Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 45 No. 2 (2024)

Design Integration and Analysis of Arduino Operated Gas Nitriding Furnace

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***Abstract*:**

Nitriding is a process in which the materials are hardened at a temperatureof 400°C to 900°C. This gas nitriding furnace is designed to be compact, automated, appropriate for all atmospheric conditions, and equipped with a configurable instrumentation system for automation. The Automated Gas Nitriding Furnace is designed and studied using the principle of heat transfer. It was created for experimental reasons. The furnace that can produce nitrogen at a specific temperature in a contained space under ideal working circumstances. The refractory bricks are formed between sheets of low carbon steel that make up the furnace. In the CREO 3D Modelling software, the components of the Gas Nitriding Furnace are modelled with all of the furnace's dimensions, and the modelled components are built in the same 3D modeling program. The draft sheets used to create the Gas Nitriding Furnace provide the output of the simulated furnace. The software Ansys Workbench 2022 R2 analyzes the total deformation and thermal stresses using static structural analysis and steady state thermal analysis. The instrumentation for the furnace is controlled and automated in this project using an Arduino and IoT technology. In the gas nitriding furnace, the temperature, voltage, gas mixture ratio, and pressure are all automatically controlled. The NodeMCU ESP8266 Microcontroller controls the furnace from a distance.

***Keywords*:** Gas Nitriding Furnace, Automation, Modelling, Analysis, Arduino, Blynk App Iot Server

1. Introduction

In order to finish the surface treatment process and boost resistance, gas nitriding is a heat treatment technique that helps dissolve nitrogen and hard nitride precipitates. By introducing nitrogen diffusion to the steel surface during the nitriding process, a hard layer is created on the material's surface.Gas nitriding, often known as ammonia nitriding, is a process where a nitrogen-rich gas, typically ammonia (NH3), serves as the donor. Ammonia splits into nitrogen and hydrogen when it comes into touch with the heated work item. The material's surface is then covered with a nitride layer as the nitrogen diffuses there.Although this process has been around for almost a century, research into the thermodynamics and kinetics has only recently become more focused. A process that can be precisely controlled has recently developed. The method can be tailored for the specific qualities required by choosing the layer thickness and phase composition of the resulting nitriding layers. A thermochemical procedure called nitriding is used to enrich the surface with nitrogen in order to increase the hardness of the surface. The method is based on the fact that iron nitrides or alloy nitrides precipitate more readily when nitrogen is less soluble in the ironic crystal structure. The diffusion zone where precipitated nitrides are uniformly disseminated in the steel matrix is coupled to the connecting nitriding. 350°C to 590°C is the typical nitriding temperature range. It is common practice to employ the surface hardening process of nitriding to improve the wear or corrosion resistance of particular steel grades. Sprockets, bearings, gears, and extrusion dies are frequently used in the aluminum extrusion business. The process of nitriding produces a hard case on treated metal and is conducted at temperatures below the temperature at which alloy steels change; therefore, the treated piece is distorted very little or not at all. With nitriding, quenching a quick cooling procedure is not required. In a heat treatment furnace that uses dissociated ammonia, an environment of hydrogen and nitrogen, the nitriding procedure is carried out. The high strength product produced by nitriding furnaces, which subject materials to active nitrogen at precisely controlled temperatures, increases fatigue strength.

1.1 Furnace Automation :

Ammonia or ammonia-hydrogen mixes are used in gas nitriding to increase the nitrogen activity. Easily separating into gaseous nitrogen and hydrogen, ammonia does so in accordance with chemical equilibrium. The industrial gas nitriding furnaces are semi-automated furnaces. The gas nitriding furnace is a heat treatment process which increases the hardness of the load samples for a given specified temperature and time. By using gas nitriding techniques to enrich the surface of ferrous components with nitrogen, nitriding produces parts with higher surface hardness, erosion and corrosion resistance, and tensile strengths. The furnaces are operated on the basis of man power. The controls of the gas nitriding furnace are human operated. The knobs, switches and displays are installed on the furnace control system. The heating system uses the temperature and pressure sensors to display the temperature and pressure of the furnace. These parameters can be controlled by use of knobs on the control system.

The furnace's automation requirements must be taken into account:

Maintaining a constant temperature, preventing a high temperature, steady pressure must be maintained continuously, Keeping the voltage variations at bay efficient gas mixture delivery to the furnace, automating the furnace's ON/OFF switch, Cycles must be added to the automated processes for the furnace, The Arduino IoT server should be used to control the complete control system. Notifies the operator of mistakes, processes, high temperatures, and voltage swings through alerts and alarm.

2. Design Methodology

2.1 Design Calculations of a Gas Nitriding Furnace

Based on Gas Nitriding Furnace the materials are to be considered to fabricate the furnace. The dimensions and parameters are to be found and the heating system is provided with the ceramic bricks material. The properties of bricks material and geometrical parameters are given below:

a) Specifications:

Height of furnace chamber= 1500mm

Width of furnace chamber = 600mm

Thickness of furnace chamber = 20mm

Taper bottom portion = 500mm

Density of brick used = 4900 kg/m^3

Density of mild steel = 7870 kg/m^3

For a brick that has a dimension =230x116x65mm

Volume of Brick = 0.23m x 0.115m x 0.065m

= 0.00173 m^3

From, density =mass/volume

Mass of one brick = density x volume of one brick

= 4900x 0.00173 = 8.49kg

Weigh of one brick, mg = 8.49x9.81 = 83.36N

b)Calculations for the internal and external diameter of the furnace.

Width of the furnace = 600mm

The space between furnace and the walls of the furnace crucible for both sides = 200mm each,

The thickness of the brick = 65mm.

The Internal diameter of the furnace = 600 + 200 + 200 = 1000mm

External diameter = internal diameter + thicknessof the bricks

External diameter = 1000+65+65+40 = 1170mm

c)Calculations for the internal and external height of the furnace.

Internal height of the furnace

= Height of chamber + $1\frac{1}{2}$ height of brick

Therefore, internal height of furnace

= 1500+115 = 1615mm

External height

= internal height of furnace + thickness of two bricks + metal sheet thickness

Therefore, External height of furnace = 1615+130+40 = 1785mm

d) Circumference of the furnace

The circumference of the furnace is = $2\pi r$

Where r = radius of the internal diameter of the furnace = 1000/2 = 500mm

Hence, the circumference = $2\pi x500$ = 3141.6mm

e) Calculating the number if bricks that could seat and stand in the furnace

Numbers of bricks that could be seating

Since the circumference = 3141mm

Therefore, seating bricks = 3141/length of brick

= 3141/230

= 13.65 ≈ 14 bricks in one layer

Since there are two layers in the bottom, 28 bricks would be needed at the bottom of the furnace

f) Number of bricks that could be standing

Standing bricks = 3141/height of bricks = 3141/116 = 27.07 ≈ 28 bricks

56 Bricks would be needed to stand round the furnace for the first layer

g)Calculating the total number of standing bricks that could be used for all the layers in the furnace

Internal height of the furnace-thickness of the brick at bottom of the furnace =1615mm-130mm =1485mm

Therefore, the number of layers of bricks = 1485/230

= 6.45 ≈ 7layers

Hence, the total number of standing bricks that would be needed to round the furnace = 4x56 = 226bricks

h)Calculating weight of the bricks

Weight of one brick = 83.36N

Total numbers of bricks in the furnace lining=282 bricks

Standing plus 56 bricks both at the bottom and top cover of the furnace.

Total weight of the bricks in the furnace = 282x83.36 = 23507.52N ≈ 23.507kN

i)Calculating for the weight of the metal sheet of the furnace

Recall that the volume of a cylinder= $\pi r^2 h$

Volume = $(\pi r^2 h)$external - $(\pi r^2 h)$internal

= $(\pi x 0.565^2 x 1.655)$- $(\pi x 0.5^2 x 1.615)$

= 0.3913m^3

Density = mass/volume

Mass= density of mild steel x volume

= 7860x0.3913 = 3075.618 ≈ 3076

Weight of the cylindrical metal sheet (mild steel)

= mg = 3076x9.81

= 30175.56N ≈ 30176N = 30.17kN

j)Calculating weight of the crucible

Since the crucible to be used is 1000kg Hence, its weight= mg = 1000 x 9.81 = 9810N = 9.81kN

k)Calculating the weight of the furnace cover

Density of the brick used = 4900 kg/m^3

Volume of one brick = 0.00173m^3

Since 28 bricks would be used at the cover, we have that its Volume= 28x0.00173 = 0.04844m^3

Mass of the furnace cover = density of brick x volume of brick= 4900x0.04844 =237.356kg

Its corresponding weight= mg = 237.356 x 9.81 = 2328.46N = 2.328kN

3. Gas Furnace Modelling

3.1 .3D Solid Parts Modelling of Gas Nitriding FurnaceUsing Creo Parametric

Creo Parametric is a 3D solid parts modelling software which initialize the various new files. The main Components of the Gas Nitriding Furnace are modelled as Part Models according to the input and obtained parameters and assembled in the Creo software.

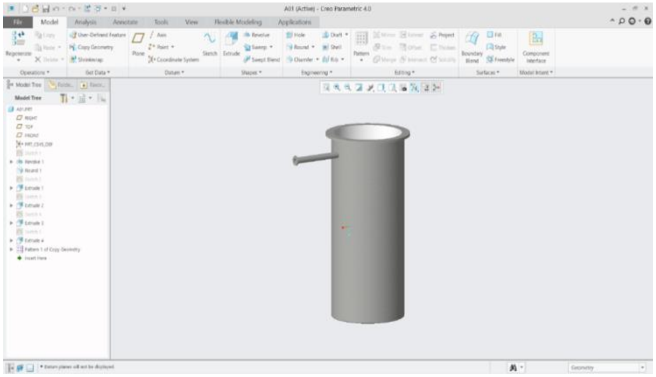


Fig 1.Furnace Chamber

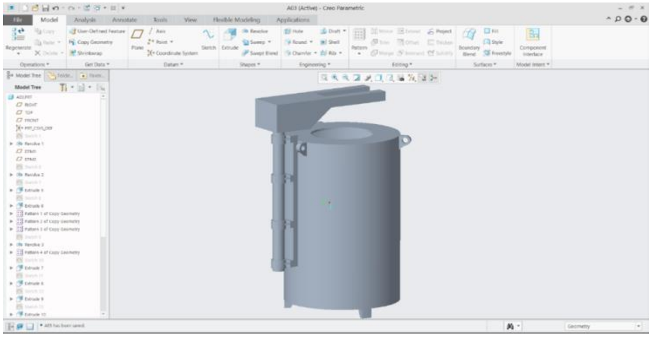


Fig 2: External furnace body

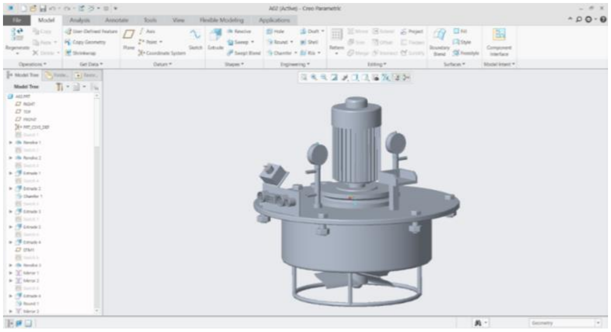


Fig 3: Furnace Lid

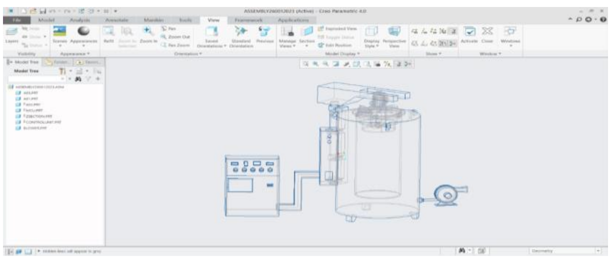


Fig 4(a):3D View of Furnace

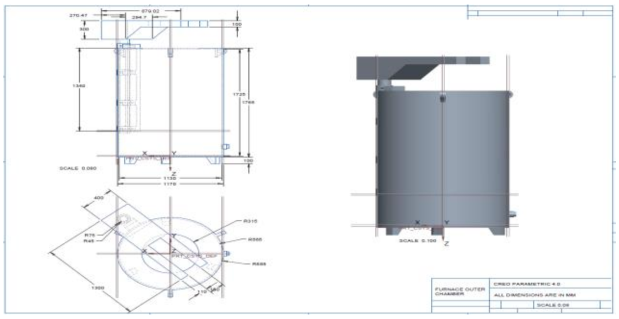


Fig 4(b): Draft Sheet of external Furnace

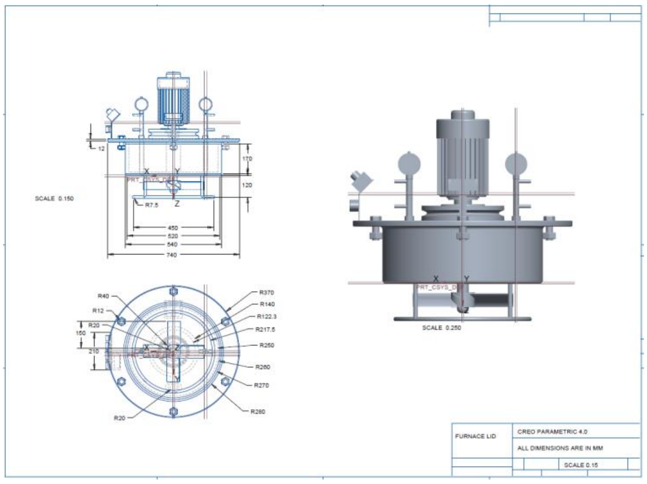


Fig.4(c): Draft Sheet of Furnace Lid

4. Structural and Thermal Analysis

4.1 Structural Analysis

Ansys Workbench is the name of the workflows and integration platform utilized by Ansys products. According to the project schematic, users may personalize their simulation processes, improve exploration through parametric management, submit jobs to the solver both online and offline, and add APIs to allow third-party software.

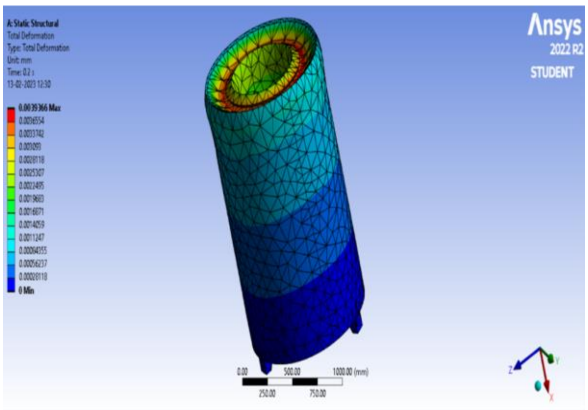


Fig 5: Total Deformation Distribution for 1000kg Load for AISI 1020

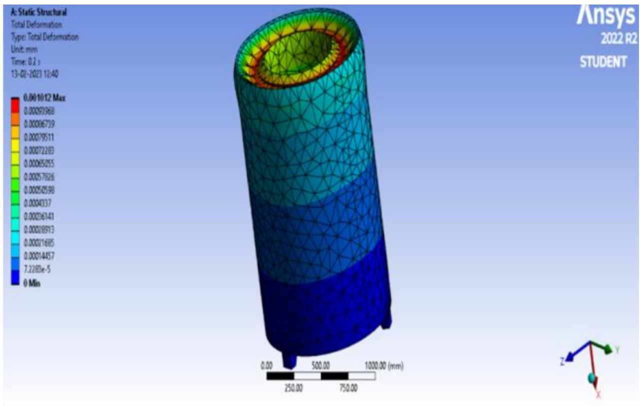


Fig 6: Total Deformation Distribution for 250kg Load for AISI 1020

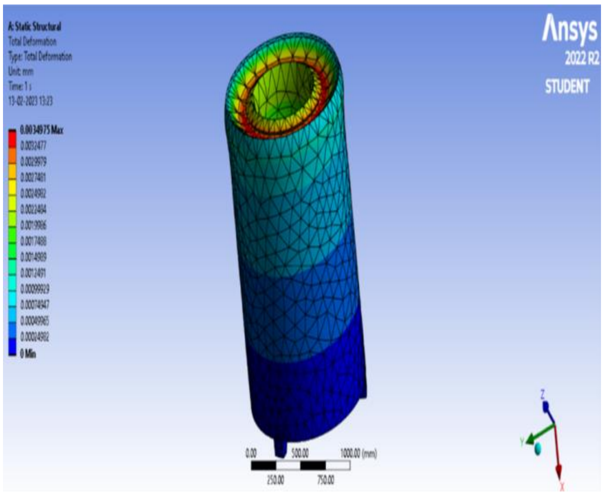


Fig7 : Total Deformation Distribution for 1000kg for Inconel 601

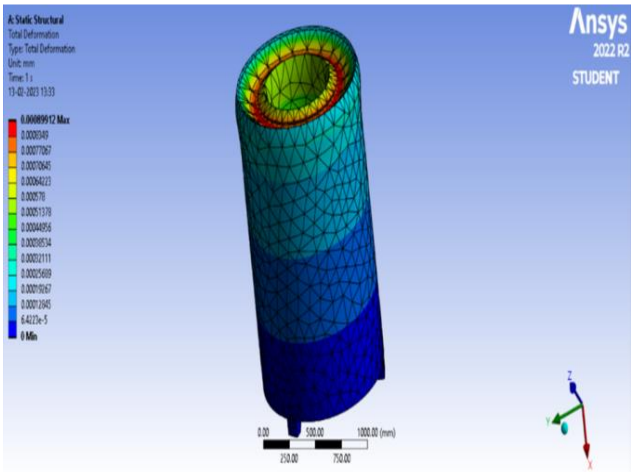


Fig 8: Total Deformation Distribution for 250kg for Inconel 601

Table 1: Results of Static Structural Analysis

Sl. No	Load (N)	Maximum Total Deformation (mm)	Maximum Equivalent Stress (MPa)	Maximum Shear Stress (MPa)	Maximum Equivalent Elastic Strain	Factor of Safety
AISI 1020						
1	**2450**	0.001012	0.85073	0.47425	4.58E-06	15
2	**4900**	0.0019868	1.6735	0.93264	9.01E-06	15
3	**7350**	0.0029617	2.4963	1.391	1.34E-05	15
4	**9800**	0.0039366	3.319	1.8494	1.79E-05	15
Inconel 601						
1	**2450**	0.00089912	0.49326	0.26627	2.39E-06	15
2	**4900**	0.0017653	0.97279	0.52514	4.72E-06	15
3	**7350**	0.0026314	1.45230	0.78402	7.05E-06	15
4	**9800**	0.0034975	1.9319	1.0429	9.37E-06	15

The findings of the static structural analysis, including total deformation, equivalent stress, shear strain, and equivalent elastic strain, are shown in the aforementioned Table 1. The aforementioned analysis examines two materials, namely INCONEL 601 and AISI 1020. The furnace is subjected to structural loads of 2450N, 4900N, 7350N, and 9800N. The overall deformation of the AISI 1020 material is 0.0039366mm for the applied load of 9800N, compared to 0.0034975mm for INCONEL 601. According to the results of the two materials mentioned above, INCONEL 601 performs better than AISI 1020.

4.2 Thermal Analysis

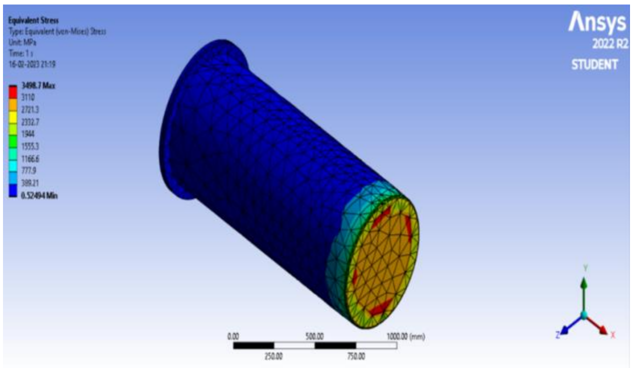


Fig 9: Thermal equivalent stress of AISI 1020 for temperature of 900°C

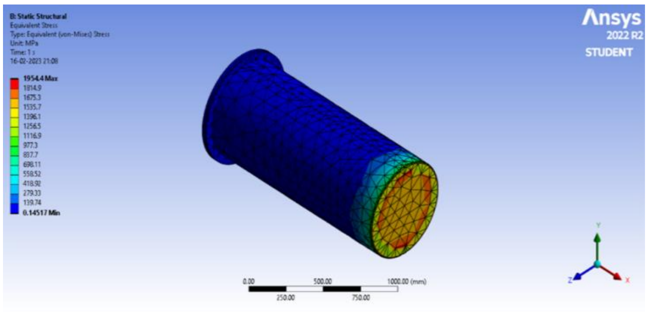


Fig 10: Thermal equivalent stress of AISI 1020 for temperature of 500°C

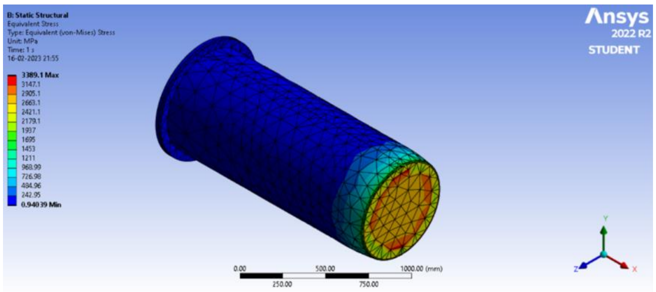


Fig 11: Thermal Equivalent Stress of Inconel 601 for 900°C temperature

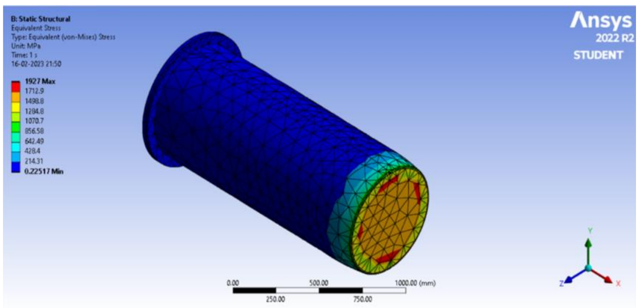


Fig 12: Thermal Equivalent Stress of Inconel 601 for 500°C temperature

The outcomes of the steady state thermal analysis are shown in table 2 below. Deformation, thermal stresses, and heat flux are the outcomes. In the analysis mentioned above, two materials, AISI 1020 and INCONEL 601, are examined. The furnace is subjected to thermal temperatures of 400°C, 500°C, 600°C, 700°C, 800°C, and 900°C. The thermal stresses of the materials AISI 1020 and INCONEL 601 are 3498.7 MPa and 3389.1 MPa, respectively, for a thermal temperature of 900 °C. According to the results of the two materials mentioned above, INCONEL 601 performs better than AISI 1020.

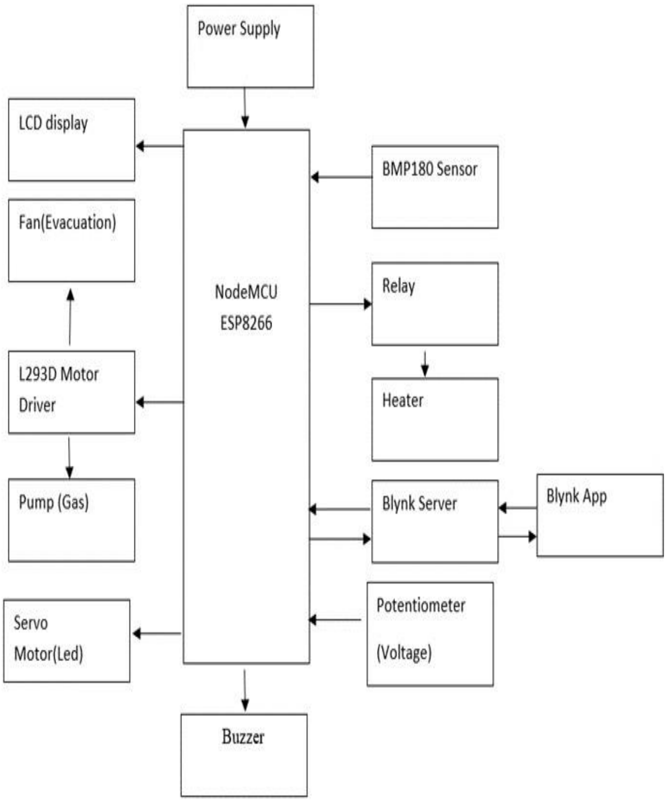
Table 2: Results of Thermal Analysis

Sl.No	**Temp Applied**	**Deformation (mm)**	**Maximum Thermal Equivalent Stress (MPa)**
AISI 1020			
1	**400°C**	7.1552	1552.1
2	**500°C**	9.0248	1954.4
3	**600°C**	10.879	2351.2
4	**700°C**	12.714	2741.4
5	**800°C**	14.528	3124.2
6	**900°C**	16.319	3498.7
INCONEL 601			
1	**400°C**	7.1098	1535.9
2	**500°C**	8.9478	1927
3	**600°C**	10.759	2308.7
4	**700°C**	12.54	2680
5	**800°C**	14.288	3040.1
6	**900°C**	16.003	3389.1

5. Furnace Instrumentation and Control System

The first step in instrumentation is joining a WiFi module to an ESP8266 microcontroller. Due to its 32-bit and 80MHz processor, the ESP8266 module may function as a standalone microcontroller and may have been used in conjunction with the Arduino library. This will help you lower the cost of your projects while still enabling design personalization. The ESP8266 modules come pre-loaded with open-source firmware. This module comes with a selection of pin-outs and an integrated USB port. The NodeMCU DevKit may be connected to your laptop using a micro USB cable, much as how Arduino is simple to flash. The entire working process will be monitored and reported to the user on a 16x2 LCD display. The hardware includes a BMP180 sensor that displays temperature and pressure information on the LCD screen.

Fig1 3 : Microcontroller Block Diagram



NODEMCU ESP8266 Microcontroller, BMP180 Sensor, L293D Motor Driver, DC Motor, Relay Switch, Buzzer, Water Pump, 16x2 LCD display, DC Fan 4010 12V, Resistors 1kilo-ohms, Potentiometer, and Powering the PIC and ESP8266 module with a 12V adapter are the hardware elements used in furnace instrumentation.

The Gas Nitriding Furnace Automation employs the Node MCU ESP8266 microcontroller, which interfaces with a variety of unique parts. Pressure and temperature are measured using a sensor known as the BMP180. A servo motor opens and closes the furnace lid. Relays are automatic ON/OFF electromechanical switches used to turn things ON and OFF. A heater is a device that acts as a heating element in a gas nitriding furnace. To regulate voltage changes, a potentiometer and microcontroller are linked. A DC fan is used in the circuit that demonstrates boiler evacuation. The L293D Motor Driver is interfaced with the microcontroller that controls the circuit. A buzzer is used to alert and notify the user of high temperatures and voltage fluctuations, and the LCD display that is built into the circuit is utilized as an LCD display. The operator has access to notifications and process parameters via an LCD display, a particular form of display. The furnace circuit is powered by a power source, and a regulator reduces the 230V power supply to 12V so that no electrical energy effects are seen by the operator. A blynk IOT server is used for IOT operations and APP development; whenever the system is powered on, the hotspot connects to the NodeMCU and starts uploading data to the server. Cycle 1 and Cycle 2 buttons in the app are used to initiate the procedure. The evacuation fan turns on for 5 seconds before turning off, the gas pump turns on for 5 seconds before turning off, and the heater turns on via relay module for 10 seconds and 20 seconds, respectively, according to cycles 1 and 2. When either of these cycles is chosen, the first will automatically open the led via servomotor for 3 seconds. A servo motor will open the lid once again after the heating process is over, ending the relevant Cycle Process and sending a notification to the app. If the temperature increases beyond 40°C, a warning system is engaged and sends a signal to the App and email. Also turned off is the furnace. The alerting mechanism activates in response to a voltage fluctuation, activating the buzzer and sending a notification to the app. and the notification area keeps track of the notifications.

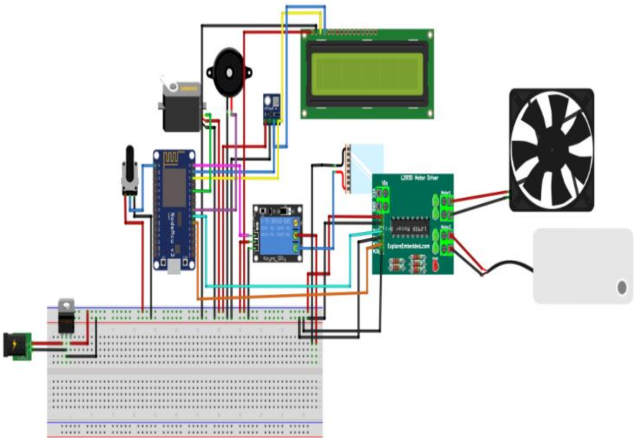


Fig 14: Circuit diagram of Arduino operated automated gas furnace

Two voltage regulator circuits make up the schematic diagram in Fig. 14. One is a 5V regulator that powers the PIC microcontroller, and the other is a 12V regulator that powers the ESP8266 module. A 7805 (Linear Voltage Regulator IC) is used to regulate 5V. The LM317 (Variable Voltage Regulator) is used to regulate 5V. In order to establish a USART communication between these two modules, ESP8266 runs at 3.3V voltage. This system's components include an LCD display, a potentiometer, a buzzer, a NodeMCU ESP8266 microcontroller, a relay module, a heating element, an L293D motor driver, a dc fan, and a pump. Using a 7805 voltage regulator, the power supply consists of a 12 volt DC and a 5 volt DC supply. The BMP180 sensor has four pins: VCC, ground, SDA, and SCL, which are connected to the power supply. The NodeMCU pins are VCC to the 5v pin, ground to the ground pin, SDA to the D2 pin, and SCL to the D1 pin of the NodeMCU. The NodeMCU connections VCC to the 5v pin, ground to the ground pin, SDA to the D2 pin, and SCL to the D1 pin are interfaced to the four pins on the LCD that are connected to the power supply. Three pins on the potentiometer—Vcc, ground, and output—are connected to the NodeMCU's A0 pin. The L293D is interfaced to the D6 and D7 pin of the controller, and the L293D is attached to the DC fan and DC pump to the Motor pins M1 and M2 of motor driver. The buzzer is attached to the D5 pin, the relay to the D0 pin, and a heating element to the NO pin of the relay.

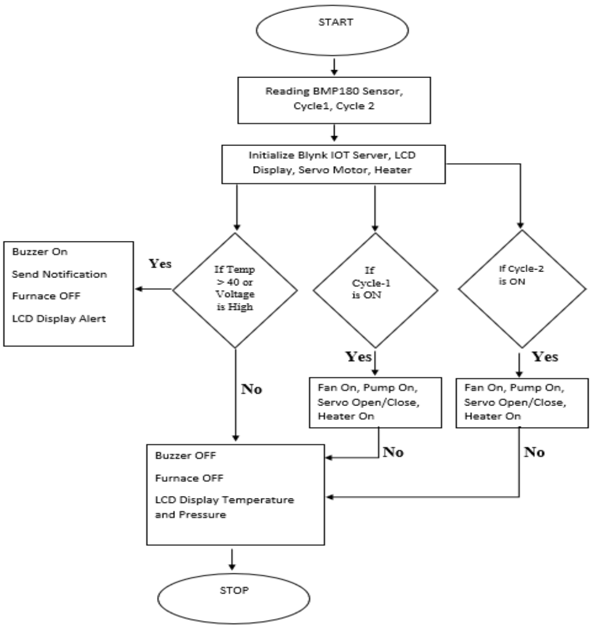


Fig.15: Flow Chart of Arduino Setup

5.1 Functioning of remote operated Furnace through Blynk & IoT Server

Fig 16: Cycle 1 Process completion notification

Fig 17: Cycle 2 Process Completion Notification

Fig 18: High Temperature Detection Notification

Fig 19: High Voltage Detection Notification

Figure 16 shows what happens if we turn on Cycle 1: the cycle begins to run and the furnace circuit receives power. Samples are loaded, the lid is closed, the container is evacuated, the heating element is heated, and then the readings are displayed on the server's screen. When Cycle 1 is finished, it alerts the user that the process is over.It also sends notifications via gmail and the app notifications. Figure 17 shows that if we turn on Cycle 2, Cycle 2 will activate, and whatever process was carried out in Cycle 1 will be carried out in Cycle 2. The server alerts the operator that Cycle 2 Process is Completed! after completing Cycle 2. In Figure 18, if the temperature reaches its maximum, the BMP180 sensor recognizes the high temperature brought on by the heating element's continuous heating and immediately sounds the alert by beeping. The furnace automatically turns off at that point, and the server alerts the operator that a high temperature has been detected! OFF! The furnace is now.Due to ongoing monitoring of the heating element's temperature, the furnace automatically turns on if the temperature drops down to its operating level. Using figure 19, Voltage variations can cause the furnace to explode and the power supply to short circuit if they are applied to the furnace. The furnace hardware has a potentiometer added to solve the voltage fluctuation issues. It continuously measures the input power supply's voltage. The furnace automatically shuts off if the voltage rises, and the IoT server connected to the furnace alerts the operator that a high voltage has been detected! Furnce is Switched OFF.

6. Conclusion

A hard layer is efficiently formed on the material's surface by adding nitrogen diffusion during the nitriding process to the load sample surfaces. The processes employed in the gas nitriding furnace are automated and minimized. The complicated, semi-automated Industrial Gas Nitriding Furnace is put under heavy weights of up to 10,000 kg. Our gas nitriding furnace is built with flexibility in mind and can handle low loads of up to 1000 kg. For load samples, the nitriding process can be carried out with little effort and under supervision. Our gas nitriding furnace makes it possible to automate all instrumentation activities, including furnace lid operation, gas mixture supply, furnace heating, and furnace evacuation. Through a mobile app, our automated furnace may be fully operated without the need for human intervention. According to the results, the maximum total distortion for Inconel is 0.0034975mm, whereas the maximum total deformation for AISI 1020 is 0.0039366mm. The selection of material in steady state thermal analysis takes into account thermal stresses. According to the findings, AISI 1020 has a maximum thermal stress of 3498.7MPa compared to 3389.1MPa for Inconel 601. According to both analyses, Inconel 601 performs better than AISI 1020 material when used to manufacture gas nitriding furnaces.

The NodeMCU ESP8266 microcontroller is used in the Automation of Gas Nitriding Furnace and is interfaced with numerous distinct components. In this Arduino hardware article, we explored how to use the Arduino library with the standalone 32-bit and 80MHz ESP8266 microcontroller that is a part of the WIFI module. A Wi-fi linked application called Blynk Server is in charge of managing all communications between the smartphone and our hardware. It may display sensor data, save data, and remotely control equipment. This paper involves interacting with the gas nitriding furnace's regulation of temperature, pressure, voltage, process cycles, processing time, and all other operations. Additionally, it can automate and regulate the gas nitriding furnace while alerting the operator to all functions and operations. It streamlines the process and eliminates the need for labor at the furnace. From any location in the world, we can control every operation and have access to the parameters and functionalities.

References:

[1] Olenyi Joseph Oghenekaro Peter Joseph Michael Irabodemeh Sheidu SumailaOnimisi,(2016), Design and Thermal Analysis of Crucible Furnace for Non – ferrous Metal, Journal of Information Engineering and Applications, ISSN 2225-0506, Vol.6, No.3, Page 5-9.

[2] F. H. Kurne Inamdar, S.B. Shelke, S.B. Sayyad R. H. Kadam,(2019),Differential Thermal Analysis of an Organic Compound using Atmega328p Microcontroller Based Embedded System,IJRAR January 2019, Volume 6, Issue 1,Pg 290-292.

[3] Mahesh Kisan Borate, Rajesh. R. Jaware, Arunkumar Shetty, Design, Manufacture &Commissioning Of 02 Ton Pit Type Furnace ForMill Scale Reduction Process, Mahesh Borate Journal of Engineering Research and Application, Vol. 8, Issue 9 (Part -I) Sep 2018, pp 08-11.

[4] Nguyen Duong Nam*, Nguyen Anh Xuan, Nguyen Van Bach, Le Thi Nhung, Le ThiChieu, (2019), Control Gas Nitriding Process: A Review, Journal of Mechanical Engineering Research & Developments (JMERD) 42(1) (2019) 17-25.

[5] ThanapornKorad*, Mana Ponboon, NiphonChumchery and John T.H.Pearce,(2013), Application of Flow Analysis in Improving Gas Nitriding Conditions in a Vacuum Furnace, Chiang Mai J. Sci. 2013; 40(5) : 909-922.

[6] Young-Min Kim, Seok Won Son, and Won-Beom Lee, (2018),Thermodynamic and Kinetic Analysis of Formation of Compound Layer During Gas Nitriding of AISI1018 Carbon Steel, Met. Mater. Int., Vol. 24, No. 1 (2018), pp. 180~186.

[7] Jerzy Ratajski, Roman Olik, Tomasz Suszko, Jerzy Dobrodziej and Jerzy Michalski,(2010), Design, Control and in Situ Visualization of Gas Nitriding Processes, Sensors 2010, 10, 218-240.

[8] I H Kurniawan, T A Y Nugraha,(2015) Analysis of Arduino Uno Application on Control SystemBased on Industrial Scale, IOP Conf. Series: Materials Science and Engineering,771,012015,Pg 1-5.

[9] D. Saber, Hamed M. Almalki, Kh. Abd El-Aziz,(2020) Design and building of an automated heattreatment system for industrial applications, Alexandria Engineering Journal (2020) 59, 5007–5017.

[10] Harshal Ingle, Ashish Talankar, Amrut Waghmare, Amit Sathawane, Prof. TinalThombare, (2018) Design and Implementation of Arduino Based Industrial Boiler Automation, IJSRST | Volume 4 | Issue 7, 23-28.

[11] Atilla Bayram, Sulaiman Abdullah Moammed and Fırat Kara, (2016), Design of Heating System Controlled by Arduino,4th International Symposium on Innovative Technologies in Engineering and Science 3-5, Pg-1583-1591, November,ISITES2016,Antalya.

[12] BalaramanujalaraoMarrey, vamsiKurmasala, Chandu Saketi and Dr.V.S.V.Satyanarayana,(2022), Design and Analysis of Arduino Based Solar-driven Rocker Bogie Robot, IEOM Society International, Proceedings of the 2nd Indian International Conference on Industrial Engineering and Operations Management Warangal, Telangana, India, August 16-18, 2022,Pg-2689-2699.

[13] Durga Prasanth &Sachidananda. H. K, (2019), Design And Analysis Of Pressure Vessel, International Journal of Mechanical and Production Engineering Research and Development (IJMPERD), Vol. 9, Issue 5, Oct 2019, 125–136.

[14] C. Anil Kumar Reddy, T. Kasivaraprasada Rao, M. Joshi, (2021), Design Integration And Analysis of Nose Dome For Application of External Pressure, Materials Today, Proceedings ,Volume 46, Part 20, 2021, Pages 10186-10203