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METC143

5/9/2018

Problem Statement: The task is to design a cable that will support a 60-ton vehicle. The cable is 25-foot-long and can have an elastic deformation of no more than 10%. Using the Modulus of Elasticity for various metals design a cable. Use standard cable diameter sizes listed below (units are inch):

Introduction: To solve this problem, like any other problems I need to first identified the issue that I would like to solve. So, since I'm trying to identify which material to use I need to know their characteristics and properties. So, I first made a table of the component elements of each metal using Matweb as illustrated in table 1. Then, after obtaining the table 1 below, I proceed to the conversion of the data that I already have to a preferable unit. Secondly, I use the 10% deformation that is in the problem statement to determine the change in length. Then I calculated the strain, stress, area and diameter of the material that are being analyzed (1045 Steel, 2014-T6 Aluminum, Copper, Titanium TI-6AI-4V (Grade 5), Annealed). After, I calculated the stress based on all common diameter sizes given in Project Instructions. Then, I obtain a plot of Stress Vs Diameter. Then I proceed the fatigue analyzes where I calculated the stress generated for aluminum and steel in order to find the maximum number of cycles for selected diameter that will survive based on the SN curve. Finally I calculate the thermal expansion of each materials and plot them in the curve.

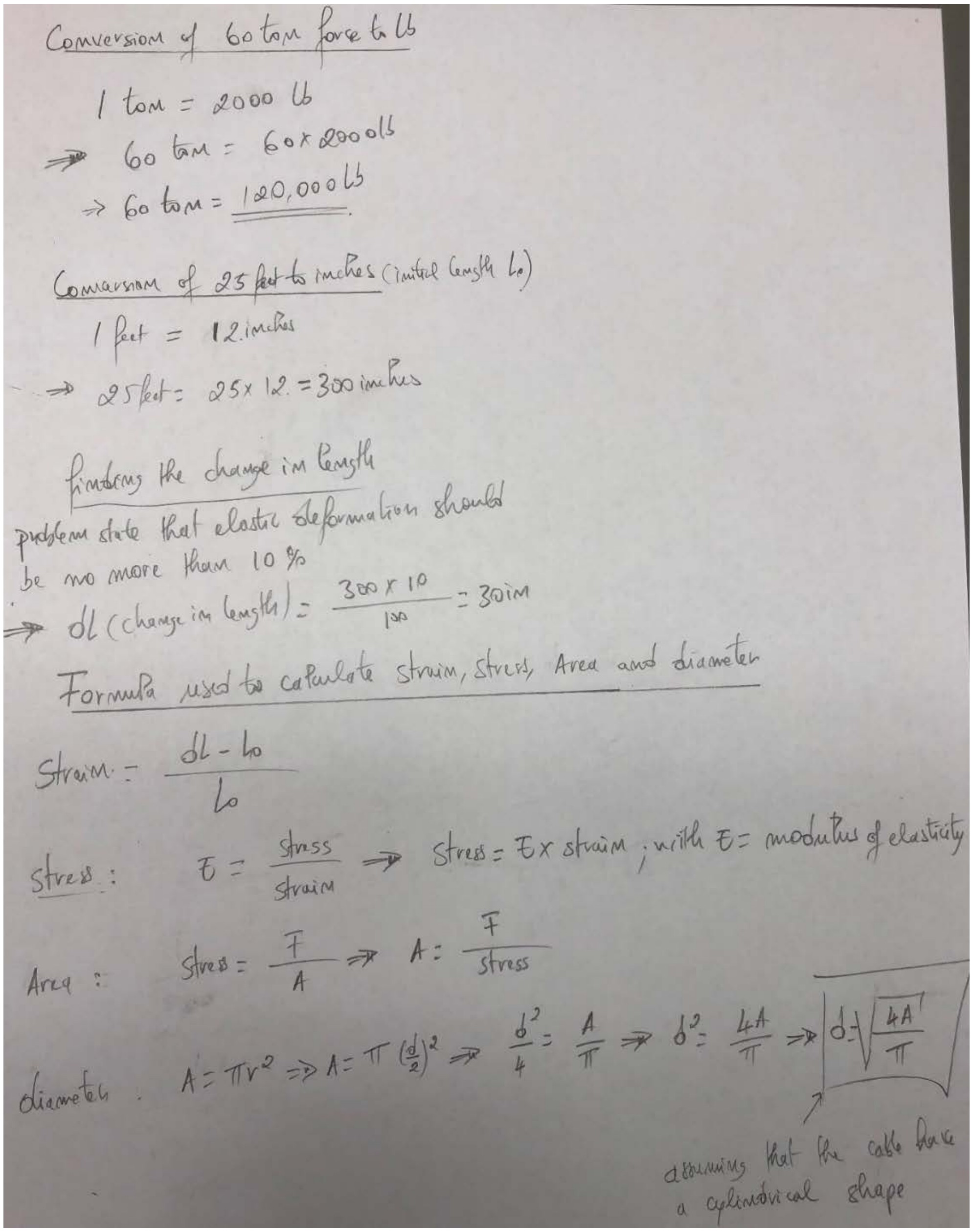
Results:

Part I

1) Material Information

Table 1: component elements properties of material to analyze

Component Elements Properties	1045 Steel	2014-T6 Aluminum	Copper	Titanium Ti-6Al-4V (Grade 5), Annealed
Carbon, C	0.42 - 0.50 %			<= 0.080 %
Iron, Fe	98.51 - 98.98 %	<= 0.70 %		<= 0.40 %
Manganese, Mn	0.60 - 0.90 %	0.40 - 1.2 %		
Phosphorous, P	<= 0.040 %			
Sulfur, S	<= 0.050 %			
Aluminum, Al		90.4 - 95 %		5.5 - 6.75 %
Chromium, Cr		<= 0.10 %		
Copper, Cu		3.9 - 5.0 %	100%	
Magnesium, Mg		0.20 - 0.80 %		
Silicon, Si		0.50 - 1.2 %		
Titanium, Ti		<= 0.15 %		87.725 - 91 %
Zinc, Zn		<= 0.25 %		
Hydrogen, H				<= 0.015 %
Nitrogen, N				<= 0.030 %
Oxygen, O				<= 0.20 %
Vanadium, V				3.5 - 4.5 %



Conversion of 60 ton force to lb

1 ton = 2000 lb

⇒ 60 ton = 60 × 2000 lb

⇒ 60 ton = 120,000 lb

Conversion of 25 feet to inches (initial length L_o)

1 feet = 12 inches

⇒ 25 feet = 25 × 12 = 300 inches

finding the change in length

problem state that elastic deformation should be no more than 10 %

⇒ dl (change in length) = $\frac{300 \times 10}{100}$ = 30 in

Formula used to calculate strain, stress, Area and diameter

Strain = $\frac{dL - L_o}{L_o}$

stress : $E = \frac{stress}{strain}$ ⇒ stress = E × strain ; with E = modulus of elasticity

Area : stress = $\frac{F}{A}$ ⇒ $A = \frac{F}{stress}$

diameter : $A = \pi r^2 \Rightarrow A = \pi \left(\frac{d}{2}\right)^2 \Rightarrow \frac{d^2}{4} = \frac{A}{\pi} \Rightarrow d^2 = \frac{4A}{\pi} \Rightarrow d = \sqrt{\frac{4A}{\pi}}$

assuming that the cable have a cylindrical shape

Figure 1: Conversion and calculation of data

1) Calculation of Required Diameter Based on Modulus of Elasticity

Table 3: calculation for the proposed diameter of the cable

Material to be analyzed	modulus of elasticity	force (lb.)	L_0 = initial length (in)	dl (change in length)	strain	stress	Area (in^2)	Diameter (in)	proposed diameter (in)
Aluminum	10,000,000	120000	300	30	0.1	1000000	0.12	0.39	1/2
Steel	30,000,000	120000	300	30	0.1	3000000	0.04	0.23	1/4
Copper	15,000,000	120000	300	30	0.1	1500000	0.08	0.32	3/8
Titanium	12,000,000	120000	300	30	0.1	1200000	0.1	0.36	3/8

Table 4: calculation of the strength of the design cable with proposed diameter

	proposed diameter (in)	radius (in)	area (in^2)	stress (lb/in^2)
Aluminum =	1/2	1/4	0.196349541	611154.9815
Steel	1/4	1/8	0.049087385	2444619.926
Copper =	3/8	1/5	0.110446617	1086497.745
Titanium =	3/8	1/5	0.110446617	1086497.745

2) Stress Calculation based on all common diameter sizes

Table 5: Stress Calculation based on all common diameter

	Stress Calculations Based on all common diameter size			
diameter	radius	Area	force	Stress
2	1	3.141592654	120000	38197.18634
1 3/4	7/8	2.405281875	120000	49890.20257
1 1/2	3/4	1.767145868	120000	67906.10905
1 1/4	5/8	1.22718463	120000	97784.79704
1	1/2	0.785398163	120000	152788.74537
3/4	3/8	0.441786467	120000	271624.43621
1/2	1/4	0.196349541	120000	611154.98147
3/8	1/5	0.110446617	120000	1086497.74484
1/4	1/8	0.049087385	120000	2444619.92589
3/16	3/32	0.027611654	120000	4345990.97936
1/8	1/16	0.012271846	120000	9778479.70357
1/16	1/32	0.003067962	120000	39113918.81426
1/32	1/64	0.00076699	120000	156455675.25706
1/64	1/128	0.000191748	120000	625822701.02823

3) Stress Vs Diameter plot

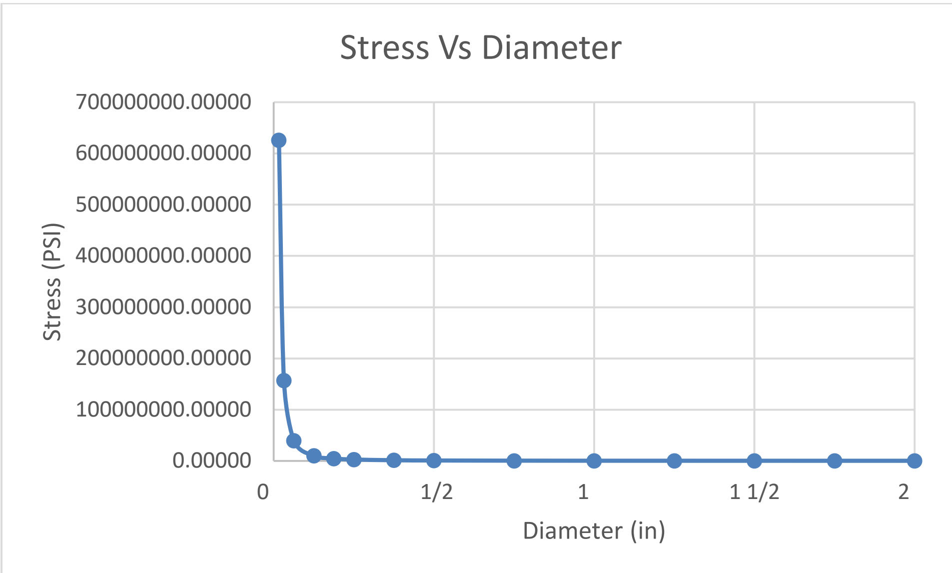
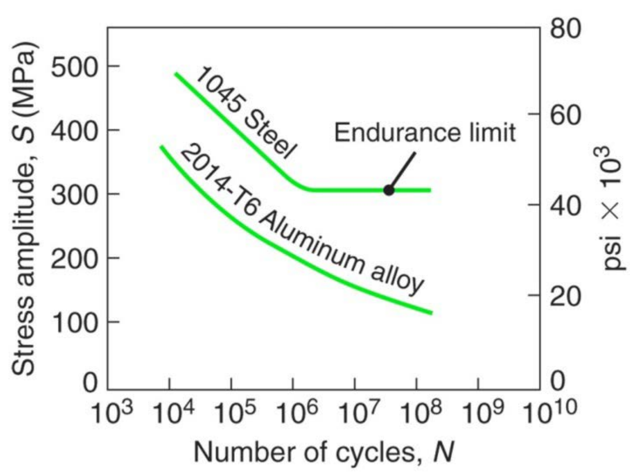


Figure 2: Plot of Stress Vs Diameter

Part II :

Fatigue Analysis:



2a)

Stress calculation for selected diameter for steel:

Table 6: Calculation of stress for steel

diameter	radius	area	force	stress
1/4	1/8	0.049087	120000	2444619.926

Stress Calculation for selected diameter for aluminum

Table 7: Calculation of stress for aluminum

diameter	radius	area	force	stress
1/2	1/4	0.19635	120000	611155

Based on my calculation, the maximum number of cycle for steel will be less than 10^3 psi and for aluminum it will be also less than that which is not normal. So, by changing my diameter for steel to ½ and for aluminum to ¼ I am able to obtain: a value of 611155 (psi) for steel and 244619.926 (psi) for aluminum which are more reasonable value. Consequently, based on those values the maximum number of cycle for steel is about 10^5 cycles and for aluminum it is about 10^7 cycles.

Thermal Analysis:

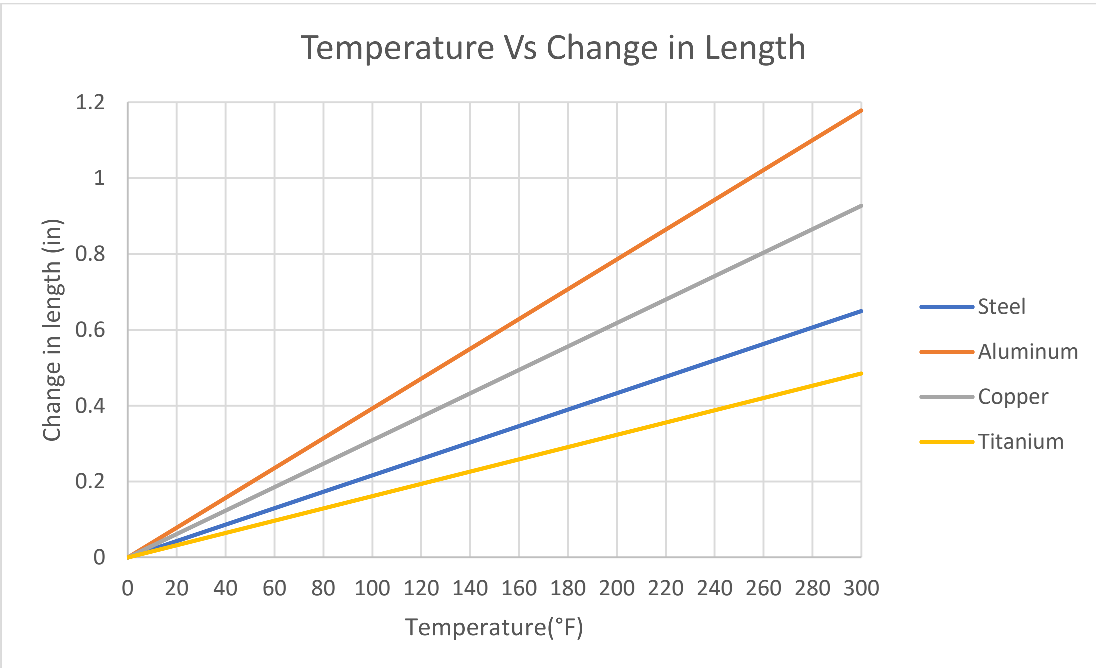
1) Calculation of thermal expansion of each material

Table 8: Thermal expansion for each material

Thermal Expansion for each material

		Steel	Aluminum	Copper	Titanium
temperature	length(in)	thermal expansion	thermal expansion	thermal expansion	thermal expansion
0	0	0	0	0	0
20	30	0.04332	0.0786	0.0618	0.03234
40	300	0.08664	0.1572	0.1236	0.06468
60	300	0.12996	0.2358	0.1854	0.09702
80	300	0.17328	0.3144	0.2472	0.12936
100	300	0.2166	0.393	0.309	0.1617
120	300	0.25992	0.4716	0.3708	0.19404
140	300	0.30324	0.5502	0.4326	0.22638
160	300	0.34656	0.6288	0.4944	0.25872
180	300	0.38988	0.7074	0.5562	0.29106
200	300	0.4332	0.786	0.618	0.3234
220	300	0.47652	0.8646	0.6798	0.35574
240	300	0.51984	0.9432	0.7416	0.38808
260	300	0.56316	1.0218	0.8034	0.42042
280	300	0.60648	1.1004	0.8652	0.45276
300	300	0.6498	1.179	0.927	0.4851

2) Plot of Temperature Vs Change in length for material



<u>Figure 3:</u> Temperature Vs Change in length graph for steel, aluminum, copper and titanium

<u>Conclusion:</u>

<u>1)</u> The size diameter that we calculated with the modulus of elasticity seems all wrong for every materials and would not be favorable to chose for the design of a cable. The reason for that is because their stresses are not high enough and the material would break easily for just a small number of cycle.

<u>2)</u> Among the 4 materials analyzed, I would pick steel but with a greater diameter. The reason for that is because it does not break easily and therefore will be more able to resist any load we exposed to the material. In addition to that, the smallest diameter that we can use for steel is ¼ inches; However It is preferable to use a diameter of ½ inches in order to have a maximum number of cycle of about 10^5 cycles which will assure that the cable resist to load for a longer period of time or cycles.