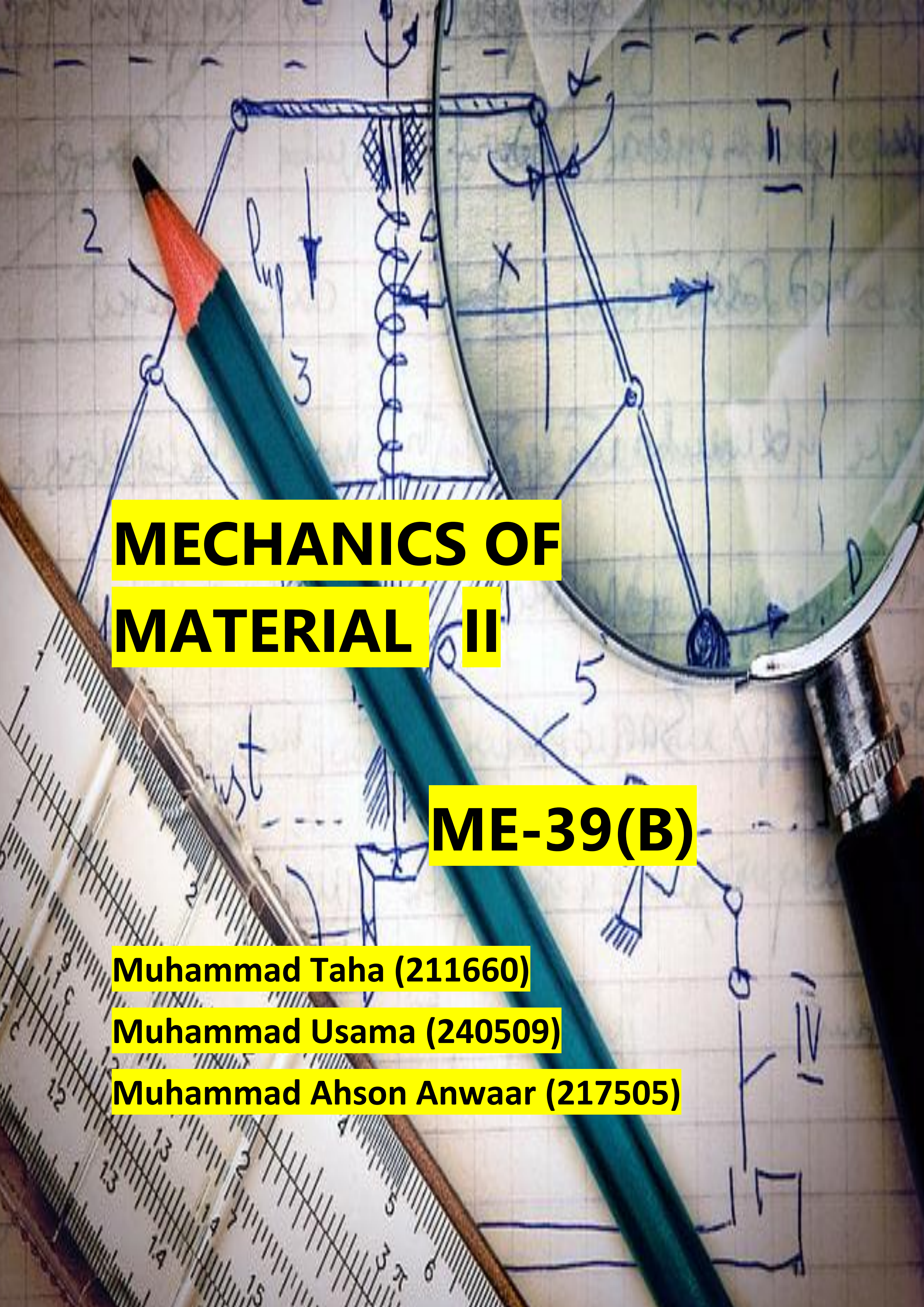

MECHANICS OF MATERIAL II

ME-39(B)

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PROJECT REPORT

Project:

Use Strain Gauges on a metal part and determine the internal stresses and applied loading using these measurements. Compare these experimental values with theoretical values.

Objective:

To use strain gauges on manufactured product and determine the strain produced in a body and the respective internal loads.

Introduction

Strain is a measurable deformation, when combined with a materials characteristic modulus, the applied force can be extracted. This is the principal of the strain gauge. This report presents a system for the estimation of strain by means of strain-gauges, Use Strain Gauges on a metal part and determine the internal stresses and applied loading using these measurements. The measured signal conditioning is performed by means of a strain gauge module BF-350. The aim of this report is to determine the strain on a mild steel turn buckle using strain gauge in an Arduino controlled arrangement. Compare these experimental values with theoretical values where the data acquisition is done by using an Arduino Uno board, because of the minimal effort and the simple control This report represents the steps we have used to determine strain. We have successfully determined the strains using logical reasoning and appropriate assumptions, all of which are discussed in subsequent sections. Also, from this project we have learned calibration of our amplifier module. Calibration of amplifier is done using data sheet and correctness of the calibration is not tested yet, however the outcomes are genuinely precise.

Apparatus:

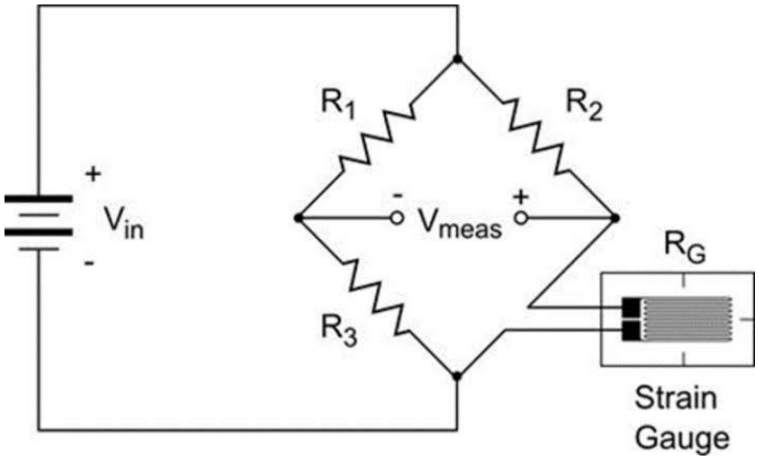
- Strain Gauges
- Metal Part (Turn Buckle)
- Connecting Wires
- Scotch Tape and Elfy
- Arduino (UNO)
- BF350 Module
- Bread Board
- Weights
- Arduino Software (IDE)
- Laptop

All the pictures of Apparatus and setup are shown in Anx-A

Principle:

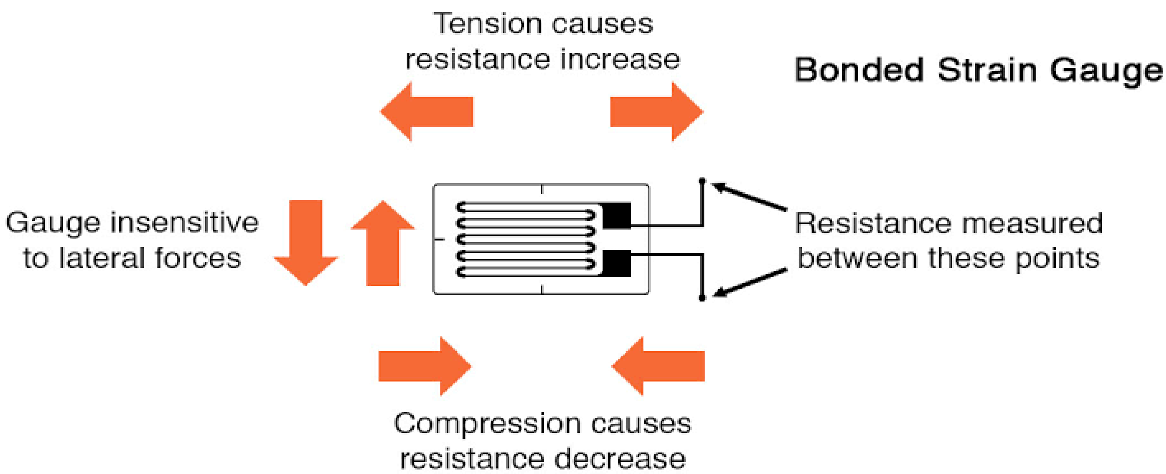
Strain gauges are used in conjunction with wheat-stone bridge. A wheat- bridge usually has 4 resistors of equal resistance connected in a diamond shape. Under normal circumstances, this arrangement is supposed to give zero deflection across the voltage measuring device (e.g. galvanometer). Any change in voltage will result in the deflection of the voltage measuring needle from its mean position. Similarly, the wheat-stone apparatus also uses a potentiometer. This 'potentiometer' allows for bringing the needle of a galvanometer to zero to maintain balance condition (i.e. when the deflection is zero).

In strain measurement, one or more of the four resistors are replaced with a strain gauge, which has its own in-built resistance. This strain gauge is attached with the specimen which measures the extension or compression of the body directly.



Working of a Strain Gauge:

Most commonly used strain gauges have electrical wires that change their resistance when they undergo deformation. This change in resistance is measured in the form of voltage change across a voltage measuring device via wheat-stone bridge. This deformation of electrical wires may be due to the deformation or change in length of the specimen to which the strain gauge is attached.



Working of Module BF 350:

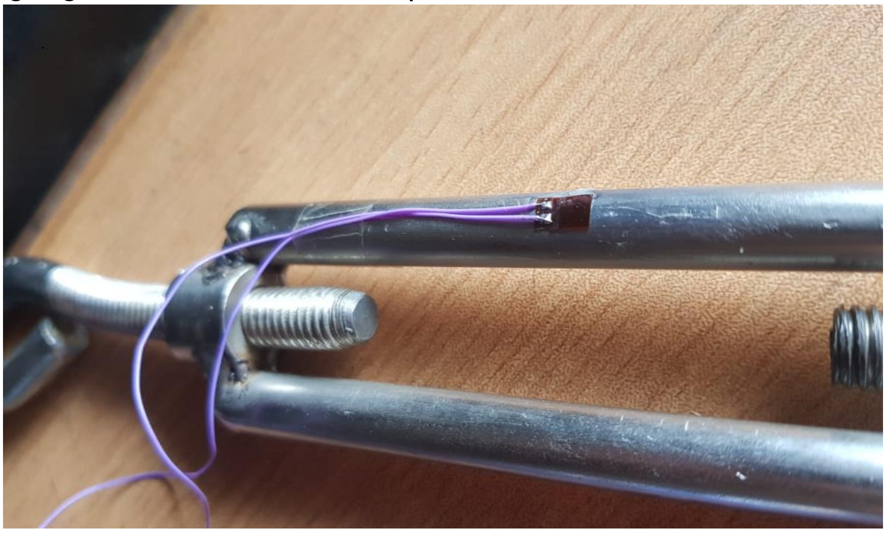
The BF 350 module is an electronic circuit mounted on a PCB Board. This circuit contains an amplifier, a wheat-stone bridge, a potentiometer and other accessories necessary for strain measurement. The resistors of this wheat-stone bridge had resistances of 350 ohm each. A voltage amplifier is also present as it amplifies the small voltage difference given by the strain gauge. The potentiometer is used for establishing balance condition in the wheat-stone circuit. Subsequently, the module has ports for making connections with the strain gauge via breadboard and also directly with Arduino.

Role of Arduino:

It is a micro controller that has several uses in electronics. Here we will be using it translate the output of the strain gauges via BF 350 through the Arduino onto the Arduino Software in the PC. This will give us our readings in terms of voltage. The programming required for this is available on the internet. Calibration of BF 350 can also be done through it.

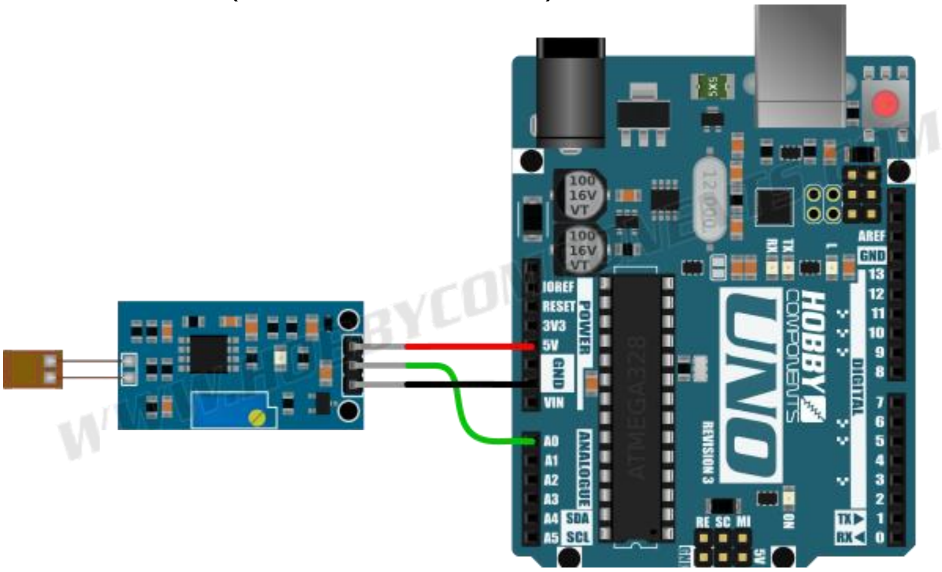
Procedure:

- The specimen used for strain measurement was our project of our course “ME-221: Manufacturing Processes”. The specimen was a “Turn Buckle”.
- The material used for the manufacturing of turnbuckle was mild steel.
- A strain gauge was attached to the specimen as shown.

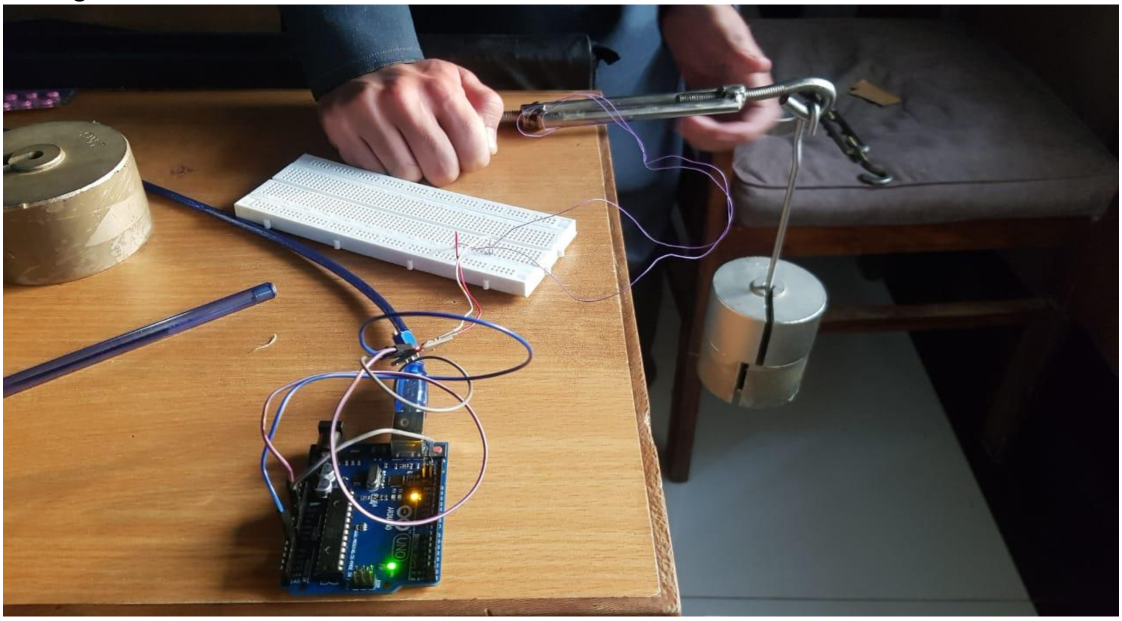


- Sand paper was used to scratch the area where the strain gauge was to be attached so that the strain gauge is attached to the part fully. Sand paper smoothens the surface of the cylinder and help achieves more accurate results due to better adhesiveness of strain gauge on its surface.
- The strain gauge was attached to specimen by means of elfy and scotch tape.
- Later two connecting wires were soldered with the gauge so that it could be used in an electric circuit.
- The wires were connected to a breadboard. From there, connections were made with the BF-350 module. This module contained a wheat-stone bridge, an amplifier and a potentiometer.

- Connections were made from the module to the Arduino (UNO) and from there to the PC (Arduino Software IDE). The connections are shown as

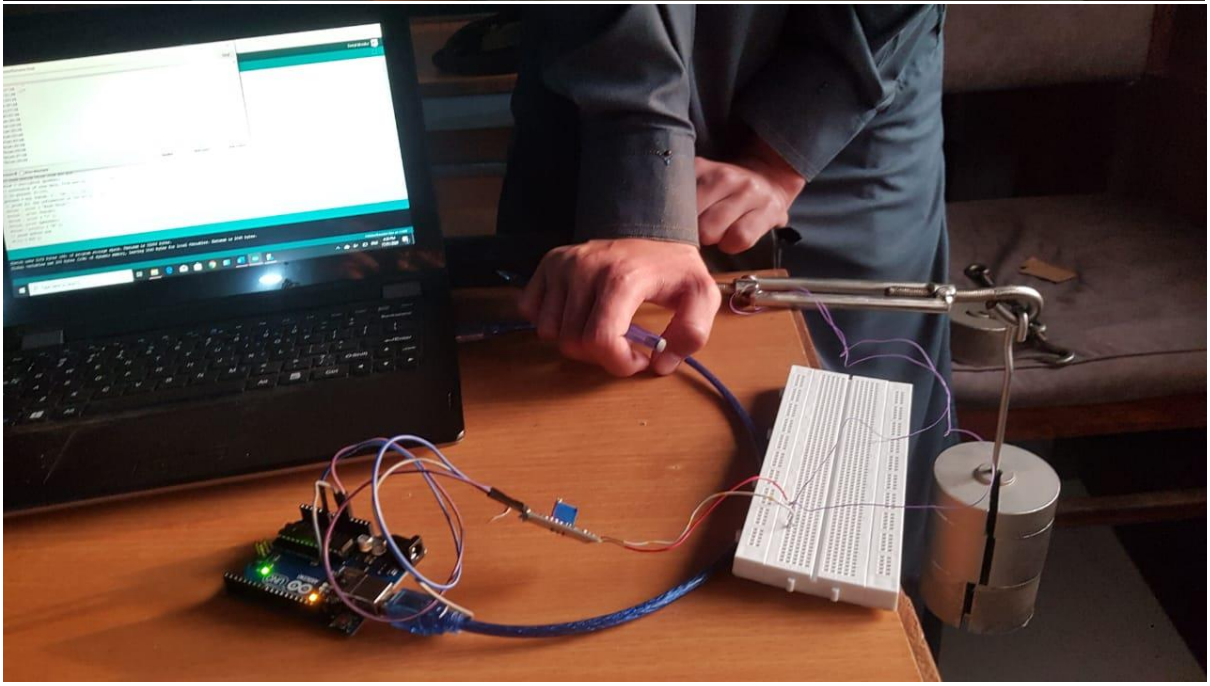


- The turn buckle was arranged as shown in the picture. This arrangement was chosen as the strain gauges showed no voltage change in the vertical position of the buckle. The reason for this was that the BF-350 module can only measure compressive strain values so it was decided that compressive bending stress be applied onto the strain gauge. Here the strain gauge is facing downwards.



- In this horizontal position, the strain gauge showed adequate voltage change.
- Loads or weights were borrowed from the dynamics lab. A maximum load for 5 kg was applied. The loads were first applied in ascending order from 1 kg to 5kg and then in descending order from 5kg to 1 kg. Readings were noted at all loads.

- These readings were being displayed on the Arduino Serial Monitor.
- Some load was applied initially and was used for the calibration of the apparatus.
- These readings were then converted into strain as shown in the calculations.
- The strains were then converted to stress.
- Theoretical stresses were calculated which were then compared with those of the experimental stresses and the error was calculated.



Observations/Problems Encountered/Learning:

- Performing the experiment was a tedious task. At least, 5 strain gauges of cost Rs. 150 were wasted during the procedure.
- The first obstacle was to paste the strain gauge. The strain gauge does not easily adhere to mild steel. 1 strain gauge was broken during this process.

Then, the surface of the turnbuckle was prepared and then the strain gauge was adhered with the help of elfy, tweezers and scotch tape.

- At first, we thought that we would first solder the strain gauge and then adhere it onto the turnbuckle, but that was an impossible task. We learnt that we should first paste the strain gauge and then solder it.
- The most difficult part was to solder the strain gauges. These strain gauges were very small in size. At first, we thought it was an easy task and tried to solder it ourselves, but after burning and breaking 5 strain gauges, we decided that this task should be done by a professional. Finally the strain gauges were soldered by a solderer from College Road.
- At first, we thought of using the lab's apparatus to calculate strain. But when we connected our strain gauge to it, it showed infinite deflection. At first, the reason was unknown, but on looking closely, we came to know the reason. We measured the resistance of all the resistors of the Wheatstone bridge and came to know that all of the resistances were of 120 ohms and that only a BF-120 strain gauge can be used with it. We had a BF-350 strain gauge due to which it showed infinite deflection even when no load was applied. BF-120 strain gauge was very rare in the market so our only option was to convert the resistance of BF-350 into 120 ohms. For this purpose, a 183 ohms resistor was to be connected in parallel with the BF-350 strain gauge and the combined parallel resistances (which combined to 120 ohms) to the apparatus. This would have given us the change in strain values for the change in resistance of the parallel combination. Now, this strain was to be converted into the individual strain resistance of the BF-350 module which was again a long procedure. Thus, we decided not to use this apparatus and use a more convenient approach that is, measure using Arduino.
- The calibration of the module was very difficult. For the calibration, we had to search through all the datasheet of the BF-350 module to infer as to what was the meaning of the values that were being shown on the Arduino serial monitor. We came to know that these values were the amplified voltage values of the Wheatstone bridge. From data sheet of "LM-358D" we came to know that the circuit has a gain of "100 dB". The calibration's calculations are present in relevant section.
- We came to know that the BF-350 module does not give change in values for tensile loads. First, we applied tensile load on our turnbuckle but there was no change, then we applied tensile bending load, there was still no change, but when we applied compressive loads, the module showed change in values. Thus, we used the setup as shown in the procedure to calculate compressive bending stress.
- However, the group overcame all obstacles and the project was completed in time.

Code used in Arduino for measuring amplified voltage of the in-built Wheatstone bridge of BF-350 module:

```
// Strain gauge module BF350-3AA

// set the pin
# define pinOut A0
// variables for saving results
int value = 0 ;
int percent = 0 ;

void  setup () {
   // start serial communication
  // at 9600 baud
  Serial . begin ( 9600 );
}

void  loop () {
   // read analog value from set pin
  value = analogRead (pinOut);
  // conversion of read data, from analog (0-700) range
  // to percent (0-100)
  percent = map (value, 0 , 700 , 0 , 100 );
  // print all the information on the serial line
  Serial . print ( "Read Value:" );
  Serial . print (value);
  Serial . print ( "|" );
  Serial. print (percent);
  Serial . println ( "%" );
  // pause before new
  delay measurement ( 500 );
}
```

CALCULATIONS:

Readings

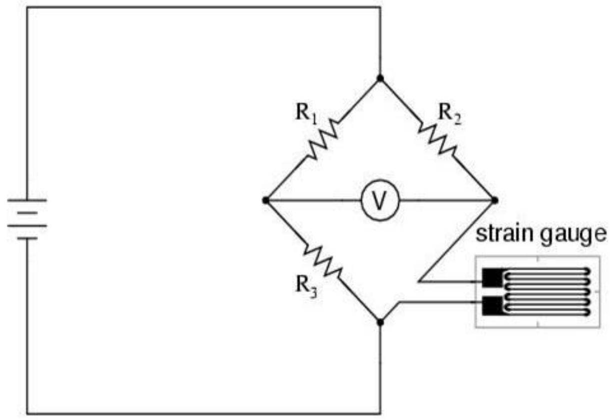
Load applied (in kg)	Value shown on Arduino
1	22
2	48
3	67
4	84
5	110

These values are the averaged values of the values shown on Arduino. The screenshots of these values are shown as Anx-A.

To calculate strain, the strain gauge is to be connected to a Wheatstone bridge and from the bridge voltage, the change in resistance is calculated and then the respective strain. The strain is calculated using:

$$\frac{V}{V_{input}} = \frac{\mathrm{K}\epsilon}{4+2K\epsilon}$$

Where V=Wheatstone bridge voltage as shown
V_{input} = the external input voltage which is provided by Arduino and is 5 V
K is the strain gauge factor which for our strain gauge BF-350 is 2 (from datasheet)



The Wheatstone bridge voltage (here shown as V) is at first zero at the balanced position, i.e; $\frac{R_1}{R_2} = \frac{R_3}{R_4}$(here R_1=R_2=R_3=$R_{strain\ gauge}$=350 Ω). If the voltage is not zero, it is brought to zero with the help of potentiometer. Since there is a small resistance change in the resistance of strain gauge upon applying loads, the corresponding Wheatstone bridge voltage change is also very small, In order to get readable voltages, this voltage is amplified by using a LM358 voltage amplifier which has a gain of 100 db. All of these components (amplifier, Wheatstone bridge with mentioned 3 resistors and a space for the fourth BF-350 strain gauge resistor, and a potentiometer are fixed onto the BF-350 strain gauge module (shown in the apparatus)

Conversion of Voltage shown on Arduino Serial Monitor to the voltage before amplification for strain calculation:

Gain = 100db (using data sheet of LM358 amplifier)

Gain of an amplifier is defined as

$$\text{Gain} = 20 \log_{10} \left(\frac{V_{amplified}}{V_o}\right)$$

Here V_o is the Wheatstone bridge voltage before amplification upon which our strain depends.

V_o= Actual Voltage

$V_{amplified}$= the voltage shown on Arduino Serial Monitor

Equating the above two equations

$$100 = 20 \log_{10} \left(\frac{V_{amplified}}{V_o}\right)$$

$$5 = \log_{10}\left(\frac{V_{amplified}}{V_o}\right)$$

$$V_o = \left(\frac{V_{amplified}}{10^5}\right)$$

Using this formula, putting values of Arduino we convert our Arduino's readings into actual Wheatstone bridge voltage as:

Arduino's Reading ($V_{amplified}$)	**$V_o=\frac{V_{amplified}}{10^5}$**
22	2.2 x 10-4
48	4.8 x 10-4
67	6.7 x 10-4
84	8.4 x 10-4
110	1.10 x 10-3

Conversion of Voltage to Strain:

Solving the Wheatstone bridge (shown above) with KVL and KCL;

$$V_o = \left(\frac{R_3}{R_3 + R_4} - \frac{R_2}{R_1 + R_2}\right)V_{in}$$

Now, the resistance R_4 is the resistance of strain gauge which changes by ΔR
Also, in our case, here $R_1=R_2=R_3=R=350\ \Omega$
When the bridge was balanced and no load was applied, R_4 was also 350 Ω=R, after applying load, R_4 becomes $R_4=R+\Delta R$
putting $R_1=R_2=R_3=R$ and $R_4=R+\Delta R$ in the above equation

$$V_o = \left(\frac{R}{2R + \Delta R} - \frac{1}{2}\right)V_{in}$$

$$V_o = \left(\frac{\frac{\Delta R}{R}}{4 + 2\frac{\Delta R}{R}}\right)V_{in}$$

By the definition of gauge factor we know that

$$K = \frac{\Delta R\ /\ R}{\varepsilon} \Leftrightarrow \frac{\Delta R}{R} = K\varepsilon$$

Putting the value of $\frac{\Delta R}{R}$ in the above equation of V_o

$$\frac{V_o}{V_{in}} = \frac{K\epsilon}{4+2K\epsilon}$$

Where V_o=Wheatstone bridge voltage as calculated above
V_{in} = the external input voltage which is provided by Arduino and is 5 V
K is the strain gauge factor which for our strain gauge BF-350 is 2 (from datasheet)
ϵ= Strain
Re arranging:

$$\epsilon = \frac{4V_o}{K(V_{in} - 2V_o)}$$

Putting values for K=2 and V_{in}=5 V

$$\epsilon = \frac{4V_o}{2(5 - 2V_o)}$$

Now putting the individual values of V_o from the above table to calculate strain for each load applied

Load	**V_o**	**$\epsilon = \frac{4V_o}{2(5-2V_o)}$ (με)**
1	2.2×10^{-4}	88.0077
2	4.8×10^{-4}	192.0369
3	6.7×10^{-4}	268.0718
4	8.4×10^{-4}	336.1129
5	1.10×10^{-3}	440.1937

Conversion of Strain to Stress:

Using generalized Hooke's law:

$$\epsilon_x = \frac{1}{E}(\boldsymbol{\sigma}_x - v(\boldsymbol{\sigma}_y + \boldsymbol{\sigma}_z)$$

Here $\boldsymbol{\sigma}_z = 0$, since there is no load on the outward surface where the strain gauge is attached. Also $\boldsymbol{\sigma}_y = 0$, since there is no stress in this direction. E=200 GPa for mild steel (This is the material used in manufacturing). Thus

$$\epsilon_x = \frac{1}{E}(\boldsymbol{\sigma}_x)$$

$$\boldsymbol{\sigma}_x = \mathrm{E}\epsilon$$

Putting the value of E

$$\boldsymbol{\sigma}_x = 200 \times 10^9 \times \epsilon$$

Now calculating stress for each value of load using the strain values of the above table

Load (kg)	**ϵ (με)**	**σ (MPa)**

1	88.0077	17.6015
2	192.0369	38.4074
3	268.0718	53.6144
4	336.1129	67.2225
5	440.1937	88.0387

Theoretical Stress:

The only stress being applied here is the bending stress (shear stress is also being applied but we do not calculate it since the strain gauge only calculate normal stresses). The load was applied to produce a bending (compressive) stress at the location where the strain gauge was attached (because the BF-350 module only records compressive loads). The loads were all applied at a distance of 15 cm from the strain gauge. Thus the moment producing the bending stress can be written as:

M=F x D
here F=load applied
D=distance from the strain gauge=15 x 10^{-2} m
so, M= (15 x 10^{-2}) (F) Nm

The diameter of the rod (where the strain gauge was attached) was measured to be 9mm. So the radius is r= 4.5mm

$$I = \frac{\pi}{4} r^4 = \frac{\pi}{4}\left(\frac{4.5}{1000}\right)^4 = 3.2206 \times 10^{-10}\ m^4$$

Since the strain gauge was attached at the outer surface of the rod the distance of the neutral axis of the rod (centre of the rod) to the strain gauge is equal to its radius so

y=r= 4.5mm

Now, bending stress= $\boldsymbol{\sigma} = \frac{\boldsymbol{My}}{\boldsymbol{I}}$

Putting values of M, y and I,

$$\boldsymbol{\sigma = F \times \frac{15 \times 10^{-2} \times \frac{4.5}{1000}}{3.2206 \times 10^{-10}}}$$

$$\boldsymbol{\sigma = F \times 2095867.563\ (Pa)}$$

Now putting values for individual loads in this equation to get stresses

Load (kg)	**Load F (N)**	**σ (MPa)**
1	9.81	20.5604
2	19.62	41.1209

3	29.43	61.6813
4	39.24	82.2418
5	49.05	102.8023

Comparison of Experimental and Theoretical Stresses:

Load (kg)	$\sigma_{Experimental}$ **(MPa)**	$\sigma_{Theoretical}$ **(MPa)**	**Error %**
1	17.6015	20.5604	14.39
2	38.4074	41.1209	06.60
3	53.6144	61.6813	13.07
4	67.2225	82.2418	18.26
5	88.0387	102.8023	14.36

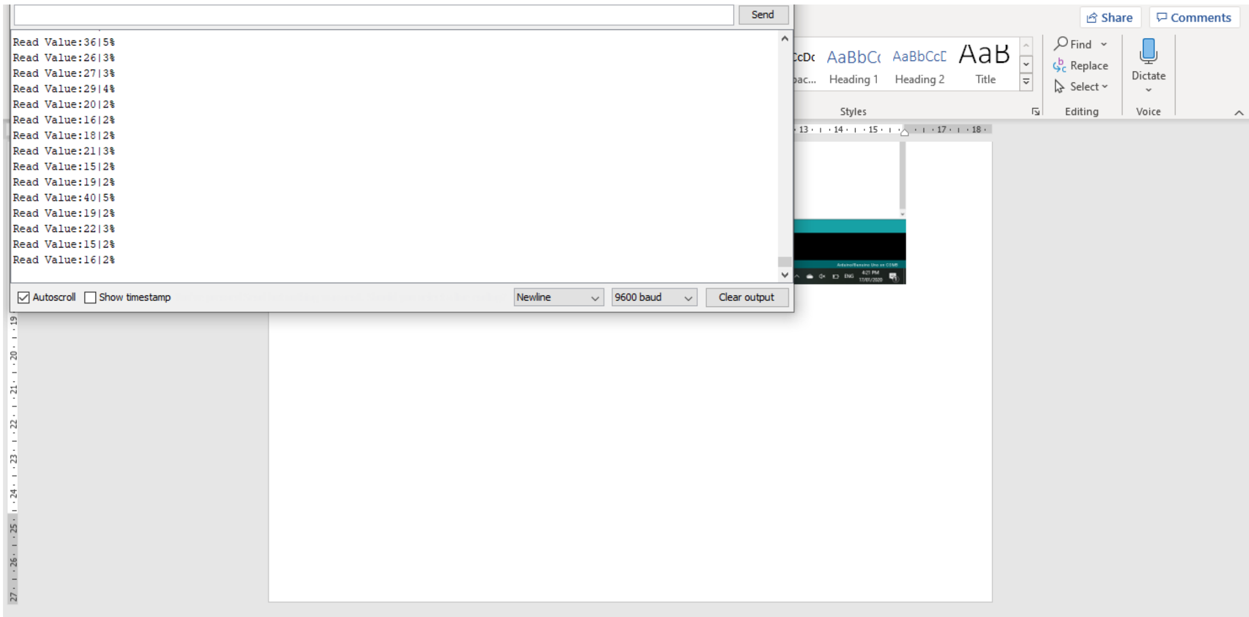
The error was caused due to some strain hardening during a little forging and due to electroplating (nickel) of the work part.

Conclusion

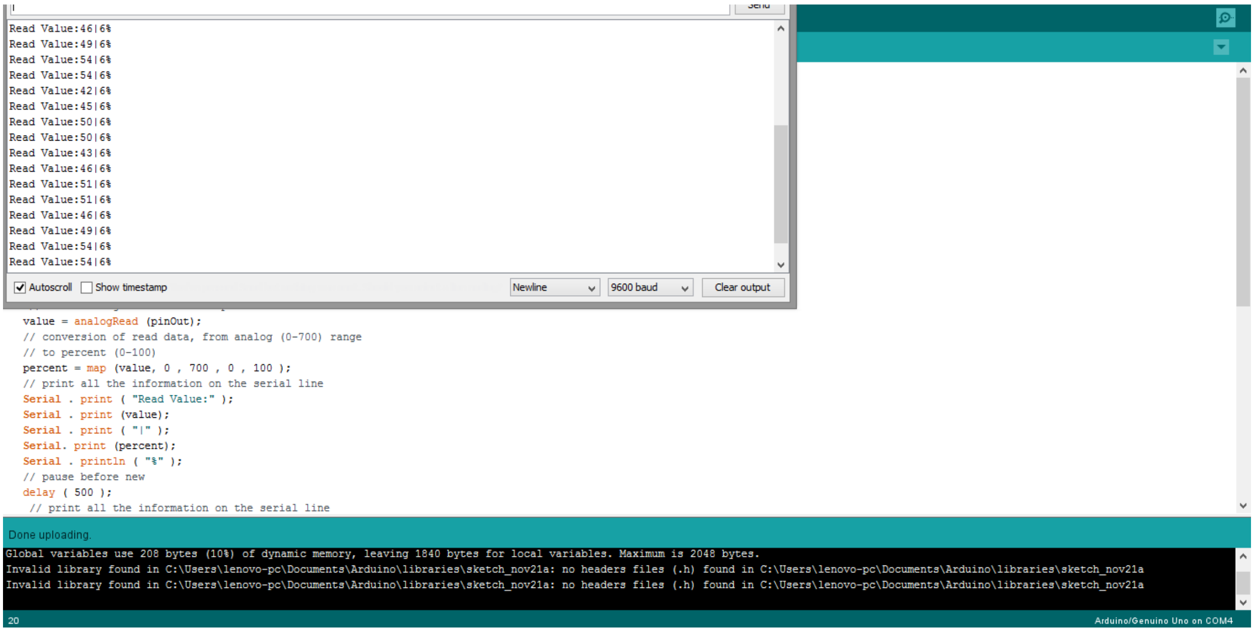
The assigned task for measurement of strains at different weights i.e from 1-5 kg is performed successfully on a Turn buckle that was manufactured by ourselves. We calibrated our module using data sheets and the results of stresses and strains are fairly accurate. This project served as an introduction to the use of Arduino, BF-350 module (containing a Wheatstone bridge, an amplifier and a potentiometer).Also, we learned a lot about strain gauges and its bonding in particular. We learned the precise work of soldering. The error was caused due to some strain hardening during a little forging and due to electroplating (nickel) of the work part and was only 6-18%

Anx-A

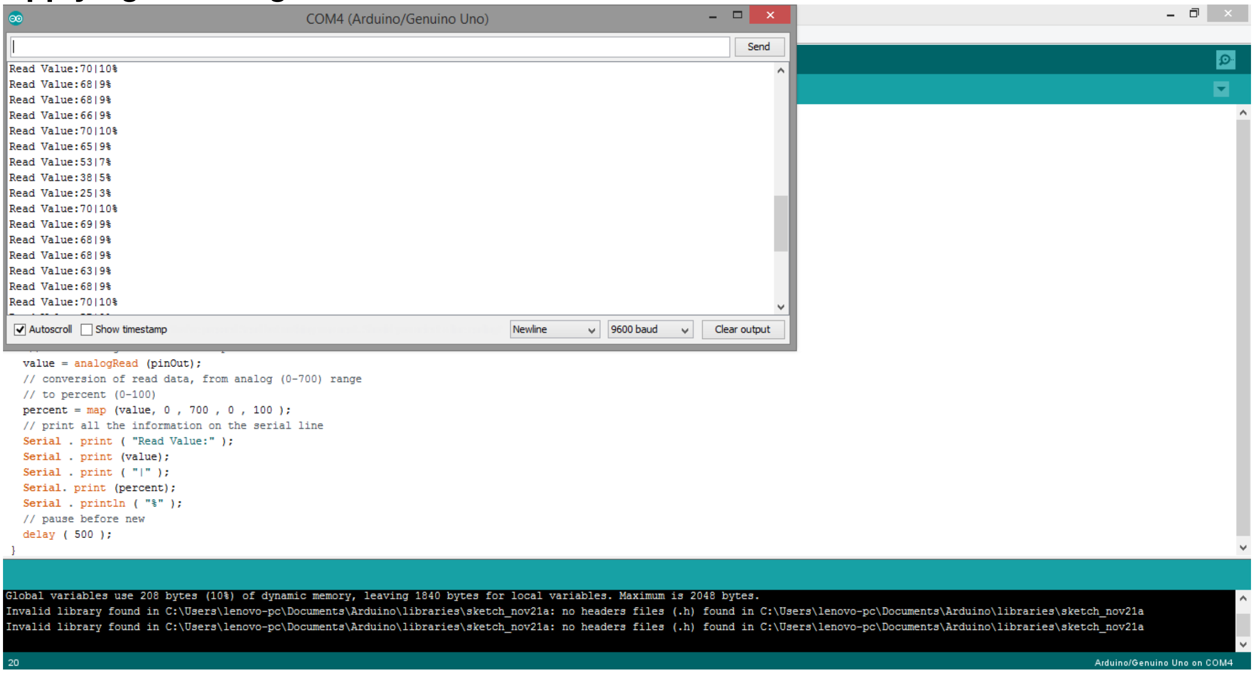
Applying load 1 kg:



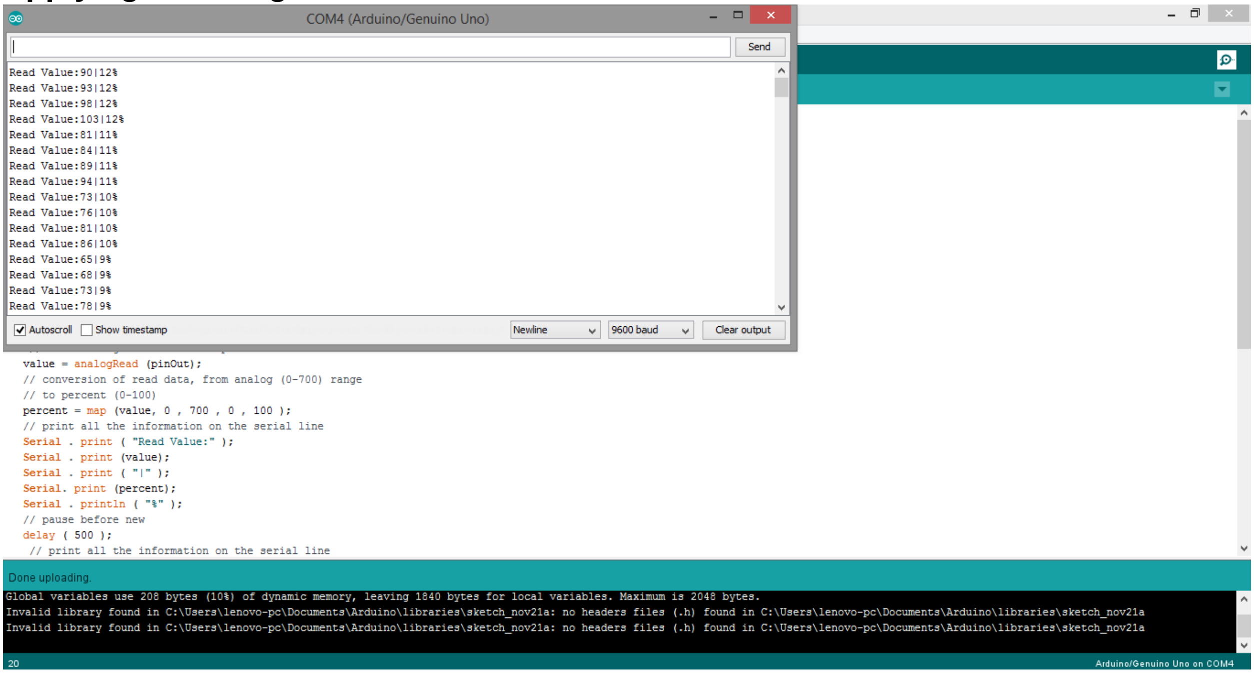
Applying load 2 kg:



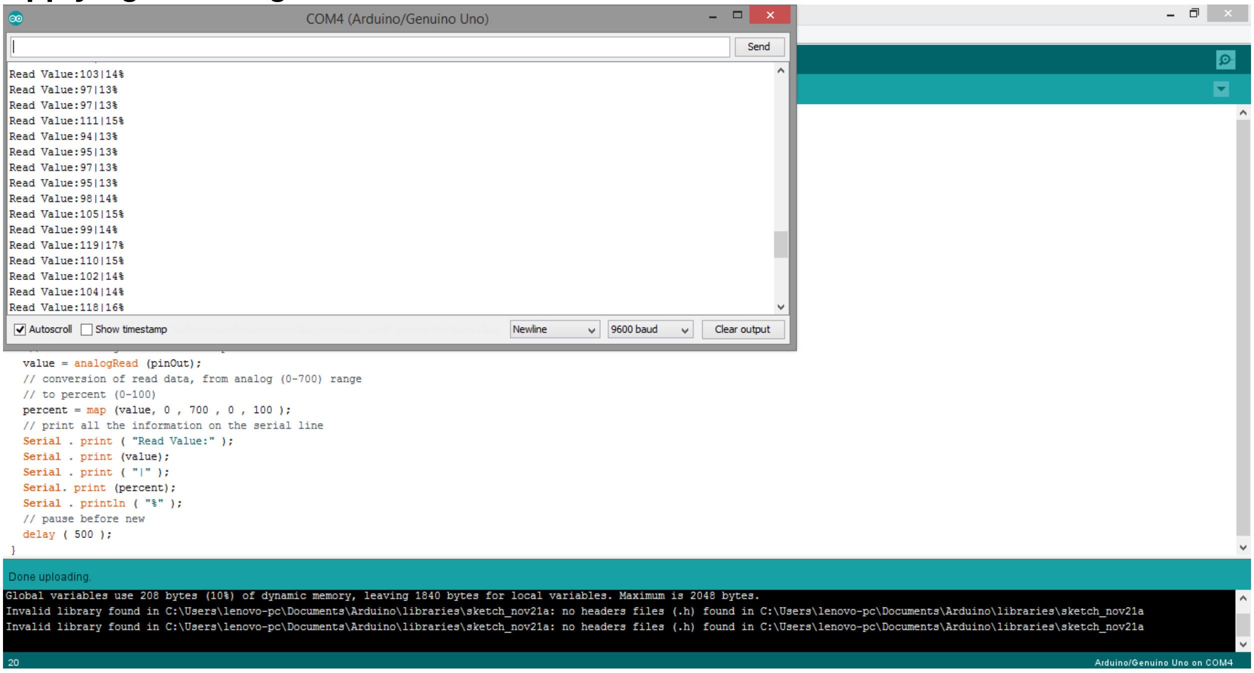
Applying load 3 kg:



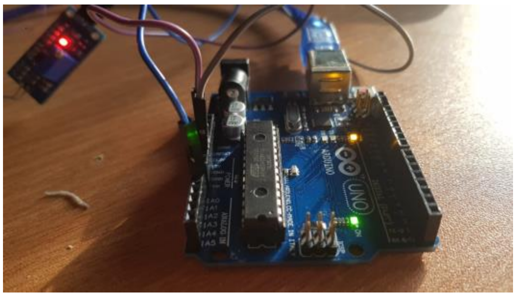
Applying load 4 kg:



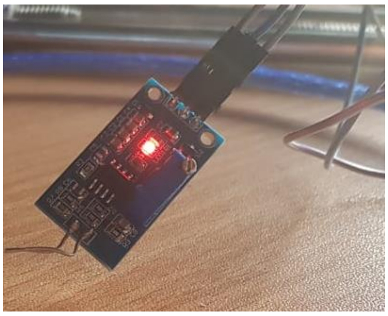
Applying load 5 kg:



PICTURES

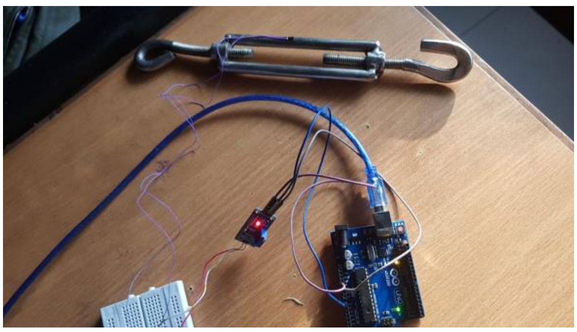


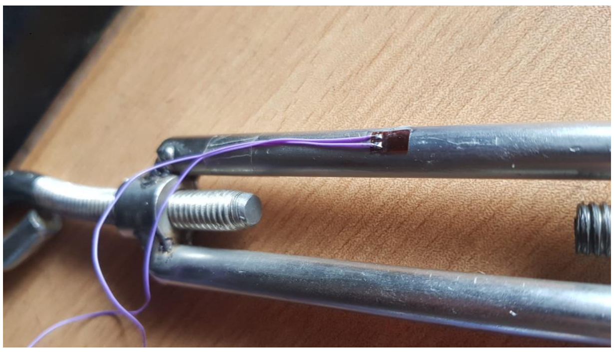
^Arduino UNO



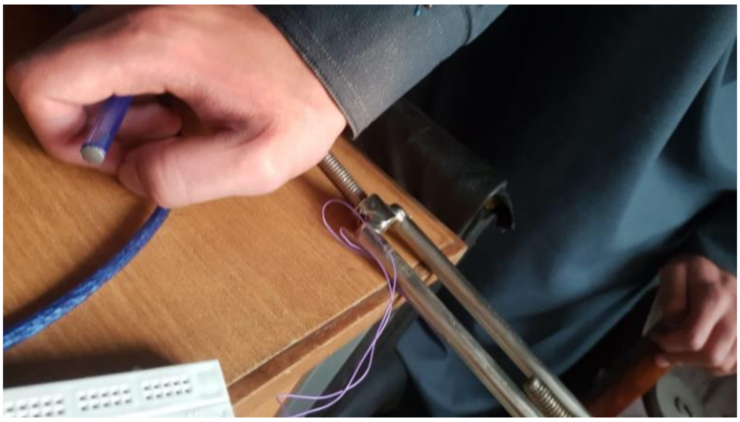
^BF-350 Module

^BF350 strain gauge

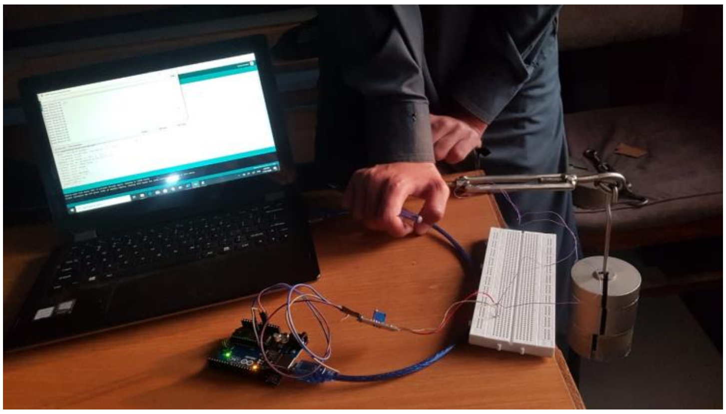




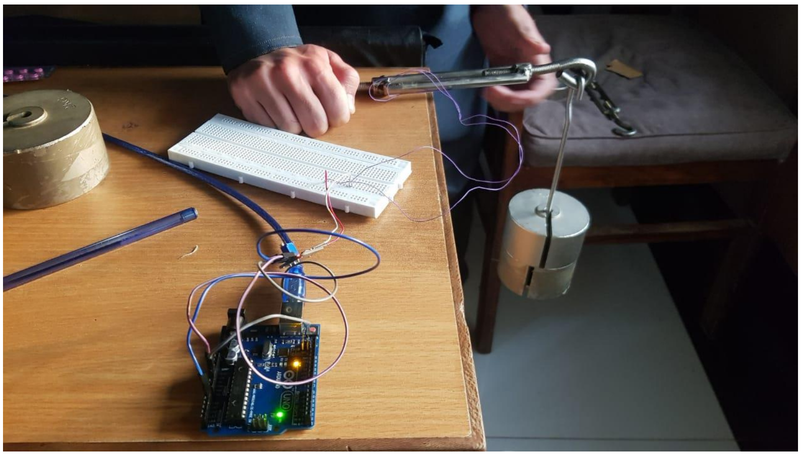
^Strain Gauge Attached to Part (Turnbuckle)



^*Successful Loads Application*



^*Overall Setup*



^*Unsuccessful Tensile strain Configuration*

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Videos will be provided