were Steel and Nickel-Titanium shape memory alloy. The same type of loading and boundary conditions were given to the both of the specimens and various behaviours were compared using Abaqus. Relative scaling of full cycle was given in the scale factor/harmonic and modal frequencies of different deformations were analysed by selecting the range up to particular modes (i.e. up to 20) and Steady state dynamic analysis was also done in specimens. Ni-Ti alloys were implemented to control the vibrations in the structures. Due to their advantages like high corrosive resistant than steel, vibration control, shape memory alloys were used in place of steel in many construction related applications, especially in tall buildings.

**Key Words:** Abaqus 6.14, Finite element method, Ni-Ti shape memory alloy, Steel, Cylindrical fatigue specimen.

## 1.INTRODUCTION

A cylindrical fatigue specimen consists of two shoulders and a gauge section, In between these two shoulders, the gauge section is placed. The zone of the shoulder is very large when comparing with the gauge zone. Due to this larger cross sectional zone of shoulders and very minimum cross section of the gauge zone. The large amount of deformation or failure is expected in the gauge zone, Due to the variation of grips in the testing machine, the manufacturing of the shoulders in the test specimen is specifically concentrated. The main two types of grips are serrated grips and pinned grips. The shoulders which are manufacturing for the serrated grips are easy and the cost for the manufacturing of these types of shoulders is low and this alignment depends upon the technician's skill. The pinned grips should make good and fine alignment. Threaded shoulders and grips make good and fine alignment. For handling this, the technician should know how to thread each shoulder in to the grip or else there is more possibility of thread to strip. In this paper round shoulders were taken to check various behaviours. For this, the material of the specimen is taken as shape memory alloy (Nickel-Titanium). The fatigue behavior of DZ125 super alloy was taken to check the effect of the

frequency and sample shape. The ultra-high cycle fatigue property of turbine blade made of DZ125 super alloy in aero engine  $f=20$  kHz was studied based on the ultrasonic fatigue test system. In this both the cylindrical specimen and plate specimen were taken for the ultra-high cycle fatigue testing. S-N curves were being drawn to check the life [1]. AZ61 magnesium alloy was taken for the investigation on humid environment. In this the applied frequencies were 1 and 10 Hz. Those investigations were done with 50C-80%RH environment; Investigation is also based on the effect of frequency on fatigue crack growth [2]. The phase transformation was first recorded in Gold-Cadmium alloy. After that many researchers found that the Nickel-Titanium alloys behave well in phase transformation, they are better in the electrical and thermo mechanical characters. Ni-Ti shape memory alloys are used in bracing in columns, base isolation, connectors in steel structures. In some cases these SMA is also used as the reinforcements [3]. Some different types of SMAs are evaluated based on their mechanical and durability properties. Among them, Ni-Ti is used in vibration control of structures. This is due to its super elastic behavior, good fatigue and corrosion resistance and great durability. In general, damping capacity of a member largely depends on the larger area of the hysteresis loop. By using SMA, we can obtain large area of hysteresis loop [4]. Piezoelectric, magnetostrictive, photochromics and thermochromics, electrostrictive, thermoelectric, shape memory alloys were the various classifications in smart materials. Smart materials were the materials in which they are having the capability to change their characters by giving external stimuli to it. Ni-Ti alloys were having extraordinary super elastic and shape memory behaviours [5]. Shape memory alloys were also used in retrofitting in structures. Best example was the retrofitting of the bell tower of the Church of San Giorgio at Trignano, Italy. The magnitude of 4.8 Rt earthquake resulted in major damage in the bell tower. Following the earthquake, the tower was rehabilitated by using SMA. The SMA damper was found to be more effective in the martensite form than the austenite form [6]. The torsion and rotating bending fatigue endurance was investigated. For that, the specimen is made as aluminium alloy. The tests for torsion fatigue were conducted at load ratio  $R=0$  and frequency of 10 Hz, the tests for rotating bending fatigue were conducted at load ratio of  $R=-1$  and the frequency of 50Hz. Fatigue endurance under the rotating bending is hundred times higher than torsion fatigue

endurance for higher loading period. Likewise fatigue endurance under rotating bending is just 20 times the corresponding to torsion testing [7]. According to Monika G. Garrell et.al, the stress distribution in this specimen was analyzed using the finite-element method. By redesigning the specimen geometry, it is possible to reduce the magnitude of the stress concentration factor for the ASTM D 638 Type IV flat tension specimen without changing its overall size [8]. V. Shlyannikov had studied the surface crack growth in the cylindrical hollow specimen prone to tension and torsion. During the test carried out, the crack opening displacement (COD) method and the optical microscope measurements are used to measure the crack length and crack depth [9]. Sometimes, the unexpected failures of the material are due to the vibrational stresses. Due to this reason studies on the high cyclic fatigue are high. Thus various geometry specimens have to be designed to reduce the fatigue due to high frequencies [10].

## 2. RESEARCH METHODOLOGIES

The specimen was modeled and analysed in Abaqus 6.14 by giving appropriate property, loading and boundary conditions to the specimen which was taken. At first line diagrams were drawn in Abaqus while creating parts, after that appropriate properties were given for the taken material. While creating the step 1, linear perturbation was given in the procedure type option and frequency was selected. In this step 2 was created as steady state dynamic (direct). In this lower and upper frequencies were given and number of points were made.

After that displacement and rotation were made as the boundary condition at one end. At last the model was meshed with the help of giving appropriate global size and mesh control and job was created. For analyzing, animations were made harmonic for full cycle.

**Table -1:** Material properties of the cylindrical specimen

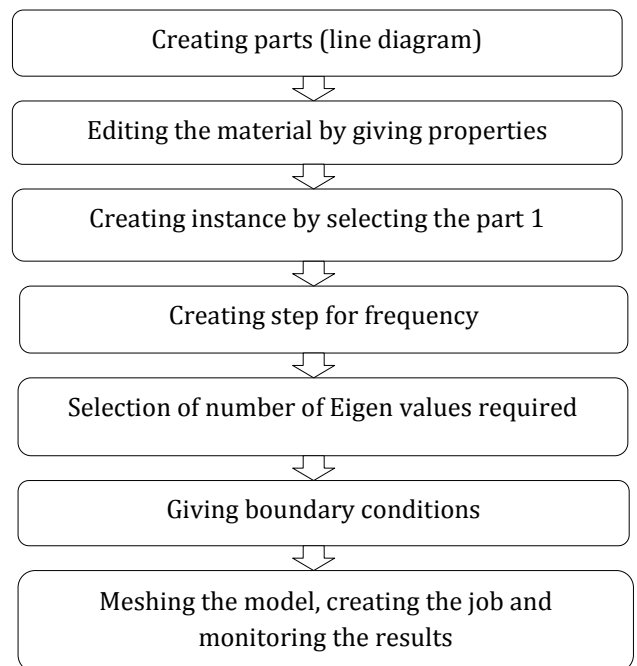
Properties	Steel	Ni-Ti Shape memory alloy (Martensite phase)
Young's modulus	2x10 <sup>11</sup> Pa	35x10 <sup>9</sup> Pa
Poisson's Ratio	0.3	0.33
Density	7800 kg/m <sup>3</sup>	6450 kg/m <sup>3</sup>

The dimension of the cylindrical fatigue specimen in this research was taken as follows. The length of the one shoulder was taken as 0.007 m, the length of the gauge as 0.014 m, the diameter of the shoulders as 0.010 m and the diameter of the gauge was taken as 0.004 m. Experimentally, the load on the specimen was applied gradually by manually turning the load-wheel at a very slow rate. The equation for the stress induced in the fatigue test specimen can be calculated from the following

$$S = \frac{32}{3.14Xd^3} \left( \frac{(m+mp)Xga}{2} + cb \right) \tag{1}$$

Where ,

*d* is the neck diameter of the fatigue test specimen, *m* is the mass in the load pan, *mp* is mass of the pan, *a* is the distance between loading point and support on either side of the simply supported beam and *C* is the weight of each chuck at distance *b* from the fulcrum.



**Chart -1:** Flow of Work in Abaqus

## 3. ANALYSIS BASED ON FREQUENCY AND DYNAMIC HARMONIC LOADING

In the cylindrical fatigue specimen, the harmonic analysis was done by selecting the linear perturbation in the step and the frequency option was selected in the step. Here the modal frequency of first twenty modes having different deformations was analysed.

The various deformations like flexion with first order, second order and third order, torsion, tension compression

were analysed. The tension compression is the most important to analyse because the gauge section in the cylindrical fatigue specimen is prone to failure. The reason for the gauge failure is due to the small cross sectional area. In this the frequency behaviours of both the steel and Ni-Ti shape memory alloy were discussed.

The first order flexion for steel specimen was occurred at the mode 7 with the frequency of 7370.9 (cycles/time), the occurrence of the first order flexion for Ni-Ti shape memory alloy specimen was at the 7<sup>th</sup> mode with the frequency of 5557 (cycles/time).

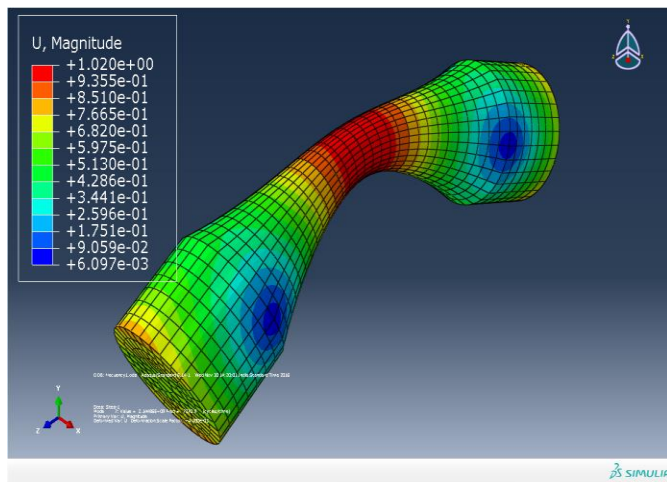


Fig -1: Flexion 1<sup>st</sup> order

The second order flexion for steel specimen occurred at the mode 10 with the frequency of 27715 (cycles/time), the occurrence of the second order flexion for Ni-Ti shape memory alloy specimen was at the 10<sup>th</sup> mode with the frequency of 20895 (cycles/time).

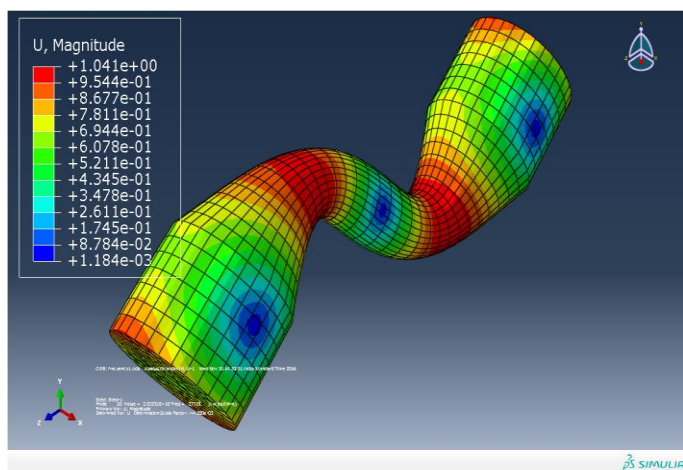


Fig -2: Flexion 2<sup>nd</sup> order

The third order flexion for steel specimen occurred at the mode 13 with the frequency of 67923 (cycles/time), the occurrence of the third order flexion for Ni-Ti shape memory

alloy specimen was at the 13<sup>th</sup> mode with the frequency of 51208 (cycles/time).

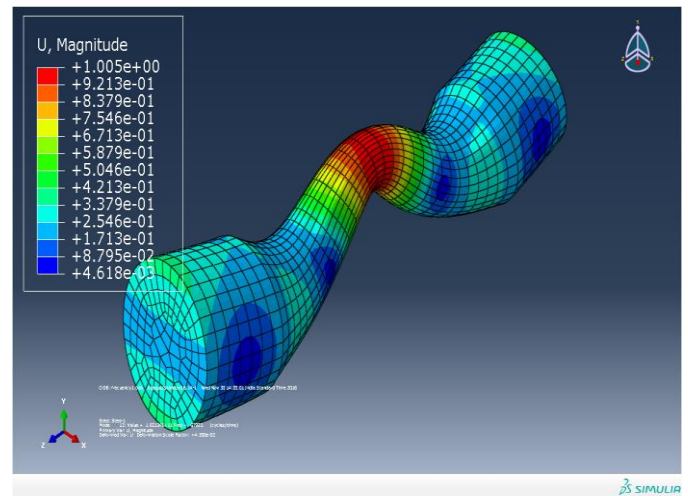


Fig -3: Flexion 3<sup>rd</sup> order

The tension compression for Ni-Ti shape memory alloy occurred at the mode of 12th, with the frequency of 34245 (cycles/time), the occurrence of the tension compression for Ni-Ti shape memory alloy specimen was at the 12<sup>th</sup> mode with the frequency of 25818 (cycles/time).

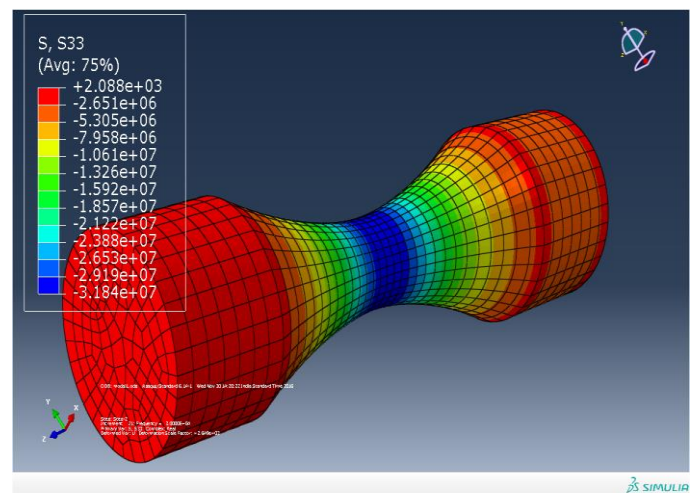


Fig -4: Tension compression of cylindrical fatigue specimen

The steady state dynamic analysis were made by application of displacement vertical of 1micro meter at one end of the specimen and the distribution of stresses was calculated for various loading frequencies from 10 kHz to 30 kHz.

The marking of the nodal points was done by creating the path in Abaqus. At the tension compression zone, the nodal points were marked in the specimen carefully and graph was plotted between the true distance along the path and the stress.

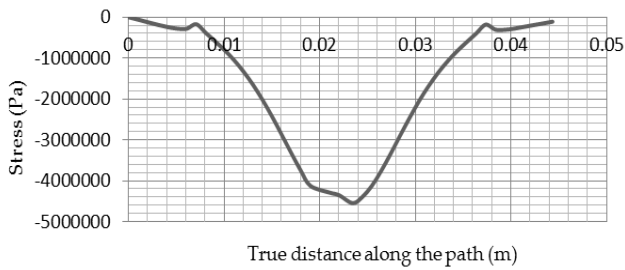


Fig -5: True distance along the nodal path vs. stress for Ni-Ti specimen

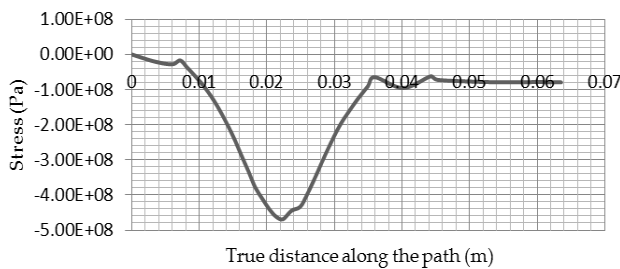


Fig -6: True distance along the nodal path vs. stress for steel specimen

Table -2: Maximum tensile stress for steel and Ni-Ti shape memory alloy specimens

Material	Maximum tensile Stress(Pa)
Steel	$-4.69 \times 10^8$
SMA	$-4.56 \times 10^6$

The tensile stress is maximum for the cylindrical fatigue specimen made of steel. This is due to the large young's modulus of steel than Ni-Ti shape memory alloy. From the results, the tensile capacity of steel is maximum than Ni-Ti shape memory alloy. The failure first occurs in the gauge section of the specimen made of Ni-Ti shape memory alloy than steel specimen. The externally applied electrical heat may definitely reduce the cracks in the failure regions of Ni-Ti shape memory alloy specimen.

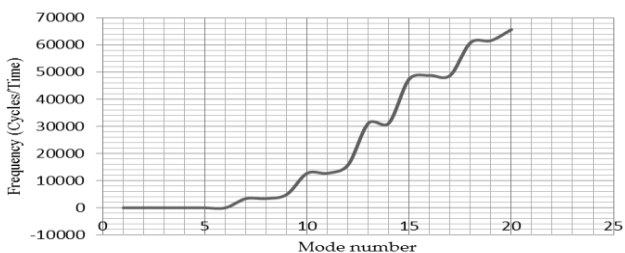


Fig -7: Mode number vs. frequency for Ni-Ti specimen

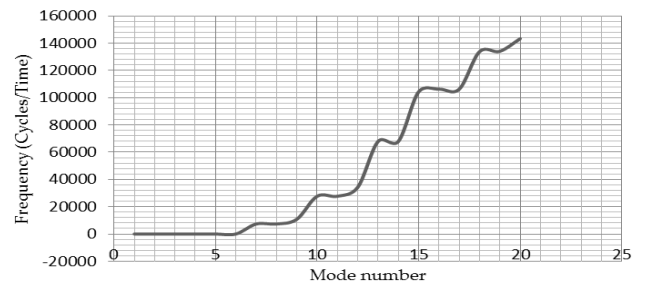


Fig -8: Mode number vs. frequency for steel specimen

Table -3: Maximum frequency for steel and Ni-Ti shape memory alloy specimens

Material	Maximum frequency
Steel	143333 (cycles/time) at mode 20
SMA	65639 (cycles/time) at mode 20

The variation of the frequencies for the various mode shapes selected was shown in the fig 7, 8 for both the materials.

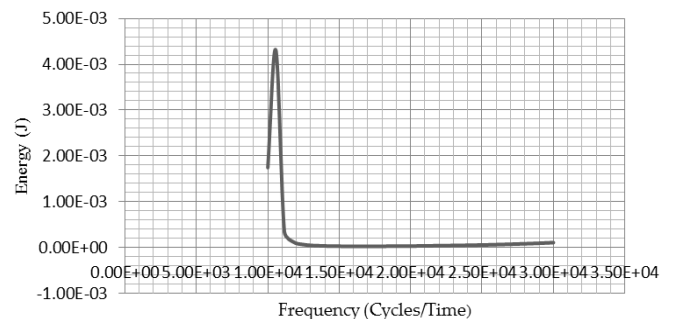


Fig -9: Energy vs. frequency for Ni-Ti specimen

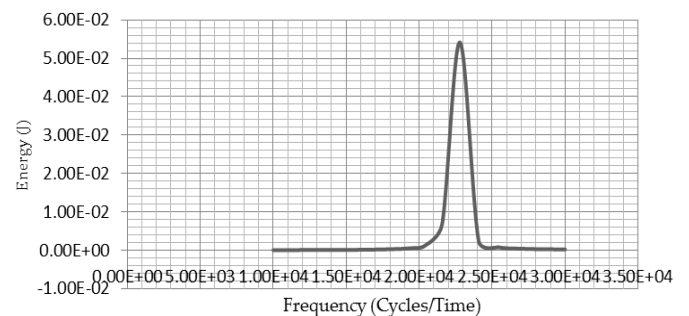


Fig -10: Energy vs. frequency for steel specimen

**Table -4:** Maximum energy for steel and Ni-Ti Shape memory alloy specimens

Material	Maximum energy (J)
Steel	0.0541529 J at 22795.1 (cycles/time)
SMA	0.00430452 J at 10564.7 (cycles/time)

The maximum kinetic energy is more for the steel specimen than steel specimen.

#### 4. CONCLUSION

The investigation and analysis of cylindrical fatigue specimen’s behaviours were discussed. It is concluded that the tensile stress concentration is more in the gauge region of the specimen. For the steel specimen the tensile stress is more in the gauge section. On comparing the tensile stress of the steel specimen, the tensile stress of the Ni-Ti shape memory alloy specimen is low due to the lesser value of the young’s modulus of elasticity than that of the steel. It is also inferred that frequency becomes significantly smaller if the dynamic stress amplitude is lower, may be because cyclic loading is almost perfectly elastic. In this specimen, maximum energy and maximum frequency is also higher for steel than Ni-Ti shape memory alloy. With the increase in the order of the flexion of the specimen, the frequency of the specimen increases Due to the higher young’s modulus of steel and high bonding capacity of the steel with the concrete, they are used as the construction materials. In seismic related application in the buildings, the shape memory alloys were implemented in the buildings in place of steel. The reason for the implementation of the shape memory alloy in the specific regions in the building is due to their energy dissipating capability and isolating capacity of the super structure during high magnitude earthquake. The externally applied electric heat to the Ni-Ti shape memory alloy will further help in reducing the cracks and improve the vibration control behaviour.

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