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WIRELESS CONTROL SYSTEM TECHNIQUE FOR EVALUATING THE BUCKLING BEHAVIOR OF 6061-T4 AL-ALLOY

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ABSTRACT

This research deals with the evaluation of buckling behavior for 6061-T4 aluminum alloy under increasing compressive dynamic loads. Two types of columns, long, and the intermediate columns were used. The number of specimens used in the dynamic axial compression test were 9 samples .(1%) of the length column is the allowable lateral deflection. For the purpose of calculating the initial deflection, the digital dial gauge was used and the instrument was set at a distance of (0.7) of length from the fixed condition for the column. A control system is designed to evaluate the critical buckling and to prevent sample failure. The control system consists of a measuring circuit (transmitter circuit) with a flex sensor installed at 0.7 of the total column length of the column's fixed condition. In addition, the system contains a shutdown circuit (receiver circuit) to switch off the machine at critical load with a mobile phone for the purpose of displaying deflection data. The connection between the transmitter circuit and the receiver wirelessly through the RF sensor and between the transmitter circuit and mobile phone also wirelessly via Bluetooth. The results obtained were experimentally compared with the Perry-Robertson formula. It was found that the Perry-Robertson formula was a good agreement with the experimental results with a safety factor of (1.2) .

KEY WORDS: Buckling , Arduino , Flex sensor , 6061-T4 AL-alloy,

تقنية نظام التحكم اللاسلكي لتقييم سلوك الانبعاج الجانبي لسبيكة الألمنيوم 6061-T4

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الخلاصة

يتناول هذا البحث تقييم سلوك الانبعاج الجانبي لسبيكة الالمنيوم (6061-T4) تحت زيادة حمل الضغط الديناميكي. تم استخدام نوعين من الأعمدة، طويلة، واعمدة متوسطة. كان عدد العينات المستخدمة في اختبار الضغط المحوري الديناميكي ٩ عينات. (١٪) من طول العمود هو الانحراف الجانبي المسموح به. ولغرض حساب الانحراف الأولي، استخدم جهاز (digital) dial gauge وتم تثبيت المقياس على بعد (٠.٧) من طول العمود من جهة التثبيت . تم تصميم نظام التحكم لتقييم الانبعاج الجانبي الحرج ومنع فشل العينة. يتكون نظام السيطرة من دائرة قياس (دائرة ارسال) مع (sensor (flex مثبت على بعد ٠.٧ من الطول الكلي للعمود من الحالة الثابتة للعمود ، اضافة الى ذلك يحتوي النظام على دائر اطفاء (دائرة استقبال) مع هاتف نقال لغرض عرض بيانات الانحراف . الاتصال بين دائر المرسل والمستقبل لاسلكيا عن طريق (RF sensor) وبين دائرة المرسل والموبايل ايضا لاسلكيا عن طريق البلوتوث. تمت مقارنة النتائج التي تم الحصول عليها تجريبيا مع صيغة بيري روبرتسون. وقد وجد أن صيغة بيري-روبرتسون تتوافق بشكل جيد مع النتائج التجريبية مع عامل أمان قدره (١.٢).

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Nomenclature	Definition	Units
σy	Yield stress	(MPa)
σu	Ultimate stress	(MPa)
L	Total column length	(mm)
Le	Effective column length	(mm)
I	Moment of inertia	(mm^4)
Cc	Column constant	
A	Cross section area	(mm^2)
D	Diameter of column	(mm)
E	Modulus of elasticity	(GPa)
r	Radius of gyration	(mm)
δin	Initial column deflection	(mm)
δcr	Critical deflection	(mm)
Pcr	Critical buckling load	(N)
S.R	Slenderness ratio	
η	is a constant depending on the material	
RF	Radio frequency	MHz
APP	application	
MIT	Massachusetts Institute of Technology	

INTRODUCTION

Buckling is a phenomenon, where a structure suddenly changes from one equilibrium configuration to another equilibrium configuration. The calculation of buckling loads of a structure is of great importance, due to the possibility of sudden failure of the structure, if the critical buckling load is reached. Some structures might loose all stability, when the buckling load is reached, which could put people at risk, if a roof or other similar structures loses all stability [Allan and Kasper ,2012]. The increasing development in the structural application of aluminum alloy is due to its several particular features over classical carbon steel, including satisfying corrosion resistance, high strength-to-weight ratio, and good formability; it also displays comparable ease of manufacture, low maintenance costs, and superior aesthetics [Yujin , 2015]. Development of control system through a wireless network open a new dimension in the perspective of the system capability. it is associated with more applications with better implementation technique and more reliable output. for example, a wireless system to control a robot has been developed to send certain instructions to the robot. it also allowed flexibility in the interconnectivity of the system, optimizing its functionality as a distributed control system by several processors[Cisneros.etal,2008]. Wireless networks are any type of computer networks that transmits information between nodes without the use of wire conduction. Bluetooth is a wireless technology standard that is used to exchange data over short distances (less than 30 feet), usually between personal mobile devices. This means that a Bluetooth-enabled device such as a smartphone is able to communicate with other Bluetooth devices, such as a wireless headset, MP3 player or printer. Bluetooth, therefore, acts much like a cord between the two devices by creating a secure, wireless personal area network in which these devices can communicate. [Ahmed, 2011]. [Al-Alkawi et al, 2016] presented some main experimental results of dynamic buckling under increasing compression load. The buckling of 304 stainless steel was inspected using Euler and Johnson formulas, which is most commonly used in industrial applications. It has been proved that metallic materials can exhibit nonlinear buckling behavior with mechanical properties dependency. This attitude yields a nonlinear model which depends on Hong's model but using the mechanical properties with cycles to failure. It was observed that the proposed model gave safe predictions while Hong's model yields non-satisfactory predictions of critical buckling loads and also design electrical LASER alarm system to avoid the failure occurs in the specimen when access to critical buckling load. [Avcar, 2014] discussed the influence of the boundary cases, cross-sections and slenderness ratios on the buckling load of the steel column. Two different boundary conditions such as Fixed-free (F - F) and pinned-pinned (P - P) with three various cross-sections area, such as square, rectangle and circle cross sections were used. Finite element model (FEM) has been performed and compared with numerical computations. They found that the buckling load of fixed-free (F – F) column was less than pinned-pinned (P – P) column. [Alalkawi and Aziz, 2009] studied the Euler and Johnson theories depended on experiment tests under compression dynamic buckling load by using 20 specimens (columns) made from two materials, 1020 Hot Rolled and 5052 Aluminum alloy. They concluded that Euler (for long columns) and Johnson (for short columns) theories can be used to estimate the dynamic critical buckling load with design factor of 3 or more. In this work the elastic buckling demeanor of solid column with fixed-pinned conditions has been studied. As well as the use of the Perry-Robertson formula to evaluate critical buckling and to determine their compatibility with experimental results have been adopted. The initial deflection of the column is measured using a digital dial gauge indicator. A control system was used, consisting of a transmission circuit and a reception circuit. The communication between the two circuits is a wireless connection with a mobile to display the results and receives the results from the transmitter circuit also wirelessly through Bluetooth. This system gives confidence and assurance that lateral buckling will not exceed 1% of the sample length. Also, the control system currently in use protects the sample from failure by automatically stopping the machine at critical loads.

Purpose of using the control system

1. It is necessary to know the amount of buckling of the column at any load using a flex sensor.
2. Receive the results wirelessly through Bluetooth to get rid of the problem of wires because the specimen is rotating during the test.
3. Preventing the sample from failure at critical loads and transmitting a signal through an RF sensor to the other circuit for the purpose of shutting off the test machine directly.
4. The wireless control system is necessary for the purpose of safety in the current research where it is permitted to take deflection data away from the machine.

THEORY

Perry-Robertson formula

Critical load was calculated using the improved formula to take into account the shortcomings of the Euler equation for long columns as well as the Johnson equation for intermediate and short columns.

$$p_{cr} = A\left[\frac{\sigma_y+(1+\eta)\sigma_e}{2} - \sqrt{\left(\frac{\sigma_y+(1+\eta)\sigma_e}{2}\right)^2 - \sigma_y\sigma_e}\ \right] \quad \text{[Hearn, 1997]} \qquad (1)$$

Where

P_{cr}= critical axial load that leads to buckling in column (N).
η is a constant depending on the material.
For a brittle material
η = 0.015 L/k
For a ductile material

$$\eta = 0.3\left(\frac{L_e}{100r}\right)^2 \quad (2)$$

Le = effective length of pinned end strut= Le = KL

$$r = \text{radius of gyration} = \sqrt{\frac{I}{A}} \quad (3)$$

$$\sigma_e = \text{Euler buckling stress} = \frac{\pi^2 E}{(L_e/r)^2}\ \text{(MPa)} \quad (4)$$

σ_y=compressive yield stress (MPa)
K= End fixity constant. Figure.1 gives the theoretical and experimental Value of K for different end fixity.

The Slenderness Ratio (S. R)

The ratio of the length of a column to the least radius of gyration of its cross section is called the slenderness ratio (S.R).

$$SR = \frac{Le}{r} = \frac{kL}{r} \quad \text{[Gere, 2009]} \quad (5)$$

The Column constant (Cc).

Columns are divided into long column and columns of intermediate length. When the actual (S.R.) for a column is less than the column constant (Cc) then the column is intermediate. In this research. Experimental examination of the fixed-pinned case will be adopted. See fig (1-C) [Fadhil, 2014] .Cc may be defined as

$$Cc = \sqrt{\frac{2\pi^2 E}{\sigma_y}} \quad \text{[Fadhil ,2014]} \quad (6)$$

EXPERIMENTAL WORK

Experimental work plan can be summarized as follows:-
1-Selection of material.
2- Testing of the chemical composition and mechanical properties.
3- Buckling test of column under increasing dynamic load.
4-Measuring initial static deflection using digital dial gauge.
5- The use of an integrated control system to measure the critical deflection for specimens at rotation state and display data over the mobile phone as well as to automatically stop the test machine in critical loads.

Chemical composition

All the materials were received from the State Company of Mechanical Industries AL-Ascandaryah and tested to obtain the chemical composition of the (6061-T4 aluminum alloy) , tested in Engineering Centre for Testing and Recondition in Al-Saydiyah. The results are listed in table (1) .Chemical analysis of the material used was done at S.C. of Geological survey and mining using X-Rays method. The results, which are compared to the American standard.

Tensile properties

The tensile test was completed using the (WDW-200E) tensile testing machine with a capacity of 200KN offered in figure (3) .The mechanical properties of (6061-T4 aluminum alloy) were obtained according to ASTM A370 specification. The tensile specimen can be shown in figure (2). The experimental results are the average of three specimens. The tensile tests are done in university of technology-material engineering department, are summarized in table (2)

Buckling Specimens

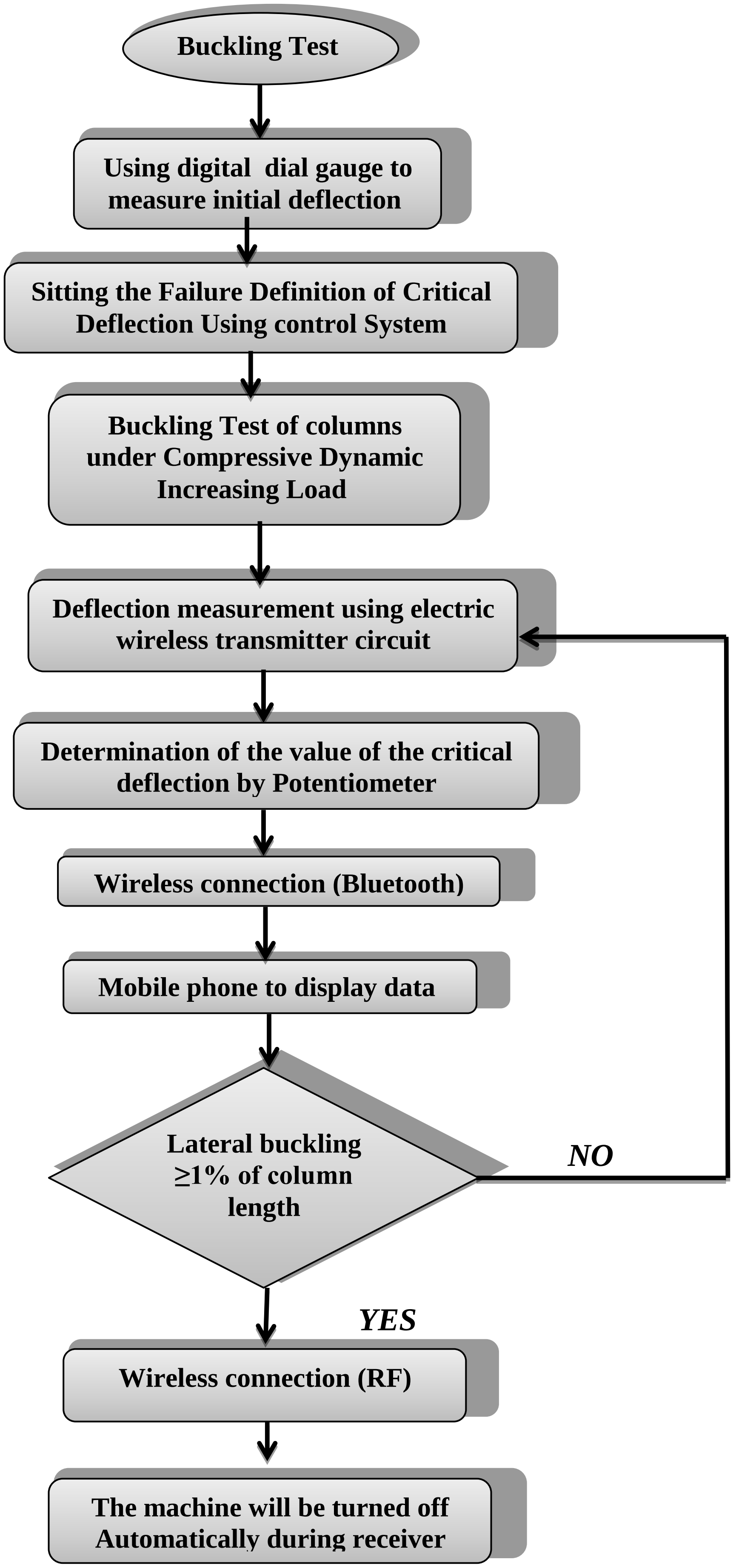
Two types of buckling specimens were prepared, long and intermediate. The dimensions of the specimens used are listed in figure (2). The specimens used in the testing of buckling were received in the form of rods of (6061-T4 aluminum alloy), in different lengths of submitted samples. Buckling specimen for different length and diameter summarized in table(3).

Buckling test

6061-T4 aluminum alloy columns were tested by buckling test-rig machine which is able to buckle the columns by apply axial compression load (The buckling machine is located in the strength laboratory in the Department of Electromechanical Engineering at the University of Technology).Column ends support of fixed-pinned with rotating speed of 17 rpm were adopted .

DESIGN AND IMPLEMANTATION OF CONTROL SYSTEM

The purpose of using sensor devices for comfort, safety, security, and reliability of service purpose is not new, but the usage, cost, design method, and quality of the system varies. The control system consists of transmitter Circuit which contains from flex sensor (it is a variable resistance that increases during bending), potentiometer, Bluetooth and RF Transmitter, All these components are connected with the microcontroller (Arduino Uno). As well as the system consists of a receiver circuit its consists of 2-channel 5 V relay module and RF Receiver, As well as these components connected with another micro controller (Arduino Uno). In addition, the system contains a mobile phone was used to display the results of the deflection. see figure (6). The flowchart for the control system is described below**.**


Buckling Test
Using digital dial gauge to measure initial deflection
Sitting the Failure Definition of Critical Deflection Using control System
Buckling Test of columns under Compressive Dynamic Increasing Load
Deflection measurement using electric wireless transmitter circuit
Determination of the value of the critical deflection by Potentiometer
Wireless connection (Bluetooth)
Mobile phone to display data
Lateral buckling ≥1% of column length
NO
YES
Wireless connection (RF)
The machine will be turned off Automatically during receiver

Hardware Design

The control system consists of two circuits, the first is a circuit called the transmitter circuit and another circuit called the receiver circuit.

Transmitter circuit

The physical architecture of the transmitter circuit contains 7 major parts: Arduino microcontroller, flex sensor, Bluetooth module, RF transmitter, potentiometer, buzzer and power supply. All of these components can be seen in figure (7).

Receiver circuit

The physical architecture of the transmitter circuit contains 4 major parts: Arduino UNO, RF Receiver, 2-Channel 5 V Relay Module and power supply as shown in figure (8)

Programming the Arduino-Uno

Programming Arduino, also called IDE (Integrated Development Environment), is a C based language which led to write programs and upload them to the Arduino UNO. In Arduino programming there are two main functions. Main functions are setup () and loop(). Setup () function is only operated once when device is booted up, it is mostly used to setup initiation settings. Loop () is ran after the setup () function has finished, loop() function will run repeatedly until power off or reset button is pushed. Arduino programming is supported by wide amount of libraries.Large amount of open-source libraries are available from Arduino community. See figure (9). Refer to Appendix for the total source code of the transmitter circuit and receiver circuit.

MIT App Inventor

MIT App Inventor is a free and open-source web application which provides users with a block-based programming language and high-level abstractions for creating Android applications. App Inventor’s goal is to decrease the barrier to entry for learning programming by providing a language and abstractions which are simple enough for people with little experience to use. It also allows developers to engage with the programs they write in a familiar environment there smart phone . It is an uncomplicated software language that enables users to create their own application on mobiles. The program is built by creating fragments in the form of a puzzle on the 2D workspace. Because of its visual nature programming is easier for beginners, but also has some drawbacks such as the user must determine where to place blocks in the workspace may require the process of rearranging another group of blocks. MIT App Inverter is a service provided by Google for Android applications . In the current work, the MIT App Inventor programming was used to build an application on the mobile through which to display deflection data of column and compare with the critical values and this is through the wireless connection via Bluetooth as shown in figure (10).[Aubrey ,2016] , [Anshul, 2012], [Kishan ,2012].

OPERATION OF CONTROL SYSTEM

The current control system used in this work consists of a transmitter circuit, a receiver circuit and a device to display the information seen in the figure (4). The flex sensor that using in the transmitter circuit is one of the essential components considered in this system. The flex sensor is a variable resistance that increases in value when bending. After the test specimen is installed in the test-rig and locate flex sensor at the 0.7 of length distance from the fixed end, where feels and send deflection data to Arduino UNO. When the test begins operating the electric motor with a low rotating speed (17r.p.m.), an axial dynamic compression load is gradually applied under the load control on the specimen by a hydraulic pump of the compression system. This pressure applied to the sample causes the deflection and the flex sensor begins to bend gradually with increasing pressure and the bending values can be observed on the mobile phone. The transmitter circuit is installed on the head stock and rotate synchronous with the sample and receives the information from the flex sensor, also the information is transmitted directly to the mobile via the Bluetooth that makes the Arduino wirelessly connect with the mobile phone. The complete circuit schematic diagram of the control system is shown in figure (11). The amount of critical deflection is determined by depending on the length of the sample, which represents 1% of the total length of the sample to be tested In the transmitter circuit, the critical deflection is specified by a variable resistor (potentiometer) that is connected with the flex sensor. The change in resistance can be also observed in mobile directly via Bluetooth. When the amount of axial pressure on the sample increases, the lateral deflection increases and when the value of the flex sensor resistance becomes equal to the pre-determined potentiometer value depending on the length of the sample, the transmitter circuit receives a signal wirelessly from the RF transmitter. The machine will be switched off Automatically by using the rely on that change from normally closed (NC) to normally open (NO) .

RESULTS AND DISCUSSION

Dynamic Buckling Load

Nine specimens have been tested under increasing compressive dynamic loading. The machine has only two speeds (17r.p.m) and (34r.p.m.). The velocity of (17r.p.m.) was adopted because the buckling phenomenon is not obvious in high speeds, and is uncontrollable besides the designing lives cannot be controlled [Hussein, 2010]. The specimens were prepared with different slenderness ratios, for testing under increasing loads from table (4), it is noticed that the specified load for failure decreases whenever the columns were changed from intermediate to long columns. The intermediate columns within the inelastic region need more stress to reach failure, so, whenever the slenderness ratio approaches intermediate columns, failure stress is more, and when the value of slenderness ratio increases, the failure stress decreases. So, the control system ensures safety when access lateral buckling to the extent is known by shut down the test-rig automatically. When the axial load is gradually increased, it reaches the stage where the column begins to buckling. The load that causes the column buckling is called buckling load or possible to be called critical load and here it is possible to say that the column is an elastic instability. Referring to figure (12) the value of buckling load is low for long columns, and relatively high for intermediate columns ,as shown in figure (12).

Application of Perry- Robertson formula

When comparing the Perry-Robertson results with the value of the critical load experimental, the prediction of Pcr due to Perry-Robertson (PR) is not satisfactory but if a factor of safety equals to (1.2) gave safety estimation for Pcr under dynamic loading. See tables. See table (5). For S.R. greater than 105 the column may change to become long column. The value equal to 51 MPa can limit the type of column, i.e. greater than 51 MPa columns are said to be long and less than this value are called intermediate columns. Figure (13) displays the relation of stress at failure and slenderness ratio as presented by Perry-Robertson formula for a long and intermediate columns compared with experimental result made of (6061-T4 aluminum alloy) with one end pinned and the other fixed (K = 0.7), having a yield strength of = 149 MPa **.**

CONCLUSIONS

1- The Perry-Robertson formula gives an approximation of the experimental results but with a safety factor of (1.2) that gives more satisfied expectations..

2- The wireless control system has succeeded in dominating the critical buckling and estimating the columns failure specific as 1% of the length of the specimen and preventing it to exceed this ratio by switching off the test machine at critical load.

Table (1) : chemical composition of 6061-T4 aluminum alloy (wt %)

6061-T4 Aluminum alloy	Al%	Cr%	Cu %	F%	Mg %	Mn %	Si%	Ti%	Z%
Standard	95.8-98.6	0.04-0.35	0.15-0.4	Max 0.7	0.8-1.2	Max 0.15	0.4-0.8	Max 0.15	Max 0.25
Experimental	balance	0.29	0.22	0.45	0.62	0.09	0.62	0.11	0.19

Table (2) : The mechanical properties of (6061-T4 aluminum alloy)

6061-T4 Aluminum alloy	σ_u (MPa)	σ_y (MPa)	E (GPa)	G (GPa)	Poi. Ratio (μ)
Standard	241	145	68.9	26	0.33
Experimental	252	149	71	27	0.32

Table (3): Gives the dimensions of solid specimen used for 6061-T4 Aluminum alloy

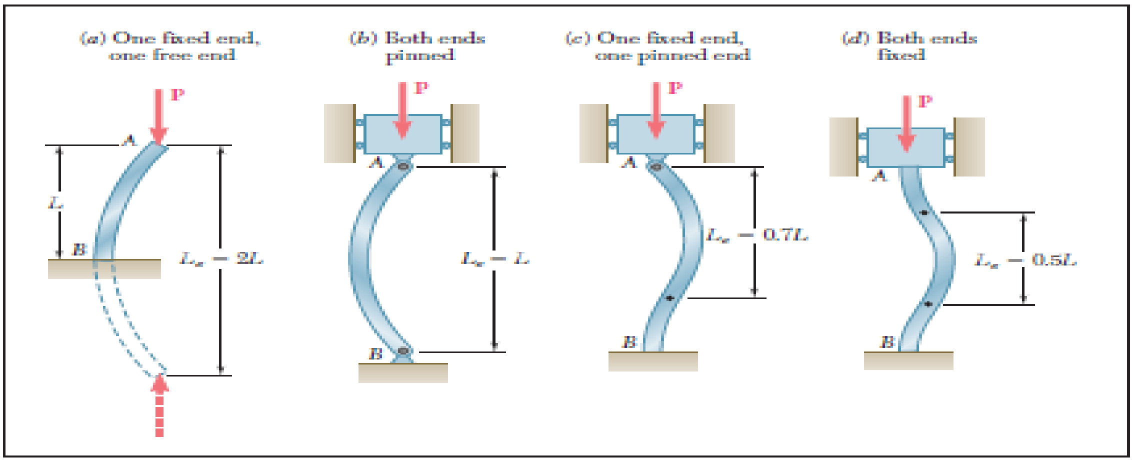
Sp No	L mm	Le mm	D mm	r mm	I mm^4	A mm^2	SR	Cc	Type of column
1	400	280	10	2.5	490.87	78.53	112	105	**long**
2	400	280	8	2	201.06	50.26	140	105	
3	300	210	8	2	201.06	50.26	105	105	
4	400	280	6	1.5	63.61	28.27	186.66	105	
5	300	210	6	1.5	63.61	28.27	140	105	
6	200	140	8	2	201.06	50.26	70	105	**intermediate**
7	300	210	10	2.5	490.87	78.53	84	105	
8	200	140	10	2.5	490.87	78.53	56	105	
9	200	140	6	1.5	63.61	28.27	93.33	105	

Table (4) :The results of the specimens tested under increasing compressive dynamic loads for long and intermediate columns (6061-T4 aluminum alloy).

Sp NO.	L mm	Leff mm	D mm	Pcr N	δin mm	δcr mm 1% of L	Type of column
1	400	280	10	4592	0.36	4	Long columns
2	400	280	8	1554	0.71	4	
3	400	280	6	494	1.2	4	
4	300	210	8	2235	0.87	3	
5	300	210	6	847	0.85	3	
6	300	210	10	5652	0.24	3	Intermediate columns
7	200	140	10	8478	0.25	2	
8	200	140	8	4532	0.39	2	
9	200	140	6	1695	0.39	2	

Table (5) Comparison between Perry-Robertson results with experimental critical load value for long and intermediate columns

Sp NO.	L mm	Leff mm	D mm	Pcr EXP (N)	P_{cr} (Perry-Robertson) (N)	P_{cr} (Perry-Robertson) (N) with S.F of 1.2	Type of column
1	400	280	10	4592	3641	3034	Long columns
2	400	280	8	1554	1554	1295	
3	400	280	6	494	492	410	
4	300	210	8	2235	2625	2187	
5	300	210	6	847	858	715	
6	300	210	10	5652	6042	5035	Intermediate columns
7	200	140	10	8478	9638	8031	
8	200	140	8	4532	5025	4187	
9	200	140	6	1695	1821	1517	



Figure(1): The types of end fixity [Fadhil ,2014]

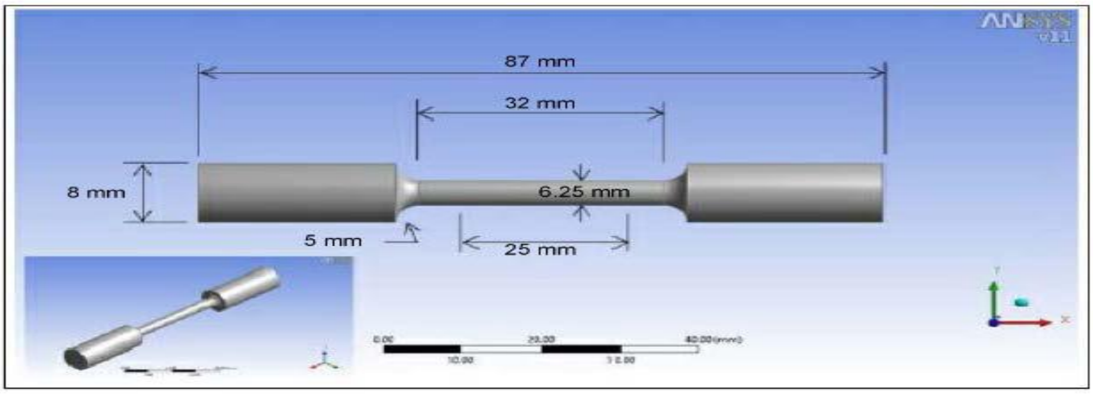


Figure (2): Tensile test sample

Figure (3) :Tensile test machine WDW-200E.

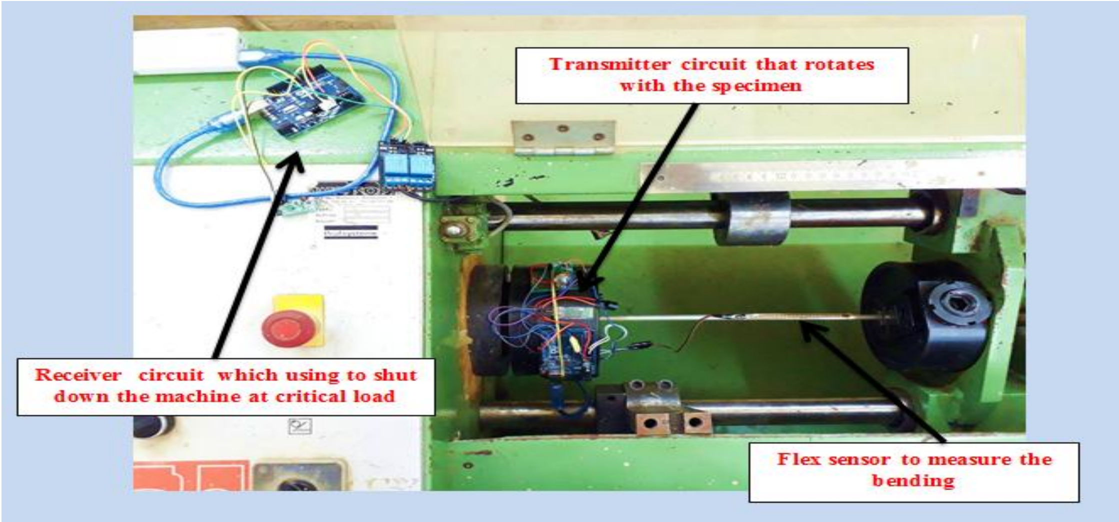


Figure (4): the control system connected with buckling test machine.

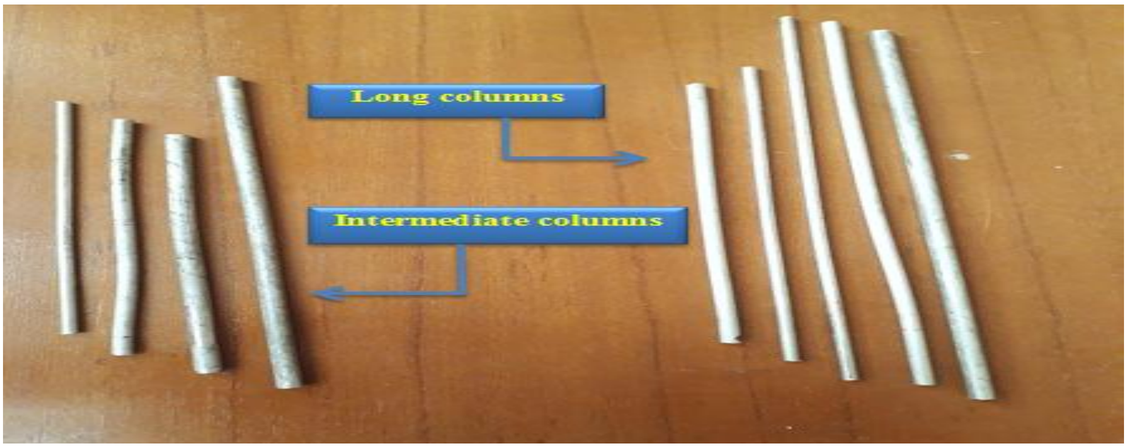


Figure (5) : Buckling specimen for long and intermediate columns.

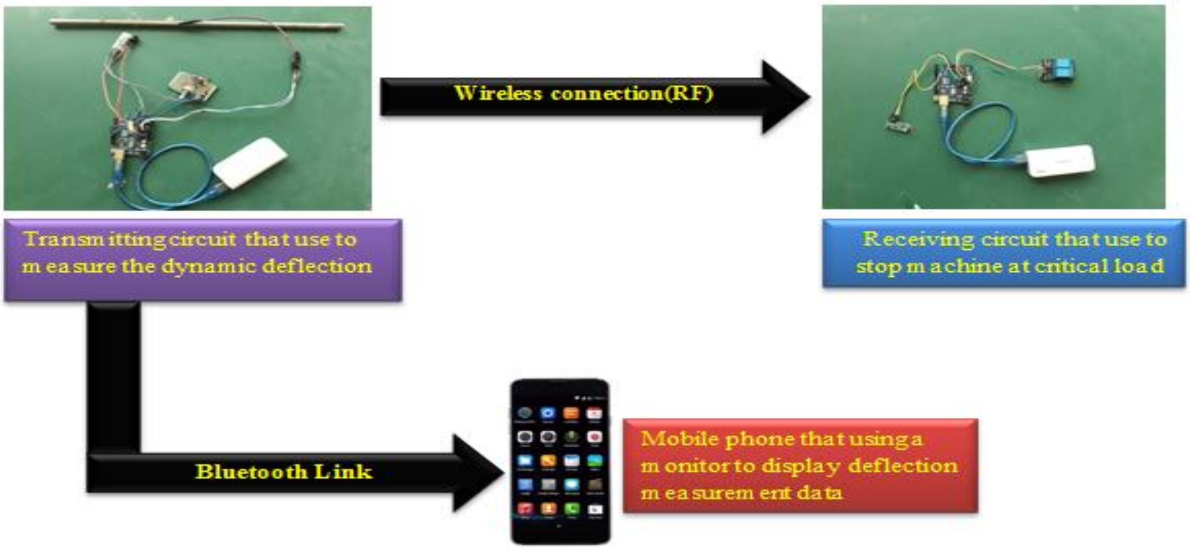


Figure (6) : modeling of a control system

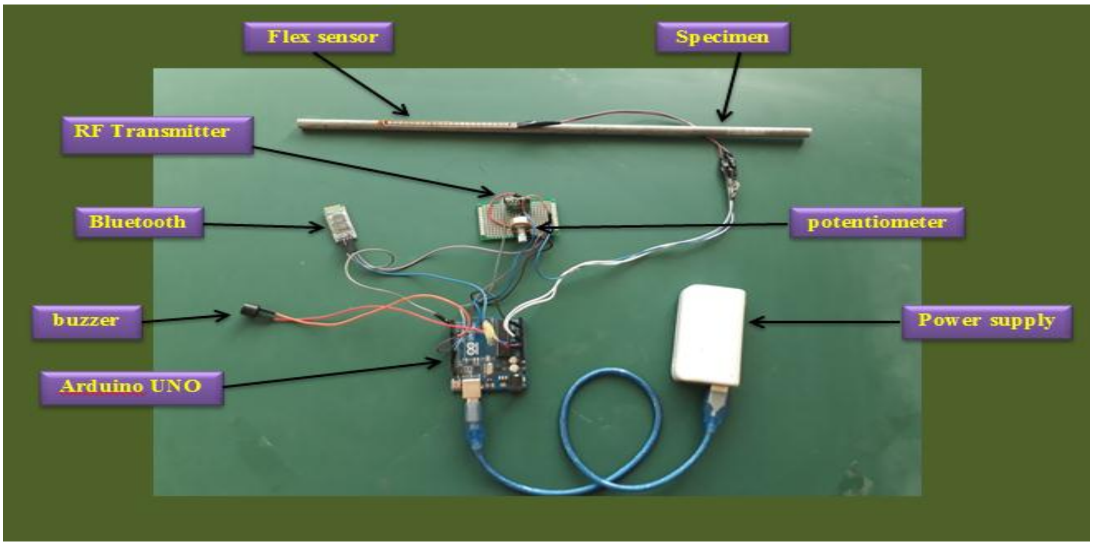


Figure (7) : Transmitter circuit components

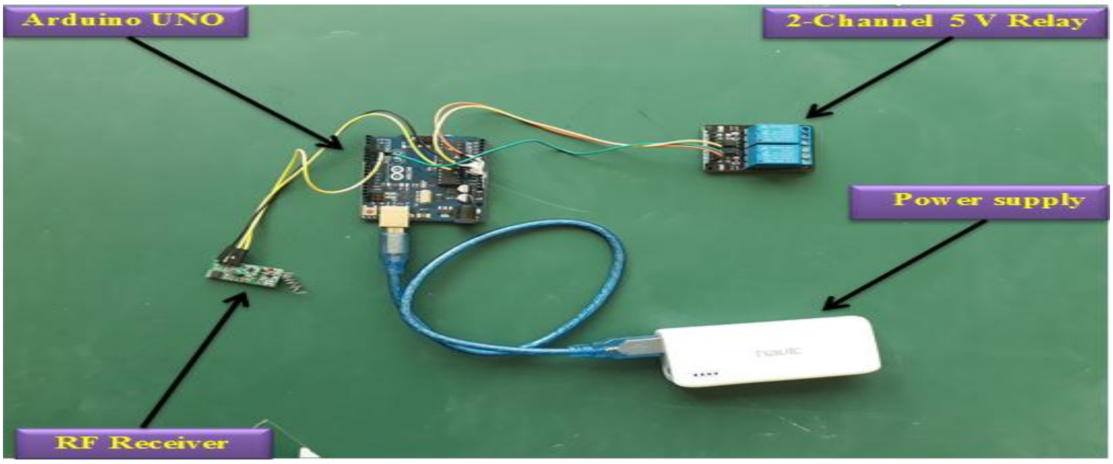


Figure (8) : Receiver circuit components

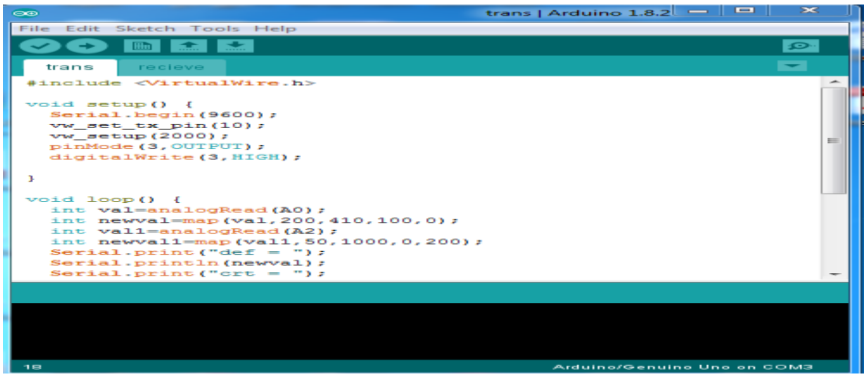


Figure (9): Programming Arduino-UNO board

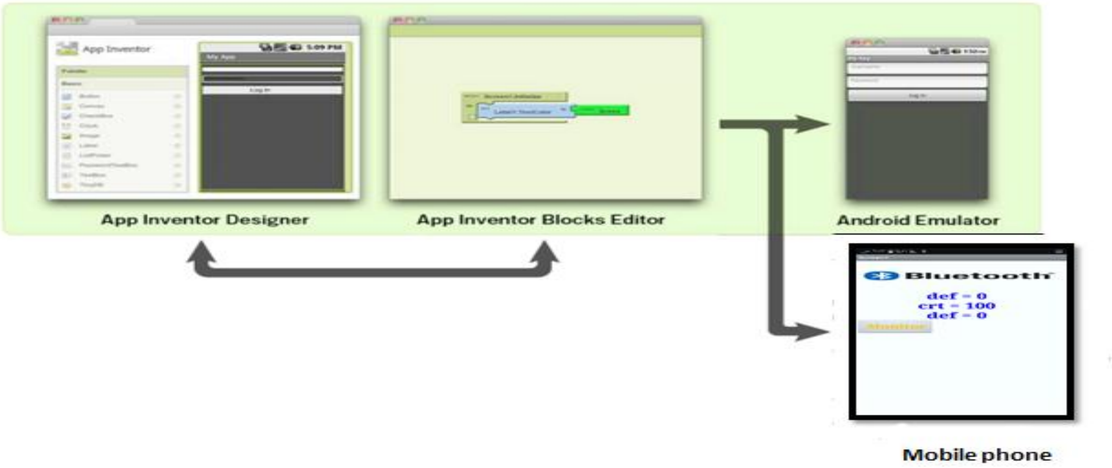


Figure (10): MIT App Inventor

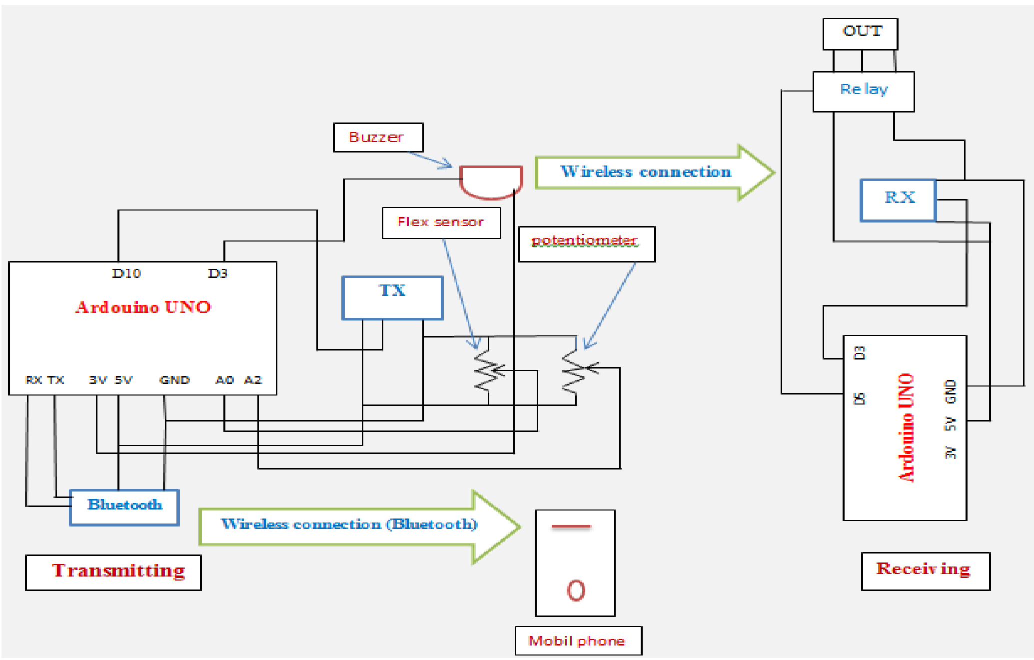


Figure (11): Circuit diagram of the control system.

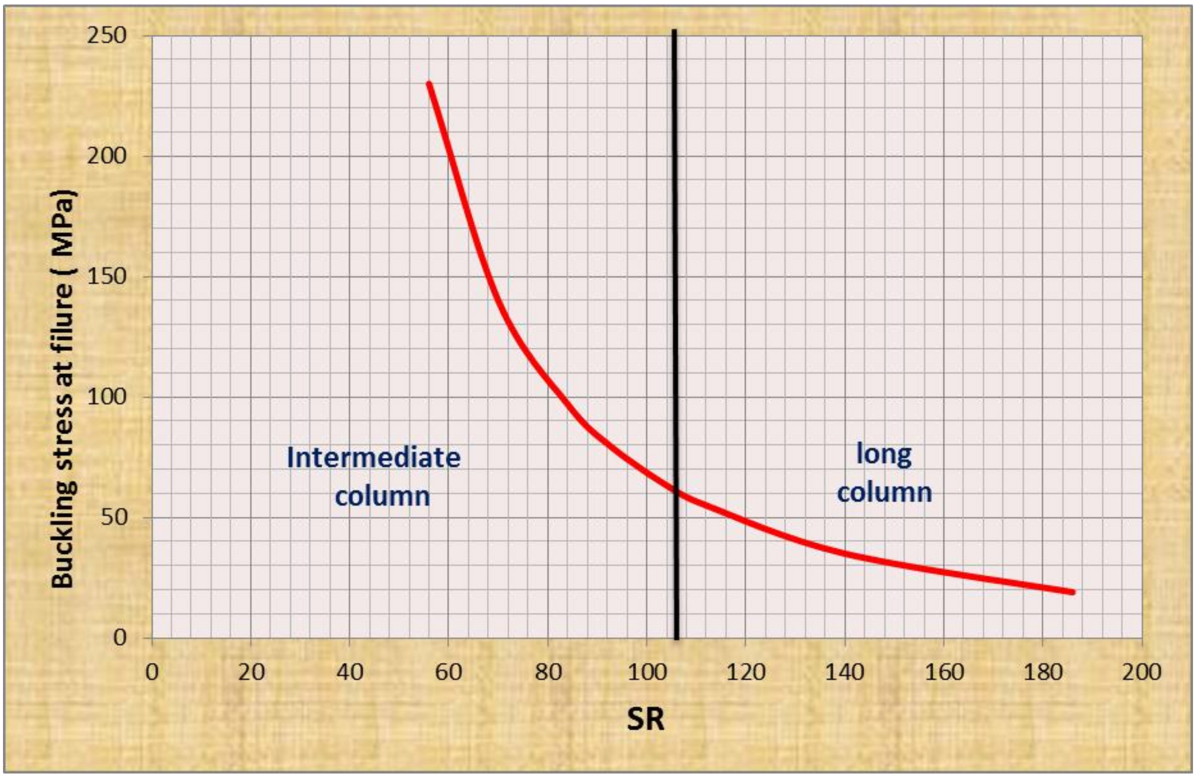


Figure (12): Dynamic compression buckling stress for (6061-T4 aluminum alloy) columns.

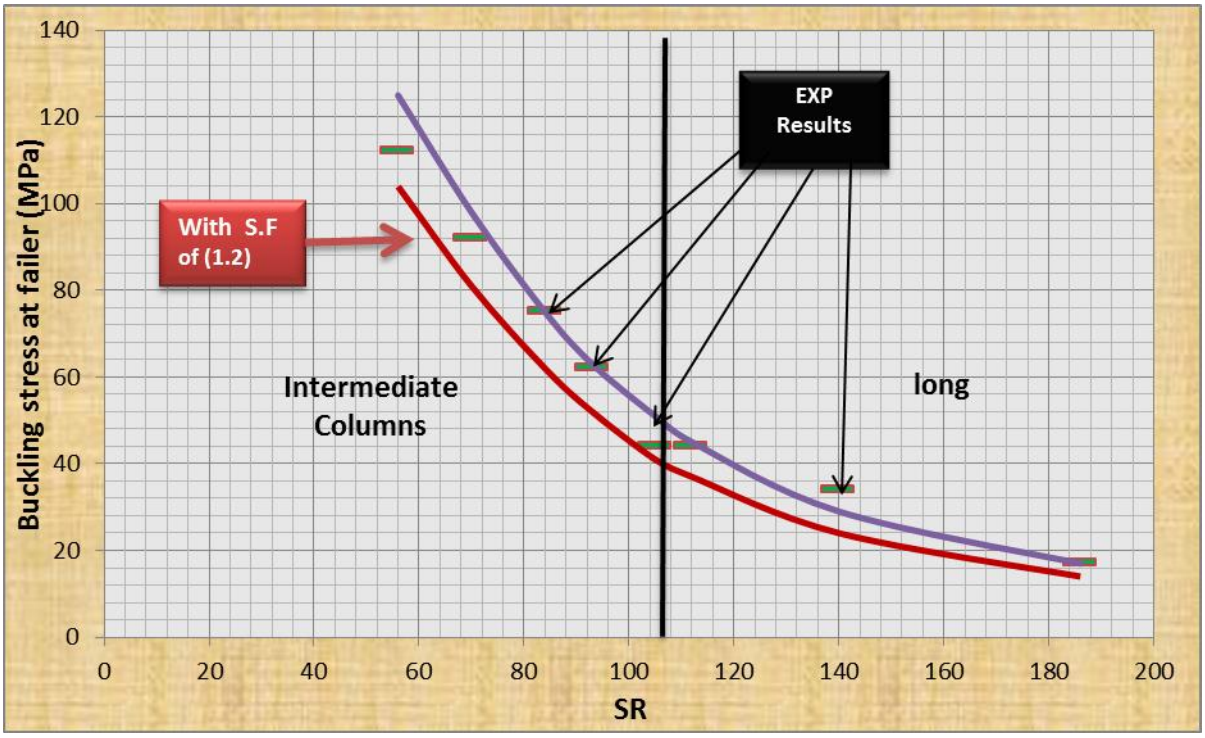


Figure (13): Perry-Robertson curve with the experimental results for 6061-T4 aluminum alloy.

REFERENCES

Allan. L. F, Kasper S. L, Methods for Decreasing the Total Solution Time of Linear Buckling Finite Element Analyses, MSc. Thesis, Aalborg University, Department of Mechanical and Manufacturing Engineering, June, 2012.

Mehmet Avcar, "Elastic buckling of steel columns under axial compression", Amerian Journal of Civil Engineering, Vol.2, No.3, 2014, pp.102 – 108.

Y. Wang, F. Fan, S. Lin, "Experimental investigation on the stability of aluminium alloy 6082 circular tubes in axial compression", Thin-Walled Structures, Vol.89, 2015, pp.54–66.

Al-Alkawi H. J. M., Ekbal H. Ali, Firas A. Jasim, "Buckling behavior for 304 stainless steel using electrical laser alarm system ", Eng. And Tech. Journal, Vol.34, No.11, 2016.

Mohamad K. Alwan, Naseem S. Abrahim, "Experimental and numerical study of buckling for carburized low carbon steel columns", Journal of Engineering and Development, Vol.18, No.2, 2014, pp.1813-7822.

Hussein Abd ulziz A., H. J.M. Al –Alkawi, "An appraisal of Euler and Johnson buckling theories under dynamic compression buckling loading ", The Iraqi Journal for Mechanical and Material Engineering, Vol.9, No.2, 2009 , pp.173-181.

E. J. Hearn, Mechanics of materials, 3^{th} ED, University of Warwick, United Kingdom, 1997.

Fadhel E. Z., Effect of Shot Peening on The Buckling Behaviour of Steel CK35 under Combined Loading, PhD. Thesis, University of Technology, Mechanical Engineering Department, April, 2014.

H. A. Hussein, Buckling of square columns under cycling loads for nitriding steel DIN (ck45, ck67, ck101), PhD. Thesis, University of Technology, Mechanical Engineering Department, March, 2010.

K. H. Al-Jubori, Column Lateral Buckling Under Combined Dynamic Loading, PhD. Thesis, University of Technology, Technical Education Department, March, 2005.

Aubrey , J ,C, " Evaluating and Improving the Usability of MIT App Inventor" MSc. Thesis. Electrical Engineering and Computer Science, 2016.

J. M. Gere, "Mechanics of Material", 7th Ed, Thomson Learning Academic Resource Centre, Stanford University, 2009.

Anshul Bhagi , " Android Game Development with App Inventor" master thesis, Electrical Engineering and Computer Science, (2012).

Appendix: Control system programming

1- Transmitter Circuit

```
#include <VirtualWire.h>
void setup() {
Serial.begin(9600);
```

```
vw_set_tx_pin(10);
vw_setup(2000);
pinMode(3,OUTPUT);
digitalWrite(3,HIGH);
void loop() {
int val=analogRead(A0);
int newval=map(val,200,410,100,0);
int val1=analogRead(A2);
int newval1=map(val1,50,1000,0,200);
Serial.print("def = ");
Serial.println(newval);
Serial.print("crt = ");
Serial.println(newval1);
delay(500);
if(newval >= newval1){
digitalWrite(3,LOW);
char msg[1] = {'1'};
vw_send((uint8_t *)msg, 1);
vw_wait_tx();
delay(200);
else{
digitalWrite(3,HIGH);}
```

2- Receiving circuit

```
#include <VirtualWire.h>
Serial.begin(9600);
vw_set_ptt_inverted(true);
vw_setup(2000);
vw_set_rx_pin(3);
vw_rx_start();
pinMode(5, OUTPUT);
digitalWrite(5, LOW);
}
void loop() {
uint8_t buf[VW_MAX_MESSAGE_LEN];
uint8_t buflen = VW_MAX_MESSAGE_LEN;
if (vw_get_message(buf, &buflen)) // We check if we have received data
Appendix
- 001 -
int i;
// Message with proper check
for (i = 0; i < buflen; i++)
Serial.write(buf[i]); // The received data is stored in the buffer
// and sent through the serial port to the computer
digitalWrite(5, HIGH);
Serial.println("Warning");
else {delay(1000);
digitalWrite(5, LOW);
```