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Research Article

The Effect of Slender-Wires Diameters Intelligent Helical Springs

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Abstract

Slender or thin diameter wires which contract like muscles when electrically driven so it's become interesting point to know the effect unique parameters as light weight value of SMA, load or distance gain with instant time response for its actuation. In this proposed work the two springs having different number of turns and different diameter as 0.1 and 0.2 mm are prepared with the help of fixture-cum-spring tool then heat treatment was provided in the furnace at 530°C for 45 min and then cooled for 16 hours just by switch-off the furnace and placed in contact of air upto 6 hr to opening of the gate of furnace. The parameters include the average wire temperature, average strain capacity, scale-load capability response and wire-current and voltage during working.

Keywords: Shape memory alloy; Manufacturing; Design; Actuator; Model.

Introduction

Ponam and Garima (2015) used the Matlab for the modeling and testing the spring elasticity. Elasticity is dependent upon three basic components as spring constant (K), damping constant(B) and mass of the object(M). They made a simulink model according to tradition spring elasticity equations by a matlab and simulink to saw the effects of mention parameters on spring elasticity and its functionalities [1]. The phase transformation of martensite to austenite phase during laser heating generates compressive stress on the surface of NiTi wire. Laser annealed straight annealed wire at 800 MPa with speed 450 mm/min and 370 mm/min were applied. The lower value of the hardness 3.8 GPa of NiTi wire signifies surface annealing of SA sample and laser induced NiTi wire which also showed better fatigue performance with improved 6500 cycles [3]. Rajkumar and Dwivedi (2014) focused systems of deferential equations form the basis of mathematical models in a wide range of fields from engineering and physical sciences. Results showed that both methods Equation modeling & state space modeling produce the same results. It proved that modeling was performed with great accuracy by understanding the dynamics of the system [2].

TEM analysis revealed a mean grain size of few tens nanometers and the presence of rather big inclusions (less than 1 μm). SAED pattern revealed these particles to be Ti4Ni2Ox inclusions. These ceramic compounds did not impair significantly the fatigue behavior of the SMA wire, since it could reach 300000 cycles without failing. In particular, it was evaluated the performance of the SMA wires for actuators in terms of functional fatigue and thermo-mechanical properties by means of an experimental apparatus design [5]. Pelton (2011) provided information about the microstructural analyses of thermal or mechanical for NiTi wires. A review of the Nitinol fatigue literature demonstrated that cyclic transformations between austenite and martensite. Accumulation of the dislocations modifies transformational behavior, resulting in changes in transformation temperatures, strain under stress-control and stress under strain-control. He included thermal fatigue, mechanical fatigue, cycles to failure and mean strain (%). Dislocation bands which were thought to be due to the effects of moving martensite interfaces, aligned with the martensite lattice invariant plane [4].

Kneissl et al (2000) considered NiTi and CuAlNi shape memory alloys and especially with the two-way memory effect which was successfully introduced in wire specimens by a

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specific thermo-mechanical heat treatment called training. Two-way shape memory effects have been successfully introduced in three different alloy systems by training under constant stress. To enable a systematic variation of the microstructure with respect to dislocation density, second phase particles and grain size, the investigations were carried out on three different alloy systems. NiTi samples [7].

Sateeshet et al. discussed low cycle fatigue life of super elastic shape memory thin wires. Experimentally, the various loading conditions such as frequency and effect of amplitude on the low cycle fatigue life of SESMA had also been studied. They found that the SESMA cycled at lower net strain has more fatigue life than the one cycled at higher net strain and the austenitic modulus is largely independent of the frequency. However, the martensitic plateau changes its shape and slope with the change of frequency [8]. The NiTi nanoparticles were observed to pin the grain boundaries to restrict the grain growth and aids in the dispersion strengthening of the nanocomposite. The synthesized materials were characterized in order to investigate their physical, microstructural and mechanical properties. Synthesized materials were characterized for their density and porosity levels, microstructural characteristics, and mechanical response. They also discussed density measurements, microstructural Characterization, coefficient of thermal expansion, mechanical Properties, Density and porosity NiTi nanocomposites, Grain size of NiTi distribution in the Mg matrix, Longitudinal section of pure Mg and Mg-NiTi nanocomposites [6].

The experiments were performed force controlled, taking into account practical actuator conditions from rehabilitation and neuroscience application. The storage modulus and the mechanical loss factor were determined and analyzed over various frequencies for typical temperature courses. They considered differential scanning calorimetry or DSC for the analysis. DSC results of the M5 alloy showed the temperature memory effect for three different heating and cooling rates. For the sake of visualization and comparability the heat flow was normalized Comparison of the temperature dependent moduli of all alloys within the examined frequency range of 1 to 21.5 Hz. Dashed lines were the modeled curves and all alloy compositions and geometries revealed an almost frequency- independent storage modulus, while the mechanical loss factor showed a pronounced dependency on the excitation frequency [9]. Akshat and Sheelam (2017) revealed the best material used for spring is Stainless steel as it can bear high stress and acts as effective spring in suspension system due to its lower deflection in their review. They also find the composite wave springs are more efficient than conventional springs due to low weight of carbon which results in lower weight of vehicle. In his work solid work model of wave spring was used and showed helical springs can be made lighter with more strength by reducing number of coils and increasing the area. Another compression spring was wave Spring in which overall length and operating heights of these springs were less than a normal helical spring due to which they reduce part weight and raw material cost for producing a spring[10].

Problem statement of the present work is given below. The slender 0.004" & 0.008" Flexinol wires were considered for observation of various parameters during their actuation on common platform. The common platform was defined by the Physical-Model (established in previous work and can be seen as “Stress evaluation technique-cum-physical model for intelligent helical sma spring”. The parameters included as average wire temperature, average strain capacity, Avg. scale-load capability and wire-current and voltage during actuation. Basically, Physical-Model comprise of Electro-Mech equipments (previously prepared Instrument) described in my previous paper work i.e. Stress evaluation technique-cum-physical model for intelligent helical SMA spring.

Materials and methodology

Material descriptions

0.004" & 0.008" Flexinol wires was obtained in drawn condition as prescribed by the seller. The smart intelligent helical springs were prepared from thin diameters wires with the help of fixture-cum- spring making tool then heat treatment provided in the furnace at 530^{o}C for 45 min. and then cooled for 16 hr by switch-off the furnace and placed in contact of air upto 6 hours by just opening of the gate of furnace. The smaller diameters are represented here in inches which having dimension in mm equal to 0.1 and 0.2 respectively. The one way shape memory SMA's in the form of NiTi wires of different dimensions have been used in which the nominal composition of 49.2% (Ni) – 50.8 % (Ti) and purchased from USA vai medorah Meditek Pvt Ltd., Gurgaon, India.

Table 1. Specification as received

Length of each wire	1 m	Diameters	0.004" & 0.008" Flexinol
Thermal Expansion Coefficient(Austenite)	11.0×10^{-6} /°C	Thermal Expansion Coefficient(Martensite)	6.6×10^{-6} /°C
Density	6.45 g/cm^3	Specific Heat	0.2 Cal/g*°C
Melting Point	2370 °F (1300 °C)	Thermal Conductivity	0.18 W/cm*°C
Latent Heat of Transformation	578 Cal/g.	Composition	49.2% (Ni) – 50.8 % (Ti)

The SMA material wires of 0.1 mm & 0.2 mm obtained in drawn condition which initially produced by the vacuum induction melting technique as prescribed by seller. The Table 1 represents the various parameters values such as length of each wire, diameters, thermal expansion coefficient (Austenite), thermal expansion coefficient (Martensite), density, specific heat, melting point, thermal conductivity, latent heat of transformation and composition.

Fixture-cum-spring tool making

These are also called spring manufacturing tools which removed the fixtures, clamping devices and wrapping wires. They are made by using the following things as:

Mild steel round bar (0.120kg/feet)

It can be seen from Figure 1, which is made with the help of Autocad software of Autodesk Company Version-2017, The Dimensions of round rod are represented as 8mmx120mm in which diameter equal to 8mm and length equal to 120 mm.

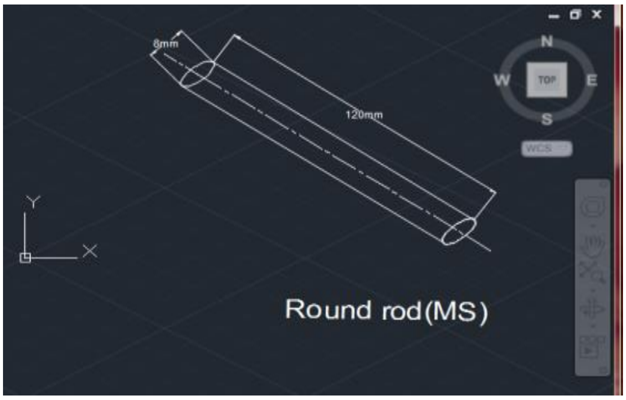


Figure 1. Mild steel round bar

The weight of this used round bar available in kg/feet also equal to 0.120kg (approx.). Here, we applied lower grade-A479 as prescribed by local city seller address as shop no. 3-4, Engg. materials, hardware Chowck, 27 Faridabad. Available Mild Steel Round Bars can be drilled, cut and welded to suit a huge number of applications as supplier mention about own products and said also supply to clients for variety of purposes.

Bench-Vice (Fixed Base)

Here we have used it as a holding device. It has two jaws to hold work piece firmly in place provided. This mechanical device used to secure an object to allow work to be performed on it. Vice have two parallel jaws, one fixed and the other movable. Gripping are available in faces of fixed and movable jaws in terms of knurling. This device used to grip the mild steel round bar and hand operating threading tool was applied to produce various external threads on the periphery of round rod.

Threading Tool (1.25mm)

This tool having the pitch equal to 1.25 mm. External threads are made with the help of a threading die or die-stock. This threading tool consist of mainly two parts as first one threading die and second one die holder. The threading die consists of a cutting body with a chamfer on either side so that it can be applied both-way so it acts as a nut with milled-in chip grooves. The threading die is set in exactly horizontal position on the bevel of the bolt and turned clockwise slowly and with slight pressure from above with right-hand thread. Only when the starting end of the thread is cut and the threading die guides itself. The breaking of chips or chip formation occurred. The die used may be varying in terms of fixed die or movable die but here used tool has fixed die. This is used for single-piece manufacture or with repair work. The manual thread cutting is a necessary working technique in my case due to technical and economical reasons in which other machines cannot use.

Electric cutter (3000rpm/400W)

The manual operated or hand electric cutter is used which moves with 3000 round in one min and working supply in terms of power consumed as 400 watts. The ceramic cutter used here which made of silicon carbide and having 6 inches diameter with a thickness of 1.0mm.The buffing wheel also made of ceramic material and applied to smoothing a work piece's surface using an abrasive and a work wheel or a leather strop. Technically, polishing referred to processes here that used an abrasive which was glued to the work wheel, while buffing used a loose abrasive applied to the work wheel. Here buffing was used on the both side faces of spring tools and face of each tool made right angled during the working.

Drill-Machine (230V/2200rpm)

This machine is mainly used to drill the mild steel with the hole of 1.0mm in the centre-face both side of spring tool. Drilling is a cutting process that uses a drill bit to cut a hole of circular cross-section in solid materials. The drill bit is usually a rotary cutting tool, often multi-point. This Forces the cutting edge against the work-piece, cutting off chips from the work piece means the hole is drilled in work piece. It includes drill chuck with locking key, pulley-based driven, vertical stand with heavy base. The pulley and drill bit rotating in same direction about a vertical axis.

Drill bit (1.0 mm)

Drill is a tool primarily used for making round holes or driving fasteners. Drill bits are cutting tools used to remove material to create holes, almost always of circular cross-section. Drill bit of 1.0 mm used here; drills are used in metalworking fabrication, construction and utility projects. Specially designed versions are made for medicine, space, and miniature applications. Drill bits come in many sizes and shapes and can create different kinds of holes in many different materials. The bit is pressed against the work-piece and rotated at rates from hundreds to thousands of revolutions per minute. This drill bit made of stainless steel material as used in my work.

Images of spring –Tools (Final)

The final Fixture-cum-spring tool can be seen in figure 2. Two wires of 0.1mm and 0.2mm wrapped over the threaded parts and holes provided in these spring-tools.

Figure 2. Fixture-cum-spring tools

Manufacturing of SMA helical spring specimens

0.004" & 0.008" Flexinol are slender or thin diameter wires so first we prepared the helical spring SMA's to know the effect of unique parameters response for its actuation. The relation in the composition of this alloy as 49.2% (Ni) – 50.8 %(Ti) and phase transformation of SMA wire varies from 250-630°C. Wires were heated here above to its critical temperature as per required properties in strain recover rate for the applications in form of mechanics actuators (helical springs) to generate force or displacement. For the accuracy of temperature parameter we have used Infrared Temperature sensor which just emitted red ray on the particular point or target cross-section, then we obtained the value of temperature shows on its screen. The wires were wounded on the two screws of same diameter & having same type of thread. Figure 3, tt can be seen that helical screws have been used. The soldering (Sn/Pb) wire in 60/40 ratio was used as the ends constrained. The screw knob removed initially, so that spring obtained must have same mean coil diameter when measured from any sides. We can use the copper or mild steel constrained because both has critical temperature above 630°C. Moreover copper critical temperature range 900-940°C & mild steel critical temperature range 1510-1537°C.

Final SMA Springs

The annealing done by temperature of muffle furnace for preset-condition by muffle regulator and the temperature maintain at 530°C. Although tolerance of ±2°C was also considered due to the fluctuation exist by auto cut supply for an instant of time with the help of regular. The time of annealing process of the SMA wires 0.1 & 0.2 was 16 hr. Then the normalizing process was also used by just opening the door of muffle furnace but piece was maintained inside of it upto 6 hr. The dimensions were obtained as.

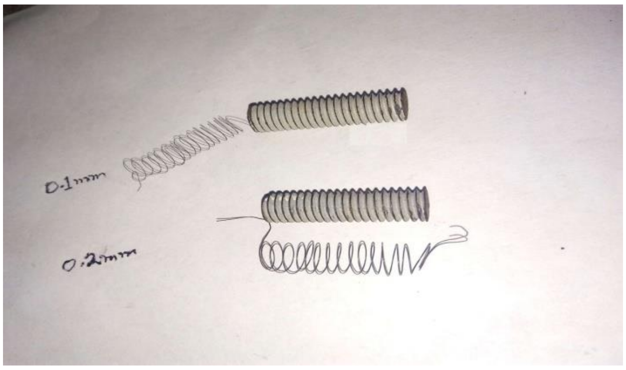


Figure 3. Final SMA Springs

Mean coil diameter of 0.1mm SMA helical spring = 6.5 mm + 0.10 mm=6.6 mm, outer coil diameter of it =6.7 mm and inner coil diameter=6.5 mm. Similarly, Mean coil diameter of 0.2 mm SMA helical spring = 6.5 mm + .02 mm = 6.7 mm, outer coil diameter of it =6.9mm and inner coil diameter=6.5 mm. No. of turn of SMA wire for 0.1 mm diameter obtained as 18 and No. of Turn of SMA wire for 0.2 diameter obtained as 16. The Spring Index of 0.1 SMA Spring$\frac{D_1}{d_1}$=6.6/0.1 =66.0. And Spring Index of 0.2 SMA Spring$\frac{D_2}{d_2}$= 6.7/0.2=67/2=33.50.

Experimental

The previously prepared physical- model has used which discuss in my paper as details mentioned in initially in problem statement. By using this physical-model, first we had evaluated the average scale value in term strain for weight (in gm) and then discussed the behavior of both the 0.2mm and 0.1mm wires during their actuation.

Average scale value

The scale values have been calculated with the help of steel hanger and steel slotted weights. The steel hanger weight was 50 gm, has been used in this work but the slotted weights of each piece also equal to 50 gm. The total 200 gm weight has been applied. The hanger has been placed on socket terminal just simply in the gap of its which is adjustable by turning the cap that present outside and behave like a nut. Placed the slotted weight of 50 gm piece one by one until the weight reached firstly 100, then150 and lastly 200 gm.

Table 2. Average scale value for 'One' gm

Sl. No.	Slotted weight (gm)	Hanging weight (gm)	Avg. Load-Cell Strain or GF value	Atm. Temp (°C)	Difference value	Scale value for 1gm
1	0	50gm	12	29	12	12/50 =0.24
2	50	100g	23.5	29.2	11.5	23.5/100=0.235
3	100	150	36	29	12.5	36/150 =0.24
4	150	200	48.5	29.1	12.5	48.5/200=0.2425
		Avg. scale value for 1 gm =(.24+.235+.24+.2425)/4 = 0.239				

The Avg. scale-value has been calculates as:
Set the initial value strain for load-cell = '0'
Avg. Strain value of hanger = 12
Avg. Strain value of first weight (100gm) = 11.5
Avg. Strain value of second weight (150gm) = 12.5
Avg. Strain value of last weight (200gm) = 12.5
Average Stain value for 50gm (48.5/4=12.125)

Avg. scale-value for 1gm = (Scale value I+ Scale value II+ Scale value III+ Scale value IV)/4 = 0.239.

Observation data during actuation of 0.1mm SMA helical spring

It can be seen from figure 4 that 0.1mm SMA wire was firstly considered the NiTi SMA helical spring for analysis in which one end had attached with socket terminal. Although socket terminal had maintained fixed also on the top jaw of iron stand and so tightened that not tilted during the loading or unloading. Then the NiTi SMA helical spring other end had attached with socket terminal such that other end of SMA helical spring had maintained fixed on the movable jaw of iron stand. Preset length condition of SMA helical spring wire represents the vertical length of spring or we can say the free length of SMA helical spring.

The spring-load value evaluated here with the help of average scale value by multiplying it, for example if '2' was strain in table 3 then value of L_s(spring load value) = 2x0.239 = 0.478. Similarly, all values were evaluated. The various actuations parameters obtained as mentioned in Table 3 for 0.1 mm SMA

Figure 4. 0.1 mm wire testing

Observation data during actuation of 0.2mm SMA helical spring

Similarly, It can be seen from Figure 5 that 0.2mm SMA wire was firstly considered the NiTi SMA helical spring for analysis in which one end had attached with socket terminal.

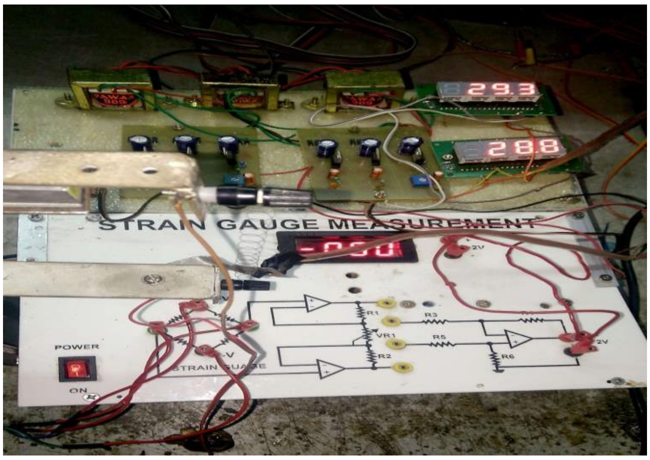


Figure 5. 0.2 mm wire testing

Socket terminal had maintained fixed also on the top jaw of iron stand and so tightened that not tilted during the loading or unloading like 0.1mm wire. Then, same way the NiTi SMA helical spring other end had attached with socket terminal such that other end of SMA helical spring had maintained fixed on the movable jaw of iron stand. Preset length condition of SMA helical spring wire represents the free length of SMA helical spring.

The spring-load value also evaluated here with the help of average scale value by multiplying it, for example if '9.5' was strain in table 4 then value of Ls(spring load value) = 9.5x0.239 = 2.271. Similarly, all values were evaluated. The various actuations parameters obtained as mentioned in Table 4 for 0.2 mm SMA.

Table 3. Observation data of 0.1 mm SMA

Sl. No.	Preset Length (cm)	Voltage Applied (Volts)	Avg. Current in wire (Amp.)	Atm. Temp (°C)	Avg. Wire Temp (°C)	Avg. Load-Cell Strain value	L_s (Spring-load) (gm)
1	14.5	0.5	0	29	29	0	Nil
2	14.5	1	0.04	29.1	30.4	0	Nil
3	14.5	1.6	0.04	29.8	31.2	2	0.478
4	14.5	2	0.07	29.7	32.5	4	0.956
5	14.5	3	0.07	30.2	33.2	4	0.956
6	14.5	5	0.07	30.1	34.1	4	0.956
7	14.5	7.8	0.07	30.7	35.5	4	0.956
8	14.5	9.2	0.07	30.4	38.9	4	0.956

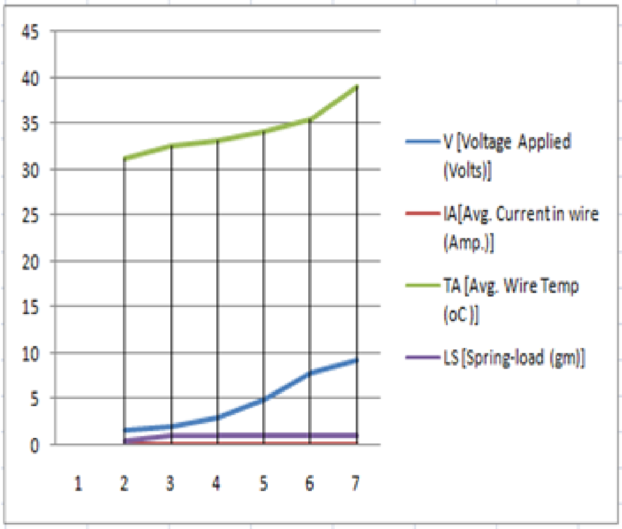
Table 4. Observation data of 0.2 mm SMA

Sl. No.	Preset Length (cm)	Voltage Applied (Volts)	Avg. Current in wire (Amp.)	Atm. Temp (°C)	Avg. Wire Temp (°C)	Avg. Load-Cell Strain value	Ls (Spring-load) (gm)
1	14.5	0.5	0.03	29	29.1	0	Nil
2	14.5	1.0	0.9	29.1	31.4	9.5	2.271
3	14.5	1.6	2.0	29.8	32.8	21	6.91
4	14.5	2	2.7	29.7	34.5	29.5	7.05
5	14.5	3	3.2	30.2	35.2	34.5	8.25
6	14.5	5	3.2	30.1	36.7	34.5	8.25
7	14.5	7.8	3.2	30.7	39.5	34.5	8.25
8	14.5	9.2	3.2	30.4	42.9	34.5	8.25

Results and discussion

For 0.1 mm SMA

The Preset length of 14.5 cm measured between the two terminals of physical- model also known as free length of 0.1 mm sma based helical. The various parameters considered as V, I_A, T_A, and L_S. These variables are taken from table no. 3 for the graphical analysis. So the only '6' readings are considered and nil value column/row values eliminated or not applied. The variation are showed the variation applied voltage (V), average current in wire (I_A), average wire temperature (T_A) and spring load (L_S). Here, particularly focused on the values of V, I_A, and L_S that can be seen in figure 6.



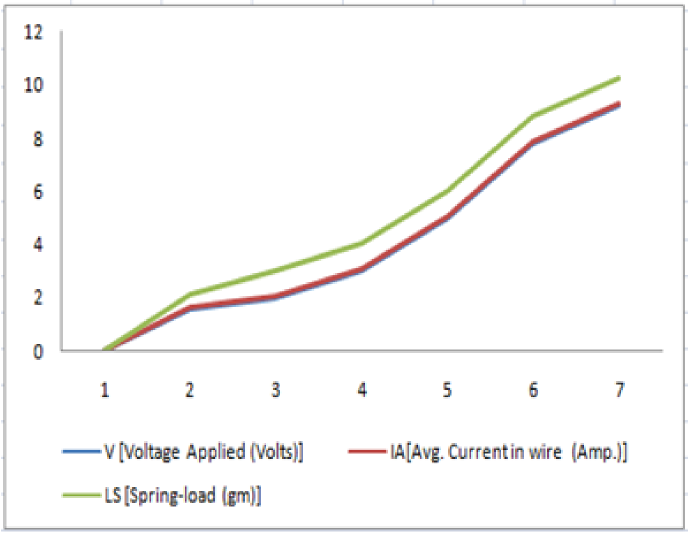


Figure 6. Variation of V, I_A, and L_S for 0.1mm SMA

For 0.2 mm SMA

The Preset length of 14.5 cm measured between the two terminals of physical- model also known as free length of 0.2 mm SMA based helical. The various parameters considered as V, I_A, T_A, and L_S. These variables are taken from table no. 4 for the graphical analysis. So here all '8' readings are considered and no nil value column/row values eliminated or not applied. The variation particularly focused on the values of applied voltage (V), average current in wire (I_A), and spring load (L_S). Here, V, I_A, and L_S values that can be seen in figure 7.

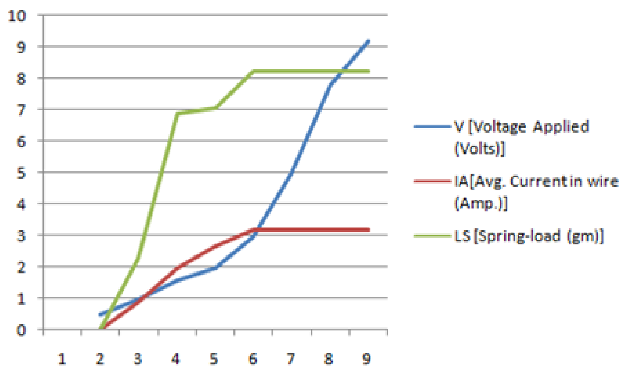


Figure 7. Variation of V, I_A, and L_S

Combined average current variations in 0.1 and 0.2 mm wires

The variation of average current (I_A) for 0.1 mm wire and 0.2 mm wire can be seen in figure 8.

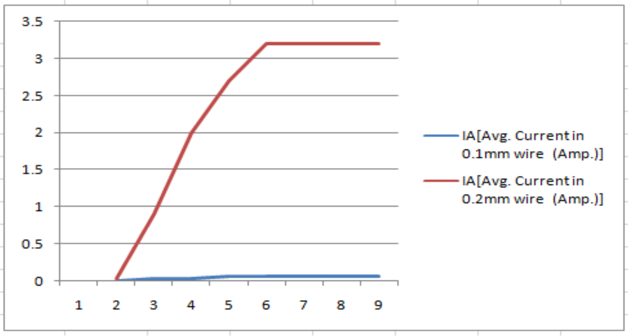


Figure 8. Variation of average current

Combined spring-load (L_S) variations 0.1 and 0.2 mm wires

The variation of spring-load (L_S) for 0.1 mm wire and 0.2 mm wire can be seen in figure 9.

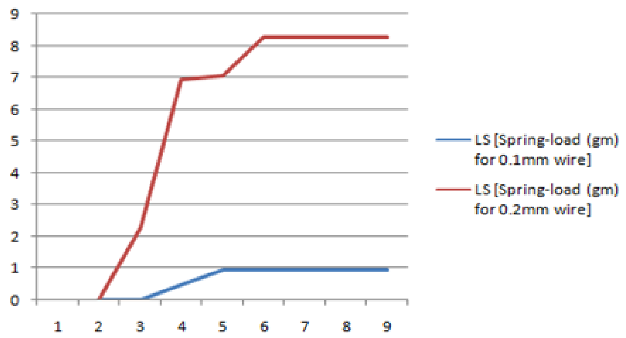


Figure 9. Variation of spring-load

Authors have found the microstructures of NiTi alloy/ Flexinol (after polishing and etching), this was done basically by the microscope which attached to camera and tablet as can be seen arrangement in figure 10. The different positions of Ni and Ti were obtained different in their microstructures that can be seen in above figures 11 and 12.

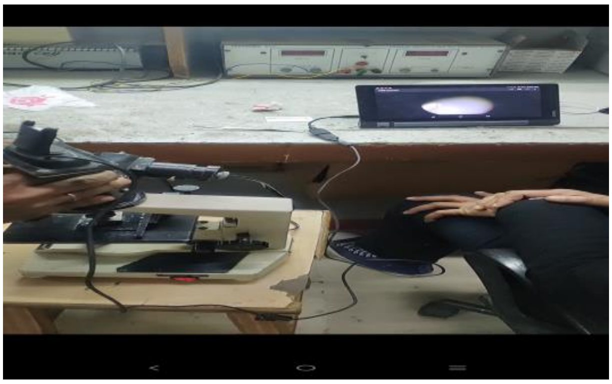


Figure 10. Microscope set up with camera and tablet

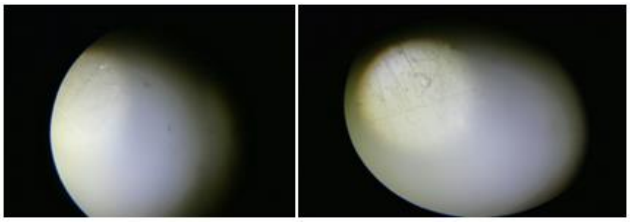


Figure 11. Before annealing of 0.1 and 0.2 mm wires

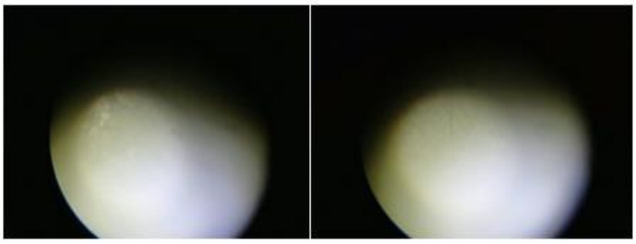


Figure 12. After annealing of 0.1 and 0.2 mm wires

Conclusions

It is evident from experimental results that 0.1 mm SMA based intelligent helical spring having negligible load capacity (< 1gm) under the effect of temperature change by using DC source or DC power supply. But the 0.2 SMA based intelligent having significant value of load capacity under the effect of temperature change by using DC source or DC power supply. Other points includes the initials voltage value (V) obtained was higher in actuation of 0.1mm SMA than 0.2 mm SMA and average current value (I_A) of 0.1 mm SMA obtained very small as compared to 0.2mm SMA. Temperatures response was smooth for the both slender-wires as it increased by increasing the power supply/voltage. This work may help to researchers that are working on NiTi based SMA's as 0.2 mm SMA spring also obtained load capacity which was very small (<10 gm). This work will divert to researchers about toward to study the microstructure behavior of slender-wires (positions of Ni and Ti in their microstructures was different).

Conflict of interest

The authors declare no conflict of interests.

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