

Development of Continuous Monitoring System for High Temperature Application

Submitted in fulfillment of the requirements for the award of
Bachelor of Engineering degree in Mechatronics

by

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**DEPARTMENT OF MECHATRONICS ENGINEERING
SCHOOL OF MECHANICAL ENGINEERING**

SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

**Accredited with Grade "A" by NAAC | 12B Status by UGC | Approved by AICTE
JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI - 600 119**

MAY - 2023



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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **Prasanna Kumar.M (39090037)** and **Nithishkar.M (39090035)** who carried out the project entitled "**Development of Continuous Monitoring System for high Temperature Application**" under our supervision from June 2022 to May 2023.

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We, **Prasanna Kumar.M (39090037)** and **Nithishkar.M (39090035)** hereby declare that the Project Report entitled “**Development of Continuous Monitoring System for high Temperature Application**” done by us under the guidance of **Dr.J.R.Deepak, M.E., Ph.D.** is submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering degree in Mechatronics.

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ABSTRACT

Process Monitoring System is implemented in the machining process to obtain the quality products, increase the precision, reduce defects, reduce machining time. The process monitoring system, involves in monitoring parameters like temperature, force, pressure, voltage, vibration etc., for the machining process like lathe operation, milling operation, drilling operation, boring, welding etc. On a traditional way of monitoring the parameters there are two techniques namely sensor-based techniques and image processing technique. In sensor-based techniques different types of sensors has been used for monitoring such as thermocouple, thermistor, RTD, pressure sensor, accelerometer, vibration sensor, load cell, strain gauge etc., these sensors are calibrated with a microcontroller for data analysis. Secondly, Image Processing technique involves in capturing the radiation of the machined/machining product by using Infrared camera, ultraviolet camera, photoelectric thermoscope, optical thermoscope, thermal image camera, continuous circuit television etc., the data captured by using the image sensing devices has been processed and analysed by using machine learning algorithm. In this research work a processing monitoring system for monitoring temperature of a weld metal welded by using MIG/TIG welding is developed. The weld monitoring system, monitors the rise in temperature of a welded metal during welding process like GTAW, GMAW, Laser Welding etc. It can be achieved by using Sensor-based technique. A K-Type thermocouple is fixed with a Low Carbon Mild Steel. This weld rig is placed under the welded metal and the heat distribution of the metal is studied and analyzed.

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LIST OF ABBREVIATIONS

RTD	Resistance Temperature Detector
GTAW	Gas tungsten arc welding
GMAW	Gas metal arc welding
TIG	Tungsten Inert Gas
MIG	Metal Inert Gas
IC	Integrated Chip
CMOS	Complementary metal–oxide–semiconductor
NTC	Negative Temperature Coefficient
PTC	Positive Temperature Coefficient
UPRT	Ultra-Precise Platinum Resistance Thermometer
SPRT	Standard Platinum Resistance Thermometer
MOSFET	Metal–Oxide–Semiconductor Field-Effect Transistors
PID	proportional–integral–derivative
PSO	Particle swarm optimization
TWT	Tool Work-Piece Thermocouple
FSW	Friction Stir Welding
FEA	Finite Element Analysis
CFRP	Carbon Fiber-Reinforced Polymers
AISI	American Iron and Steel Institute

CHAPTER 1

INTRODUCTION

1.1 PROCESS MONITORING SYSTEM

Process monitoring system, continuously monitors various parameters like temperature, pressure, vibration, force, voltage, current, etc. using various sensor and image processing-based techniques. Process monitoring system are applied in industrial machining process like drilling, milling, boring, welding, cutting, lathe operations, CNC machining etc. Various types of parameters monitored for various machining process has been shown in the figure 1.1.

The work piece and the work tool-piece are monitored in every machining process for a good quality finished product and also for proper machining operation. The defects such as cracks, blowholes, overlap, undercut, slag formation, over processing, tool breakage, change in weariness of the metal etc., can be avoided by using a Process Monitoring System. Cracks, blowholes, slag inclusion, excessive heating are few defects that occur in both the workpiece and tool used in various machining process like lathe machining, drilling, boring, milling, welding etc., due to the improper process monitoring of the machining system. Temperature, force, pressure, speed, time etc., are few process parameters that are to be continuously monitored and maintained during the machining process. Temperature is the most important factor that needs to be monitored during welding operation. If the temperature is not monitored continuously, it leads to major defects like burn through, lack of penetration, lack of fusion, excessive reinforcement, wider heat affected zone, deformation of metal etc. Temperature can be monitored by a sensor-based technique where temperature is measured by direct physical contact and Image capturing-based technique where temperature is monitored by using an imaging sensor. Sensor-based technique is simple, cost effective, easy to adapt to any machining process and can measures very accurate temperature values. In the sensor-based technique, the temperature is monitored with the help of array temperature sensors.

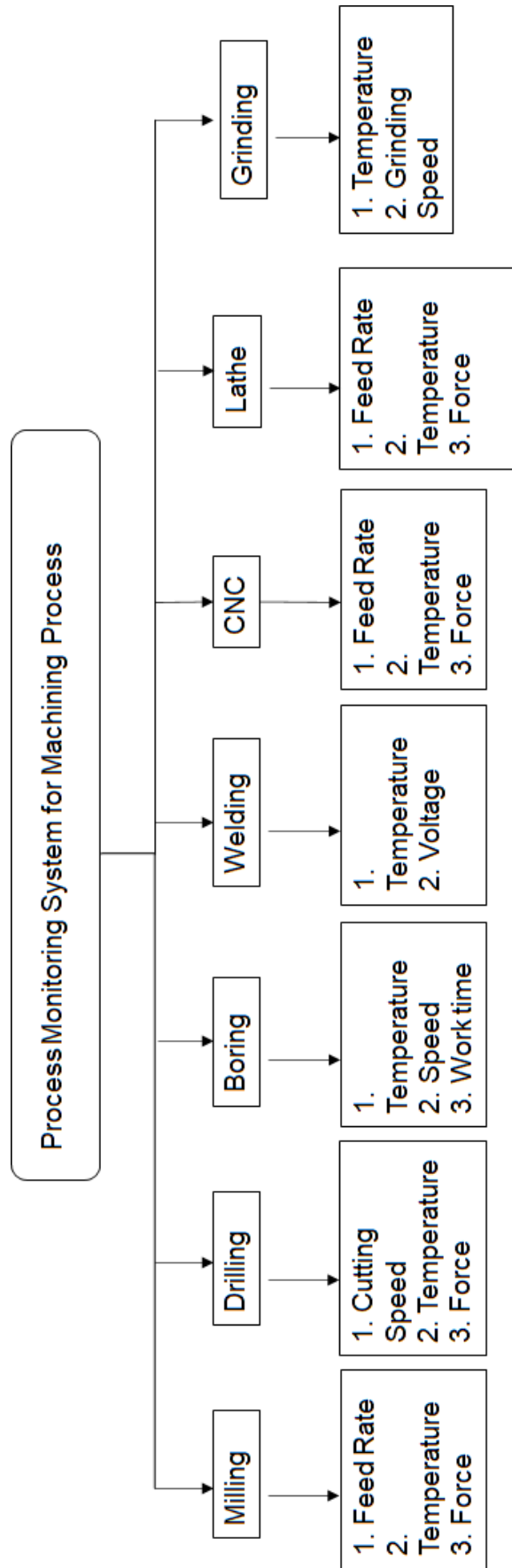


Fig:1.1 : Process Monitoring Classification for Machining Process

The Process Monitoring System is monitored by two methods 1. Sensor based monitoring 2. Image capturing technique. The Sensor based monitoring techniques uses different types of sensors for monitoring different parameters. These data are amplified by an amplifier and then collected for the data processing. In Image capturing technique infrared radiation camera, ultrasonic radiation camera, photoelectric camera etc., are used for the image capturing and a machine learning algorithm is used for data processing. The figure 1.2 represents the different types of sensors used to monitor different types of parameters in sensor based and image capturing technique for machining process.

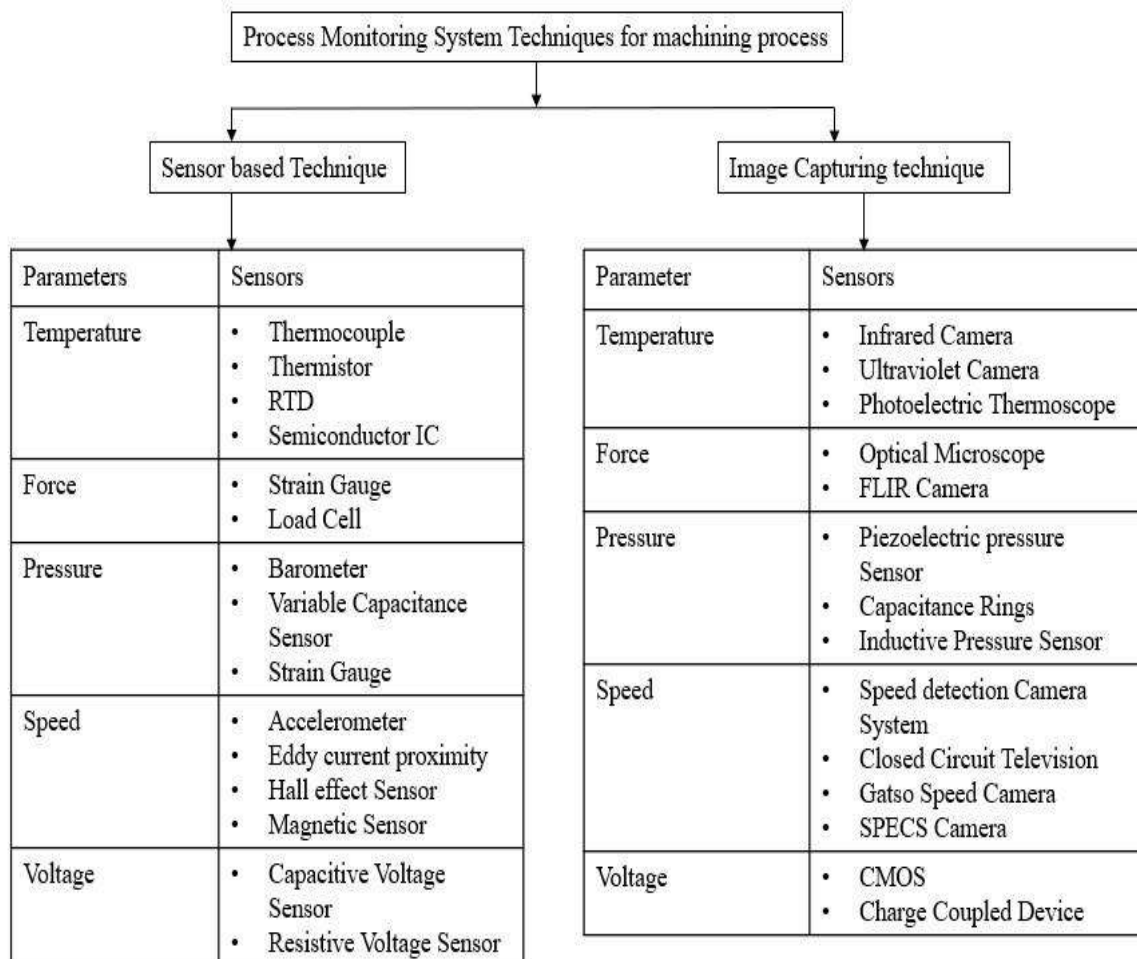


Fig:1.2 : Process monitoring system techniques for machining process

In welding process monitoring system, the important parameter to be monitored is temperature. The temperature for a process monitoring system can be monitored by using various types of sensors like thermocouple, thermistor, RTD, Integrated IC.

Namely in welding monitoring system Thermocouple and RTD are being used. These sensors are differed according to their properties and chemical composition.

1.2 THERMISTOR

Thermistor is a combination of two parameters namely “Temperature” and “Resistance”. The change in temperature changes the resistance of the metal. Thermistor is a type of a resistor, and its resistance is depended on the Temperature. It is classified into two types of PTC (Positive Temperature Coefficient) and NTC (Negative Temperature Coefficient). In PTC the resistance increases with increase in temperature and in NTC resistance decreases with increase in temperature. PTC thermistors are prepared from barium, sodium or lead titanates. NTC thermistors are prepared from oxide families of iron group like iron-oxides, chromium, manganese, cobalt, nickel.

NTC thermistors have a decreasing resistance as temperature increases, while PTC thermistors have an increasing resistance as temperature increases. The change in resistance is highly nonlinear and varies significantly with temperature, making thermistors highly sensitive temperature sensors. These thermistors are being used in lithium battery circuits, 3d printers, voltage-controlled oscillators and also in low temperature measurements. The thermistor is differentiated according to their Ohms range.

In addition, NTC thermistors are used in electronic circuits to compensate for changes in resistance due to changes in temperature. They are also used in automotive applications to measure the temperature of engine coolant, transmission fluid, and other fluids. NTC thermistors have a number of advantages over other types of temperature sensors, including their small size, low cost, and high accuracy. However, they do have some limitations, including a limited temperature range, and sensitivity to self-heating effects. Thermistors are commonly used in applications where high sensitivity is required, such as in temperature compensation circuits, in medical devices, and in automotive applications. They are also generally less expensive than other types of temperature sensors, such as RTDs, but their accuracy can be affected by self-heating and noise. The different types of thermistors are shown in the table below.

Table 1.1 : Thermistor types and its temperature range

Model	Resistance value(K Ω)	Temperature range ($^{\circ}$ C)
TCS605	5	-20 to +33
TCS610	10	-8 to +50
TCS10K5	10	-8 to +50
TCS620	20	+6 to +69
TCS650	50	+25 to +92
TCS615	100	41 to 114

Sourcefile:<https://www.teamwavelength.com/download/Datasheets/tcs605.pdf>

1.3 RTD

Resistance Temperature Detector works in the principle of change in temperature, changes the resistance value. The RTD is made with a heat resistance ceramic core connected with a fine wire. The wire is made of using a pure material namely platinum, nickel, copper. The RTD is classified into three types UPRTs (Ultra Precise Platinum Resistance Thermometer), SPRTs (Standard Platinum Resistance Thermometer), Industrial PRTs. These types are differed according to their applications. The RTD is differed from thermistor based upon the temperature range. As the temperature of the RTD changes, the resistance of the platinum wire also changes. This change in resistance is proportional to the change in temperature, according to a mathematical relationship called the temperature coefficient of resistance. The electrical resistance of an RTD increases as its temperature increases. This change in resistance can be measured using a Wheatstone bridge circuit, which is a commonly used electronic circuit for measuring small changes in resistance. The Wheatstone bridge circuit consists of four resistors, including the RTD, arranged in a diamond pattern. The voltage across the bridge is proportional to the RTD's resistance, which can be measured and converted to temperature using calibration data. The most commonly used RTD material is platinum because of its stability, linearity, and repeatability. The most common type of platinum RTD is the PT100, which has a resistance of 100 ohms at 0 $^{\circ}$ C. Other types of RTDs include nickel, copper, and tungsten. RTDs are used in a variety of industrial and scientific applications, including chemical processing, food and beverage, pharmaceuticals, and

aerospace. They are used in applications where precise and accurate temperature measurement is essential. One advantage of RTDs over other temperature sensors is their high accuracy and stability over a wide temperature range. They can measure temperatures from -200°C to $+850^{\circ}\text{C}$ with an accuracy of up to 0.1°C . Another advantage of RTDs is their long-term stability and reliability. They have a very low drift over time, which means that their calibration remains accurate for extended periods. To obtain accurate temperature measurements with RTDs, it is essential to take into account various factors that can affect the RTD's resistance, such as the lead resistance, self-heating, and temperature gradients. These factors can be compensated for by using specialized RTD instruments or by using techniques such as three-wire or four-wire configurations. Overall, RTDs are highly accurate, reliable, and versatile temperature sensors that are widely used in various industrial and scientific applications. They offer high accuracy, stability, and repeatability over a wide temperature range, making them an essential tool for precise temperature measurement. This relationship is well-defined and repeatable, which makes RTDs highly accurate and reliable temperature sensors. The average temperature range of an RTD is 600°C - 700°C , at 390 ohm the maximum temperature can be measured is 1560°C . RTDs are used in automotive, industrial, in high temperature measurements with high accuracy rate and RTDs are used in a wide variety of applications, from laboratory research to industrial process control. They are particularly useful in applications where high accuracy is required, and where the temperature range is between -200°C and 850°C . However, RTDs are generally more expensive than other types of temperature sensors, such as thermocouples or thermistors, and are more susceptible to damage from vibration or shock.

1.4 INTEGRATED IC

An Integrated IC is a type of temperature sensor which can measure temperature from -70 degree Celsius to 150 degrees Celsius. Basically, an integrated IC is a semiconductor diode which consists of two similar diodes that are sensitive to temperature. Its operational temperature is about 3V to 5V . Most likely these types of temperature sensor are used in embedded circuit and other small applications like body temperature monitoring etc.

An integrated circuit or monolithic integrated circuit is a set of electronic circuits on one small flat piece of semiconductor material, usually silicon. Large numbers of tiny MOSFETs (metal–oxide–semiconductor field-effect transistors) integrate into a small chip. This results in circuits that are orders of magnitude smaller, faster, and less expensive than those constructed of discrete electronic components. The IC's mass production capability, reliability, and building-block approach to integrated circuit design has ensured the rapid adoption of standardized ICs in place of designs using discrete transistors. ICs are now used in virtually all electronic equipment and have revolutionized the world of electronics. Computers, mobile phones and other home appliances are now inextricable parts of the structure of modern societies, made possible by the small size and low cost of ICs such as modern computer processors and microcontrollers.

1.5 THERMOCOUPLE

Thermocouple works in the principle of see-beck effect. Two different metals are bonded together in a junction to form an electrical circuit. The difference in the temperature between the junction changes the flow of electric current in the circuit. These thermocouples are classified into many types, such as B, C, E, J, K, N, R, S, T. Thermocouples are being used in various industries such as Automotive sensing, rocket and aircraft engines, food processing, electric power generation. The main difference between the thermocouple and RTD is precision and accuracy of the sensor. Thermocouples are high accurate but not precise. Thermocouples are differed depending upon the metal combination. Thermocouples are widely used in various industrial and scientific applications where precise temperature measurement is required. They are relatively inexpensive, durable, and can measure temperatures over a wide range, from -270°C to $+2300^{\circ}\text{C}$, depending on the type of metals used. Common types of thermocouples include type K, type J, and type T. Type K thermocouples are made of chromel (90% nickel, 10% chromium) and alumel (95% nickel, 2% manganese, 2% aluminium, and 1% silicon) wires. Type J thermocouples are made of iron and constantan (55% copper, 45% nickel) wires, while type T thermocouples are made of copper and constantan wires. Thermocouples are used in a variety of industries, including food and beverage, pharmaceuticals, chemicals, and manufacturing. They are often used to monitor and control temperature in ovens, furnaces, and other heating equipment. They are also used in medical applications,

such as monitoring body temperature during surgery. To obtain accurate temperature measurements with thermocouples, it is essential to consider various factors that can affect the thermoelectric voltage generated, such as the temperature of the reference junction, the resistance of the wires, and the quality of the connection between the wires and the measuring instrument. To compensate for these factors, various techniques can be used, such as using a reference junction temperature sensor, using compensated cables that have known resistance, and using cold junction compensation techniques that measure the temperature at the reference junction and adjust the temperature readings accordingly. Overall, thermocouples are reliable and versatile temperature sensors that are used in a wide range of applications where accurate temperature measurement is essential. The thermocouple temperature range and metals used are shown in the table below.

Table 1.2 : Thermocouple and its temperature range

Types	Temperature Range	Metal combination
B-Type	1370-1700°C	Platinum - Rhodium
C-Type	1650-2315°C	Tungsten - Rhenium
E-Type	95-900°C	Chromel - Constantan
J-Type	95-760°C	Iron - Constantan
K-Type	-200-1260°C	Chromel - Alumel
N-Type	650-1260°C	Nickel - Chromium
R-Type	870-1450°C	Platinum - Rhodium
S-Type	980-1450°C	Platinum - Rhodium
T-Type	-200-350°C	Copper - Constantan

1.6 CHALLENGES AND PRECAUTIONS TO BE FOLLOWED BEFORE USING THERMOCOUPLE

Thermocouples are not accurate as RTD, and these types of sensors are highly corrosive when it is not insulated properly. The output signals are not linear. The accuracy level compared to RTD is less. While using the thermocouple, avoid contact with the magnetic field. If using in an electrolytic process, avoid contact with the electrode. The thermocouple needs to be periodically checked to see if it is functioning properly. Thermocouples have a specific temperature range, and when they are utilised beyond it, they risk being harmed. Before using, the thermocouple's temperature range should be examined, and a suitable thermocouple should be chosen.

CHAPTER 2

LITERATURE SURVEY

2.1 TEMPERATURE MEASUREMENT IN FRICTION ELEMENT WELDING PROCESS WITH MICRO THIN FILM THERMOCOUPLES

A micro thin film thermocouple was developed for the temperature measurement of friction stir welding of Al 6005 and JSC 980 steel of 40*40 mm dimension. An array of micro thin film thermocouples (TFTC) was fabricated on top of a multi-layer insulating die electric film on the JSC 980 Steel.

The dimension of the K-Type thermocouple is 50*50 μm and it is composed of 120 nm of chrome and 180 nm of alumel. The TFTC used in this work has a linear sensitivity of 41.3 V/ $^{\circ}\text{C}$ to a temperature of 1000 $^{\circ}\text{C}$. This method measured the temperature reading from 219 $^{\circ}\text{C}$ to 414 $^{\circ}\text{C}$ at a distance of 3.15 mm.

Study of temperature evaluation of the FEW processes is done. The microstructure analysis is done for each step of FEW for the study of temperature distribution on the weld metal.[13]

2.2 CALIBRATION OF DYNAMIC TOOL-WORKPIECE INTERFACE TEMPERATURE MEASUREMENT DURING FRICTION STIR WELDING

The thermocouple is configured with the FSW (Friction Stir Welding) tool for monitoring the temperature of the work tool. The machining process, where the tool-workpiece will produce a huge amount of heat, can be monitored using this technique.

The tool used in friction stir welding is typically spun at 1000RPM, which will produce high heat in the work piece. In this FSW process, the K-Type thermocouple is placed between the probe and the shoulder of the tool for the measurement of temperature. The FSW tool is made of H13 steel of shoulder diameter 15mm and tip diameter 5mm, and the K-Type thermocouple is surrounded by magnesium oxide (MgO) and mounted using thermocouple cement (Omega Bond 600).

At the shoulder, the temperature 1 measured is 520 $^{\circ}\text{C}$ –540 $^{\circ}\text{C}$ while rotating the tool at an angle of 0 $^{\circ}$ –210 $^{\circ}$ and the temperature 2 measured is 545 $^{\circ}\text{C}$ –550 $^{\circ}\text{C}$ while rotating the tool at an angle of 30 $^{\circ}$ –180 $^{\circ}$. The temperature measured at the probe is 498 $^{\circ}\text{C}$ –508 $^{\circ}\text{C}$ while rotating the tool at an angle of 0 $^{\circ}$ –240 $^{\circ}$ and 502 $^{\circ}\text{C}$ –506 $^{\circ}\text{C}$ while rotating

the tool at an angle of 30°–150°. The one-dimensional model has been created using the temperature readings.[6]

2.3 STUDY ON HIGH-SPEED HIGH-TEMPERATURE ADAPTIVE FUZZY PID CONTROL SYSTEM

Using a high-speed, high-temperature adaptive fuzzy PID control system in the welding process, the temperature is monitored and controlled. This control system has two parameters: the Photoelectric Thermoscope and the Fuzzy Logic PID controller. The real-time thermal image of the weld is captured by the photoelectric thermoscope, and the Fuzzy logic PID controller is used for monitoring temperature and maintaining the temperature of the welding process.

The photoelectric sensor is a device that will capture all types of heat signals in an image format. The fuzzy logic PID controller improves the response time of the photoelectric sensor and increases its precision. The photoelectric thermoscope has a range of 200 °C–1100 °C at a soldering temperature of 500 °C–800 °C.

Using this technique, the temperature is monitored, and it can also be set/controlled to a particular temperature range while welding. The study of temperature is done for the welding process.[5]

2.4 STUDY OF ON-LINE TEMPERATURE MONITORING SYSTEM FOR HULL WELDING BASED ON XGBOOST-PSO

In this work, the temperature is monitored for the hull welding process using a K-Type Magneto-Thermocouple and the data is sent through via the internet. This data is manipulated using the Xgboost-PSO algorithm.

The output value of the magneto temperature sensor is amplified using MAX series amplifiers and filtered using a filtering-circuit with a frequency rate of 50Hz. By using the STM-32 microprocessor, this data is shared on the internet.

The GBDT and Xgboost algorithms increase the accuracy of the thermocouple and solve non-linearity problems in it. The PSO algorithm reduces the error dynamically. The gradient lifting decision tree has high precision over the data and is used for on-line temperature monitoring. The temperature measured in the On-line temperature monitoring was 250 °C–500 °C with a reduced absolute error of 1.0 to 0.3.[11]

2.5 PEAK TEMPERATURES DURING FRICTION STIR WELDING OF Ti-6Al-4V

The study of the temperature distribution of FSW (Friction Stir Welding) process in the Ti-6Al-4V was done by using a K-type thermocouple.

The K-Type thermocouple with a diameter of 0.8mm is configured with a Ti-6Al-4V of 12mm thickness. The data is communicated with the help of a GL800 digital data collector. The chemical composition of Ti-6Al-4V is Ti-6.28Al-0.1C-0.21Fe-0.010N-0.13O-4.05. The result shows that for 300 rev/min at 100 mm/min, the peak temperature was about 1100 °C. At a spindle speed of 300 RPM-500 RPM and a feed rate of 100 mm/min-150 mm/min, the maximum temperature reading is around 1000 °C-1200 °C.

The temperature developed in the weld metal has been studied at different spindle rates and feed rates in the FSW process of Ti-6Al-4V metal.[12]

2.6 DEVELOPMENT AND APPLICATION OF A TEMPERATURE MEASUREMENT DEVICE USING THE TOOL-WORKPIECE THERMOCOUPLE METHOD IN TURNING AT HIGH CUTTING SPEEDS

When the cutting speed of the tool-piece increases, the cutting temperature of the work piece also increases, and it will affect the machining process as well as the material property. Hence, to control the temperature developed in the work piece, a K-Type thermocouple is configured with the cutting tool.

In the machining process, the workpiece used is 1350 aluminium alloy and 7075-T6 aluminium alloy. These alloys are cooled in water and artificially aged at 120°C for 24 hours. The cutting operation is carried out on a CNC machine powered by 11 kW, and it has a maximum spindle speed of 300RPM. For 1350 Al, the temperature developed was 300°C-430°C and for 7075 Al, the temperature developed was 450°C-660°C.

Thus, the temperature developed in the work piece is studied and the cutting temperature is maintained.[14]

2.7 THERMOELECTRIC MEASUREMENTS FOR TEMPERATURE CONTROL OF ROBOTIC FRICTION STIR WELDING

Temperature monitoring system is developed in a robotic friction stir welding by using a TWT method. The welding is taking place in the AA6082-T6 metal. The robotic FSW is ISO 25239-4 approved machine which can produce 1500N – 7500N of force.

In Tool Workpiece Thermocouple (TWT) the thermocouple is configured at the TTC-Probe, TTC-Shoulder and TTC-Corner of the 12mm thick FSW tool. The average temperature developed in TTC-Corner: 594°C-607°C, TTC-Shoulder: 555°C - 596°C, TTC-Probe: 522°C-554°C. At core of the weld the temperature developed is 607°C. Using TWT method the overall temperature developed at the operating speed: applied force: temperature developed is 5mm/s:2500N – 7500N:510°C, 10mm/s:2500N-7500N:560°C.

The study of the temperature of the tool and work piece is done and controlled over the temperature developed.[3]

2.8 WORKPIECE TEMPERATURE INVESTIGATION IN MICRO MILLING OF TITANIUM ALLOY

A technology has been developed for monitoring the temperature of the work piece as it undergoes micro milling operations. The micro milling operation is done in two different metals, namely Ti-6Al-4V and H13 steel.

The temperature is monitored by using a T-Type thermocouple and it is fixed in the surface of the work piece. An AlCrN-coated carbide micro cutter is used for the milling operation. The temperature is studied in an experimental method using a sensor and also simulated by using Third Wave Edge software. By using 2D FEA, while using a 100 µm micro cutter with an edge angle of 90°, the maximum temperature monitored was 300 °C for H13 steel, and while using a 508 µm micro cutter, the maximum temperature monitored was 100 °C for Ti-6Al-4V alloy.

The experiment proved that the temperature is highest at the up-milling side, and as the temperature increases, the tool weariness also increases. The study of temperature is done by using the 2D FEA method.[8]

2.9 EXPERIMENTAL AND THEORETICAL INVESTIGATIONS ON TEMPERATURE DISTRIBUTION AT THE JOINT INTERFACE FOR COPPER JOINTS USING ULTRASONIC WELDING

Using K-Type thermocouples, the temperature is monitored in the ultrasonic welding of copper joints. The ultrasonic welding machine works at 2500 W, 20 kHz.

In this work, the weld metal used is Cu and its thickness is 0.2mm-0.3mm. The temperature measured at a low-level frequency of welding is 110°C, and at a high frequency of welding, the temperature measured is 155°C-250°C. The mathematical modelling is done using FDM in MATLAB at the weld temperature of 200°C. The temperature developed at the weld interface is simulated in the FEA software.

The temperature developed in the weld metal is studied, and the mathematical modelling is done using the FDM method. This work concludes with the increase in work time increasing the temperature of the weld metal.[16]

2.10 CUTTING TEMPERATURE MEASUREMENT ON MILLING PROCESS OF CFRP

The cutting temperature measurement on Milling Process of CFRP is developed for monitoring the operational temperature in CFRP metal of thickness 7mm by using K-Type thermocouple.

The machining process is done in Vertical milling machine with a maximum rotational speed of 12,000/min and the power consumed is 18.5W. In the milling machine the cutting tool used is of 8mm diameter. The K-Type thermocouple is fixed in the CFRP metal under the machined surface level of 0.7mm. The thermocouple is connected with a resistor and to the data logger. The maximum temperature monitored at a cutting speed of 300mm/min is 60°C.

The temperature developed in the workpiece while milling operation is studied and microstructure analysis is done.[17]

2.11 CUTTING TEMPERATURE MEASUREMENT BY A MICRO-SENSOR ARRAY INTEGRATED ON THE RAKE FACE OF A CUTTING TOOL

Using thin film thermocouple, the temperature is monitored in the rake face cutting tool. The cutting process is done in a nylon material for medical application.

At the cutting edge of the cutting tool the Cr thin metallic line (Hot junction) and the Al₂O₃ metallic line (cold junction) is cemented by using WC-Co and named as Thermocouple A. At the chip friction area another thermocouple has been attached and named as Thermocouple B. The difference in the temperature between two thermocouples are 2°C. While machining process the temperature measured at cutting edge is 40°C – 80 °C and at chip formation area the temperature measured is 38°C - 78°C.

The temperature between two junctions has been monitored and studied. [10]

2.12 ON THE MEASUREMENT AND PREDICTION OF TEMPERATURE FIELDS IN MACHINING AISI 1045 STEEL

The temperature developed in the AISI 1045 steel while machined in the orthogonal cutting machine has been monitored by using an Infrared Microscope.

The AISI 1045 steel is machined at a different feed rate and different cutting speed. The infrared microscope is kept in a particular direction that captures the thermal image of the chip which is removed from the workpiece. The temperature readings are taken for four different chip thickness. (a)48 µm -100°C to 800°C (b)40 µm -100°C to 800°C (c)31 µm -100°C to 700°C (d)23 µm -100°C to 700°C.

The temperature is monitored and studied. FEA model is created. A relation between friction coefficient and temperature is obtained.[9]

2.13 AN INTEGRATED TELEMETRIC THERMOCOUPLE SENSOR FOR PROCESS MONITORING OF CFRP MILLING OPERATIONS

In CFRP process drilling and milling operations are done, for both the operation the tool has a critical temperature of 180°C to 270°C, the temperature of the tool was monitored by using Integrated Telemetric Temperature (ITT) sensor.

The ITT sensor has been configured inside the CFRP carbide tool. The dynamic response testing and then calibration in LabVIEW has been carried out for the temperature readings obtained in the tool. The bulk temperature obtained from the tool in the milling process is 175°C.

The temperature of the CFRP tool has been monitored, studied and maintained.[7]

2.14 TEMPERATURE MEASUREMENTS DURING FRICTION STIR WELDING

Measurement of temperature of the Friction Stir Welding (FSW) Tool of aluminium alloy. The temperature of the tool is measured with the TWT method.

The TWT method is a technique in which the thermocouple is fixed in the FSW tool for the temperature monitoring. The variation of force and the spindle rate changes the temperature developed in the tool of FSW tool. Which cause defect in the work piece. Hence the temperature developed in the tool is studied for different spindle rate. The temperature developed at the probe of the tool is 300°C to 600°C and at the shoulder the temperature developed is 350°C to 600°C.

The temperature developed in the tool of FSW process was monitored and controlled over the temperature.[15]

2.15 THERMOCOUPLE AND INFRARED SENSOR-BASED MEASUREMENT OF TEMPERATURE DISTRIBUTION IN METAL CUTTING

Temperature monitoring system was developed by using thermocouple and infrared sensor for the cutting process of AISI 4140 steel.

At the initial stage of the machining process AISI 4140 is heat treated with T6 to form aluminium 6082-T6 and machined by cutting tool in lathe machine. The K-Type thermocouple is configured in the work tool for monitoring the temperature developed in the work tool and infrared pyrometer is configured for measuring the cutting temperature and the temperature of the chip. The aluminium is machined with a different cutting speed and feed rate. The average temperature developed in the tool is 57°C to 80°C and the average temperature of the chip is 410°C to 500°C.

The temperature is monitored and studied with the help of ANSYS finite element method.[1]

2.16 A COMPARATIVE REVIEW OF THERMOCOUPLE AND INFRARED RADIATION TEMPERATURE MEASUREMENT METHODS DURING THE MACHINING OF METALS

The relevance of temperature monitoring in machining processes is briefly discussed, along with the benefits and drawbacks of various temperature measurement

techniques. Thermocouples are inexpensive, highly accurate, and capable of real-time temperature measurement in machining.

The overall review of the use of thermocouples for temperature measurement in machining operations is described by "Thermocouple-Based Temperature Monitoring in Machining: A Review." The benefits and drawbacks of thermocouples are discussed in the study, along with the various types and measurement methods, problems and solutions. The use of thermocouples in various machining processes is also illustrated by how the thermocouples can enhance process control and optimisation.[2]

2.17 DEVELOPMENT OF A WELDING MONITORING SYSTEM FOR IN-PROCESS QUALITY CONTROL OF THICK-WALLED PIPE

When two or more materials are heated to their melting points and then allowed to cool and solidify, a bond is formed. This process is known as welding. The temperature, pressure, and duration of the welding process are some of the variables that affect the weld's quality. The metallurgical characteristics of the welded material, such as its microstructure and mechanical properties, are affected by temperature, making it a crucial welding parameter.

This method is efficient in monitoring the temperature while welding. The technology offered real-time temperature information that is helpful for process optimisation and quality control. Also, it was observed that the system is simple to use and minimal training to operate.[4]

Table 2.1: Summary of various methods of temperature monitoring system

S.no	Machining process	Material	Sensor	Temperature measured	Outcome
1	Friction Stir Welding	Al 6005, JSC 980	Thin film thermocouple	219°C -414 °C	A study of temperature and microstructure analysis is done.[13]
2	Friction Stir Welding (Cutting tool)	H13 steel	K-Type thermocouple	520°C	A one-dimensional model is created using the temperature reading.[6]
3	Welding	Any metal	Photoelectric sensor	200°C-1100°C	Temperature is studied. [5]
4	Hull Welding	Any metal	K-Type thermocouple	250°C-500°C	On-Line monitoring of temperature is studied.[11]
5	Friction Stir Welding	Ti-6Al-4V	K-Type thermocouple	1000°C-1200°C	Temperature is studied at different feed and spindle rates.[12]
6	CNC Machine	1350 Alloy and Ti-6Al-4V	K-Type thermocouple	300°C -430°C and 450°C-660°C	Cutting Temperature is monitored and controlled. [14]
7	Robotic Friction Stir Welding	AA 6082-T6	Tool, work piece thermocouple	522°C-607°C	The temperature of tool and workpiece is monitored.[3]
8	Micro Milling	Ti-6Al-4V, H13 steel	T-Type Thermocouple	100°C, 300°C	Temperature is studied.[8]
9	Ultrasonic Welding	Copper	K-type thermocouple	135°C -250°C	Mathematical model is created in FDM. [16]
10	Milling	CFRP	K-type thermocouple	60°C	Microstructure analysis. [17]

11	Cutting	Nylon	Thinfilmm thermocouple	40°C -80°C	Temperature is studied. [10]
12	Cutting	Steel	IR microscope	100°C - 800°C	FEA model is created. [9]
13	Drilling and Milling	CFRP tool	ITT sensor	180°C - 270°C	Dynamic Response [7]
14	FSW	Aluminum alloy	Thermocouple	300°C - 600°C	Temperature in monitored and controlled. [15]
15	Cutting	AISI 4140 steel	Thermocouple and IR thermoscope	57°C - 80°C And 410°C - 500°C	Study of temperature is done.[1]

CHAPTER 3

AIM and SCOPE

3.1 AIM

To develop a Temperature monitoring system for Welding using Sensor based technique for deduction of improper weld.

3.2 OBJECTIVES

Identifying improper weld in a welded metal.

To capture the temperature value of the weld metal while welding.

To analyse the temperature and identify the proper weld region.

3.3 PROBLEM DEFINITION

Due to the improper process monitoring system the metal which is welded can result in defects such as blowholes, cracks, spatters, metal deformation. A kit which is developed for monitoring while welding. The heat dissipated in the weld metal is recorded in an array. With the help of the kit the metal deformation temperature and the proper weld region can be found.



Fig: 3.1: Deformed weld metal while welding.

3.4 CHALLENGES AND PRECAUTIONS

Thermocouples are not accurate as RTD, and these types of sensors are highly corrosive when it is not insulated properly. The output signals are not linear. The accuracy level compared to RTD is less. While using the thermocouple, avoid contact with the magnetic field. If using in an electrolytic process, avoid contact with the electrode. The thermocouple needs to be periodically checked to see if it is functioning properly.

CHAPTER 4

COMPONENTS USED AND EXPERIMENTAL WORK

4.1 FLOW CHART FOR DEVELOPMENT OF THE WELD RIG

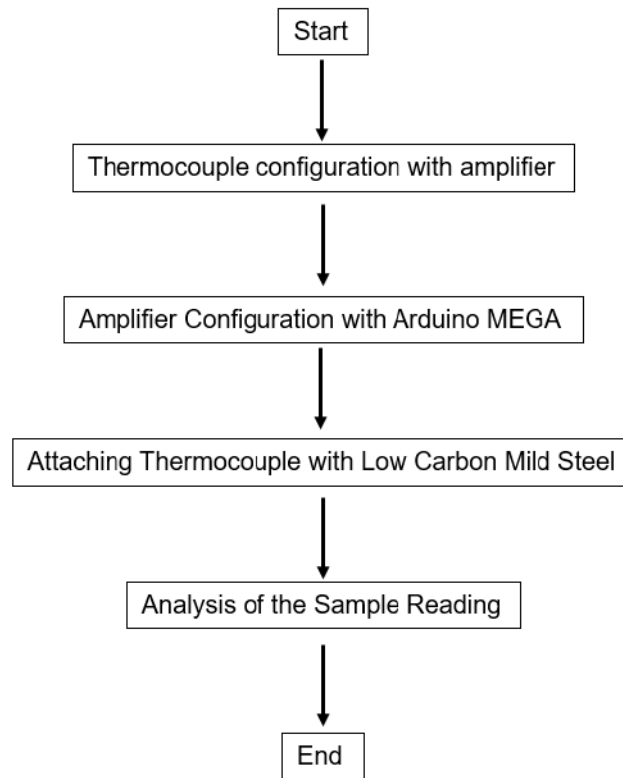


Fig:4.1 : Step by step procedure for developing the weld rig

4.2 COMPONENTS USED FOR DEVELOPMENT OF THE WELD RIG:

4.2.1 Mild Steel

Mild steel, also referred to as carbon steel or low carbon steel, is a type of steel that contains a relatively low percentage of carbon, typically between 0.05% and 0.25% by weight. It is one of the most widely used materials in the world due to its affordability, versatility, and ease of manufacturing. Mild steel has a wide range of applications in various industries, including construction, automotive, manufacturing, appliances, and general engineering. In this detailed explanation, we will delve into the properties, characteristics, uses, and manufacturing of mild steel, providing a comprehensive overview of this important material.

Mild steel has several key properties that make it suitable for numerous applications. One of the main properties of mild steel is its low carbon content, which contributes to its relatively low strength compared to other types of steel. However, mild steel still offers sufficient strength and durability for many common uses. Its malleability is another important property, allowing it to be easily shaped, formed, and fabricated into various structures and components. Mild steel is also known for its ductility, which refers to its ability to deform under stress without breaking, making it suitable for applications that require bending, stretching, or forming.

Another property of mild steel is its excellent weldability, which makes it easy to join using various welding techniques, such as arc welding, MIG welding, and TIG welding. Mild steel can also be cut and machined using common cutting and machining methods, making it versatile in fabrication processes. Additionally, mild steel has good thermal and electrical conductivity, making it useful in applications that involve heat transfer or electrical conductivity.

However, mild steel is also susceptible to corrosion, as it contains iron, which can rust when exposed to moisture or corrosive environments. Therefore, proper surface treatment or coating is often necessary to protect mild steel from rusting and improve its durability and longevity in corrosive environments.

Composition and Manufacturing of Mild Steel Mild steel is primarily composed of iron and carbon, with small amounts of other elements and impurities. The exact composition of mild steel may vary depending on the specific grade or type, but generally, it consists of around 99% iron and 0.05-0.25% carbon by weight. Other trace elements such as manganese, silicon, sulphur, and phosphorus may also be present in mild steel, but in small amounts.

Mild steel is typically manufactured through a process known as hot rolling or cold rolling. Hot rolling involves heating the steel to a high temperature and then passing it through a series of rollers to shape it into the desired form. Cold rolling, on the other hand, is done at room temperature and involves passing the steel through rollers to shape it. Hot rolling generally results in a rougher surface finish, while cold rolling produces a smoother finish.

After the rolling process, mild steel can be further processed through various fabrication methods such as cutting, bending, forming, and welding to create a wide

range of products, from structural components to finished goods. The versatility and ease of manufacturing of mild steel are among the reasons for its widespread use in various industries.

Types and Grades of Mild Steel Mild steel comes in different types and grades, each with its own specific properties and characteristics. Some of the common types and grades of mild steel include:

- **Low Carbon Mild Steel:** This is the most common type of mild steel and contains the lowest carbon content, typically ranging from 0.05% to 0.15%. It is known for its good weldability, formability, and machinability, making it suitable for a wide range of applications. Low carbon mild steel is often used in general structural applications, such as in building construction, automotive components, and manufacturing of appliances and furniture.
- **Medium Carbon Mild Steel:** This type of mild steel contains a slightly higher carbon content, typically ranging from 0.15% to 0.3%. It offers higher strength compared to low carbon mild steel but may have reduced formability and weldability. Medium carbon mild steel is commonly used in applications that require higher strength, such as in machinery, equipment, and tools.
- **High Carbon Mild Steel:** This type of mild steel contains a higher carbon content, typically ranging from 0.3% to 0.5%. It has higher strength and hardness compared to low and medium carbon mild steel but may be more brittle and less ductile. High carbon mild steel is often used in applications that require high wear resistance, such as in cutting tools, springs, and gears.
- **Structural Mild Steel:** This grade of mild steel is specifically designed for structural applications, such as in building construction, bridges, and infrastructure projects. It is characterized by its high strength, durability, and toughness, and is often used in heavy-duty applications that require load-bearing capabilities.
- **Drawing Quality Mild Steel:** This type of mild steel is specifically designed for applications that require excellent formability, such as in sheet metal forming, stamping, and drawing processes. It has a low carbon content and is often used in automotive and appliance industries for manufacturing of components that require complex shapes and precise dimensions.

4.2.2 K-Type Thermocouple

A thermocouple is a sensor used to measure temperature, consisting of two dissimilar metals joined together at one end. The thermoelectric effect is the basis of thermocouples, which produce a voltage proportional to the temperature difference between the two junctions. K-type thermocouples are widely used in industry due to their wide temperature range and low cost. In this paper, we will discuss the basic principles of K-type thermocouples, their applications, and limitations.

The K-type thermocouple is made of two different metals, namely Chromel (90% nickel and 10% chromium) and Alumel (95% nickel, 2% aluminum, 2% manganese, and 1% silicon). The Chromel and Alumel wires are joined together at one end to form a hot junction, while the other ends are connected to a measuring device, such as a digital thermometer.

The thermoelectric effect, also known as the Seebeck effect, is the basis of thermocouples. It is a phenomenon in which a voltage is generated between two dissimilar metals when they are connected together and a temperature gradient exists across them. The magnitude of the voltage generated is proportional to the temperature difference between the hot junction and the reference junction. The voltage generated by a K-type thermocouple is about 41 microvolts per degree Celsius ($\mu\text{V}/^{\circ}\text{C}$) at room temperature.

K-type thermocouples are widely used in industry due to their wide temperature range (-200°C to $+1350^{\circ}\text{C}$), high accuracy, and low cost. Some of the applications of K-type thermocouples are:

- Temperature measurement in industrial processes: K-type thermocouples are used to measure the temperature of furnaces, ovens, and other industrial processes.
- HVAC systems: K-type thermocouples are used to monitor the temperature of heating and cooling systems in buildings.
- Food industry: K-type thermocouples are used to measure the temperature of food products during processing and storage.

- Automotive industry: K-type thermocouples are used to measure the temperature of engine components, exhaust systems, and brakes.
- Aerospace industry: K-type thermocouples are used to measure the temperature of jet engines and rocket motors.

K-type thermocouples are widely used in industry due to their wide temperature range, high accuracy, and low cost. They are used in various applications, such as temperature measurement in industrial processes, HVAC systems, food industry, automotive industry, and aerospace industry. However, K-type thermocouples have some limitations, such as non-linearity, cold junction compensation, environmental factors, and material degradation. These limitations must be considered when using K-type thermocouples for temperature measurement.



Fig:4.2 : Thermocouple

4.2.3 MAX6675 Amplifier:

Amplifiers is an electronic device with amplifies the electronic signal. It converts the milli electron volts into readable output voltage. The property of the amplifier will change according to the application we are using. Namely, Power amplifiers, operational amplifiers, switched mode amplifiers, negative resistance amplifiers. In amplifying the thermocouple signal the Power amplifier is used. MAX6675 amplifier powers up the output mill voltage signal of the thermocouple and gives readable voltage as output. The MAX6675 is a thermocouple-to-digital converter that is commonly used in temperature sensing applications. It is designed to measure the temperature of a thermocouple sensor and convert the temperature reading into a

digital format that can be easily read and processed by a microcontroller or other digital devices. The MAX6675 is popular among hobbyists, engineers, and electronics enthusiasts due to its accuracy, ease of use, and low cost.

The MAX6675 amplifier comes with a range of features and specifications that make it suitable for various temperature sensing applications. Some of the key features and specifications of the MAX6675 include:

- **Temperature Range:** The MAX6675 can measure temperatures in the range of -200°C to $+700^{\circ}\text{C}$, making it suitable for a wide range of temperature sensing applications.
- **High Accuracy:** The MAX6675 has a typical accuracy of $\pm 2^{\circ}\text{C}$, making it suitable for applications that require precise temperature measurements.
- **Digital Output:** The MAX6675 provides a digital output in the form of a 12-bit temperature reading, which can be easily interfaced with a microcontroller or other digital devices.
- **SPI Interface:** The MAX6675 uses a Serial Peripheral Interface (SPI) to communicate with the microcontroller or other digital devices, making it easy to integrate into a variety of projects.
- **Low Power Consumption:** The MAX6675 has low power consumption, making it suitable for battery-powered or low-power applications.
- **Cold Junction Compensation:** The MAX6675 incorporates cold junction compensation, which compensates for the temperature difference between the thermocouple junction and the MAX6675 chip, ensuring accurate temperature measurements.
- **Small Form Factor:** The MAX6675 comes in a small form factor with a wide operating voltage range, making it easy to integrate into compact and space-constrained projects.

The MAX6675 amplifier has a simple circuit diagram and pinout, which makes it easy to understand and connect in a temperature sensing application. The typical circuit diagram and pinout of the MAX6675 include:

- **VCC (Pin 1):** This pin is used to provide the power supply voltage to the MAX6675. The operating voltage range of the MAX6675 is typically between 3.0V and 5.5V.

- GND (Pin 3): This pin is connected to the ground or common reference voltage of the circuit.
- SCK (Serial Clock) (Pin 2): This pin is used to provide the clock signal for the SPI communication between the MAX6675 and the microcontroller or other digital devices.
- CS (Chip Select) (Pin 3): This pin is used to enable or disable the MAX6675 for data communication. When CS is low, the MAX6675 is enabled, and when it is high, the MAX6675 is disabled.
- MISO (Master In, Slave Out) (Pin 4): This pin is used to transmit the temperature data from the MAX6675 to the microcontroller or other digital devices.
- T+ (Pin 5): This pin is used to connect the positive terminal of the thermocouple sensor to the MAX6675.
- T- (Pin 6): This pin is used to connect the negative terminal of the thermocouple sensor to the MAX6675.

The MAX6675 amplifier works based on the Seebeck effect, which is the phenomenon where two dissimilar metals, when joined at the junction, generate a voltage proportional to the temperature difference between the junction and the other end of the metals. In the case of the MAX6675, the thermocouple sensor is connected to the T+ and T- pins, and the voltage generated by the thermocouple due to the temperature difference is converted into a digital output by the MAX6675. The MAX6675 uses a type K thermocouple, which is one of the most commonly used thermocouples due to its wide temperature range and accuracy. The MAX6675 includes an internal cold junction compensation circuitry that compensates for the temperature difference between the thermocouple junction and the MAX6675 chip. This ensures that the temperature reading provided by the MAX6675 is accurate and reliable. The MAX6675 communicates with the microcontroller or other digital devices using the SPI protocol. The microcontroller sends a clock signal (SCK) to the MAX6675, and the MAX6675 responds by sending the temperature data (MISO) to the microcontroller. The chip select (CS) pin is used to enable or disable the MAX6675 for data communication. The temperature reading provided by the MAX6675 is a 12-bit digital value, with the most significant bit (MSB) representing the sign (positive or negative) of the temperature and the remaining 11 bits representing the temperature value. The temperature value

is in Celsius, with a resolution of 0.25°C per bit. The microcontroller can then process this digital temperature reading and use it for various temperature sensing applications.



Fig:4.3 : MAX6675 amplifier

4.2.4 Arduino mega:

The Arduino Mega is a microcontroller board based on the ATmega2560 microcontroller. It is part of the Arduino family of open-source hardware and software platforms that allow users to easily create electronic projects. The Arduino Mega is designed for projects that require more processing power, memory, and I/O capabilities than the standard Arduino boards. It has 54 digital I/O pins, 16 analog inputs, and 4 UART (serial) communication ports, making it a versatile board for a wide range of applications. The ATmega2560 microcontroller on the Arduino Mega runs at 16 MHz and has 256 KB of flash memory for storing code and data. It also has 8 KB of SRAM and 4 KB of EEPROM for storing variables and data. The Arduino Mega can be programmed using the Arduino Integrated Development Environment (IDE), which is a free, open-source software tool that allows users to write, compile, and upload code to the board. The IDE provides a simple and user-friendly interface that allows even beginners to get started with programming and electronics. One of the unique features of the Arduino Mega is its compatibility with a wide range of shields. Shields are plug-in boards that can be stacked on top of the Arduino board to add functionality and features, such as sensors, motors, displays, and communication modules. The Arduino Mega is commonly used in a variety of projects, such as robotics, home

automation, and data logging. It is also used in educational settings to teach programming and electronics to students. One disadvantage of the Arduino Mega is its size and cost, which can make it less suitable for smaller or cost-sensitive projects. However, its versatility and capabilities make it a popular choice for more complex projects. Overall, the Arduino Mega is a powerful and versatile microcontroller board that offers a wide range of I/O capabilities, making it suitable for a variety of projects. Its compatibility with shields and the Arduino IDE makes it a popular choice among hobbyists, educators, and professionals alike.

4.2.5 Circuit and Circuit pin configuration of test rig:



Fig:4.4 : Circuit diagram for interfacing Arduino with amplifier

Table 4.1 : Circuit pin Configuration with Arduino.

Amplifier no	Amplifier Pins	Arduino Pin no's
1	VCC	5v
	GND	Gnd
	ktcSO1	22
	ktcCS1	24
	ktcCLK1	26
2	VCC	5v
	GND	Gnd
	ktcSO2	28
	ktcCS2	30
	ktcCLK2	32
3	VCC	5v
	GND	Gnd
	ktcSO3	34
	ktcCS3	36
	ktcCLK3	38
4	VCC	5v
	GND	Gnd
	ktcSO4	40
	ktcCS4	42
	ktcCLK4	44
5	VCC	5v

	GND	Gnd
	ktcSO5	46
	ktcCS5	48
	ktcCLK5	50
6	VCC	5v
	GND	Gnd
	ktcSO6	31
	ktcCS6	52
	ktcCLK6	35
7	VCC	5v
	GND	Gnd
	ktcSO7	37
	ktcCS7	39
	ktcCLK7	41
8	VCC	5v
	GND	Gnd
	ktcSO8	43
	ktcCS8	45
	ktcCLK8	47
9	VCC	5v
	GND	Gnd
	ktcSO9	49
	ktcCS9	53

4.3 EXPERIMENTAL WORK:

In this research a test rig to continuous monitor the temperature during the welding process is developed. The heat dissipated during the process of welding from the weld zone, heat affected zone and the base metal is analyzed. The weld bed consists of the K-Type thermocouple, fixed in the metal made up of Low carbon mild steel. The continuous temperature monitoring test rig is made of two parts made of 3mm thick Mild steel plate of dimension 200 x 100 x 3 mm. An array of 3 x 3 matrix of 10 mm holes are drilled and threading is carried out on the holes from the middle of the welding edge with 10mm and 15mm apart as shown in figure 1. The K-Type thermocouple sensor is inserted in these arrays of holes.

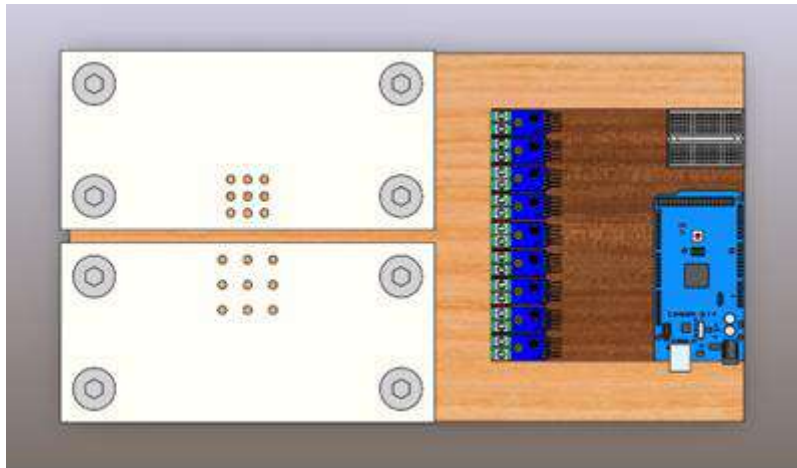


Fig:4.5 : Hole placement on the Test rig for insertion of K-Type thermocouple

The heat developed during the welding process can be taken up to a maximum distance of 30mm from the weld zone. The distance of heat observed during the welding process varies due to factors like thickness and the type of metal welded.

The temperature values will differ according to the change in the emf induced in the thermocouple, the emf value is measured in milli voltage, to convert it into readable values the amplification process is carried out with the help of a MAX6675 amplifier, and it transmits the data to the Arduino. These voltage readings are converted into temperature values by the Arduino with the help of predefined algorithms. The default

time delay has been set to 5 sec in Arduino mega in which for every 5 second the temperature reading will be taken. In addition to the time delay an external switch is added for on/off operation of the test rig. The Cool Term software collects the temperature data through the serial port and saves it in Excel.

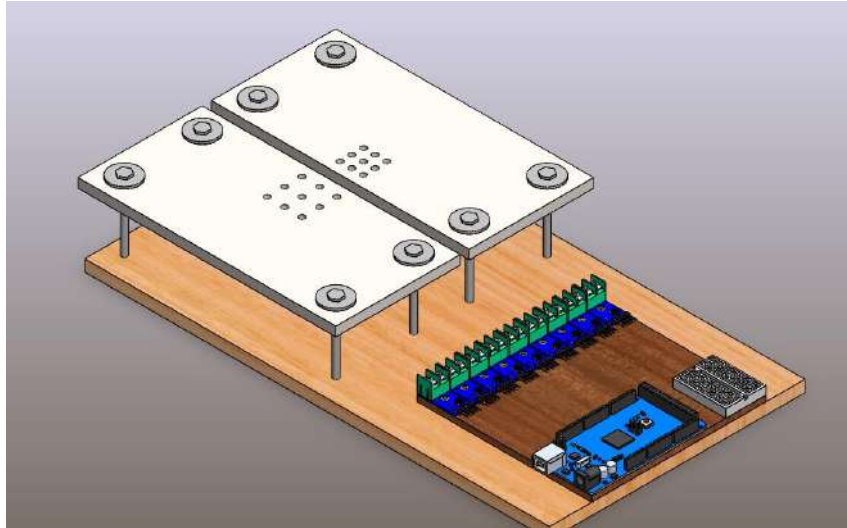


Fig:4.6 : Continuous temperature monitoring system for high temperature CAD model of the test rig.

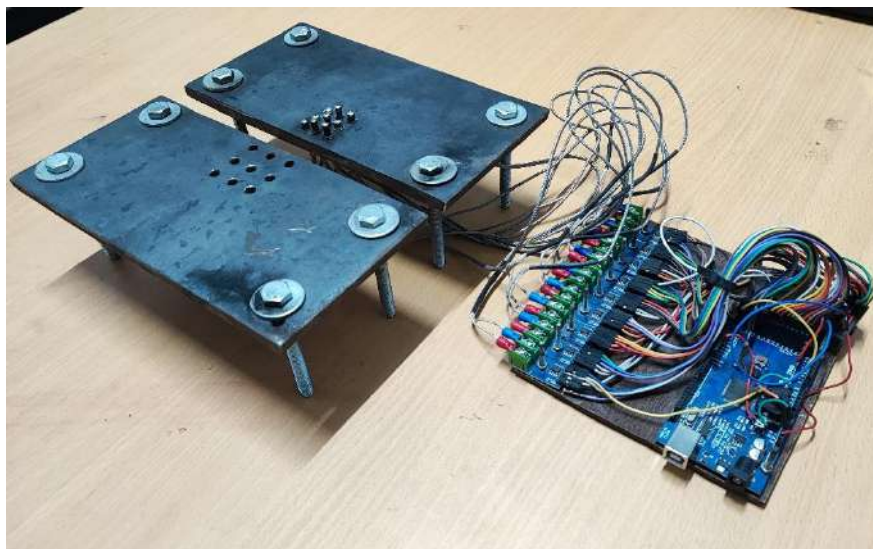


Fig:4.7 : Continuous temperature monitoring system of the test rig.

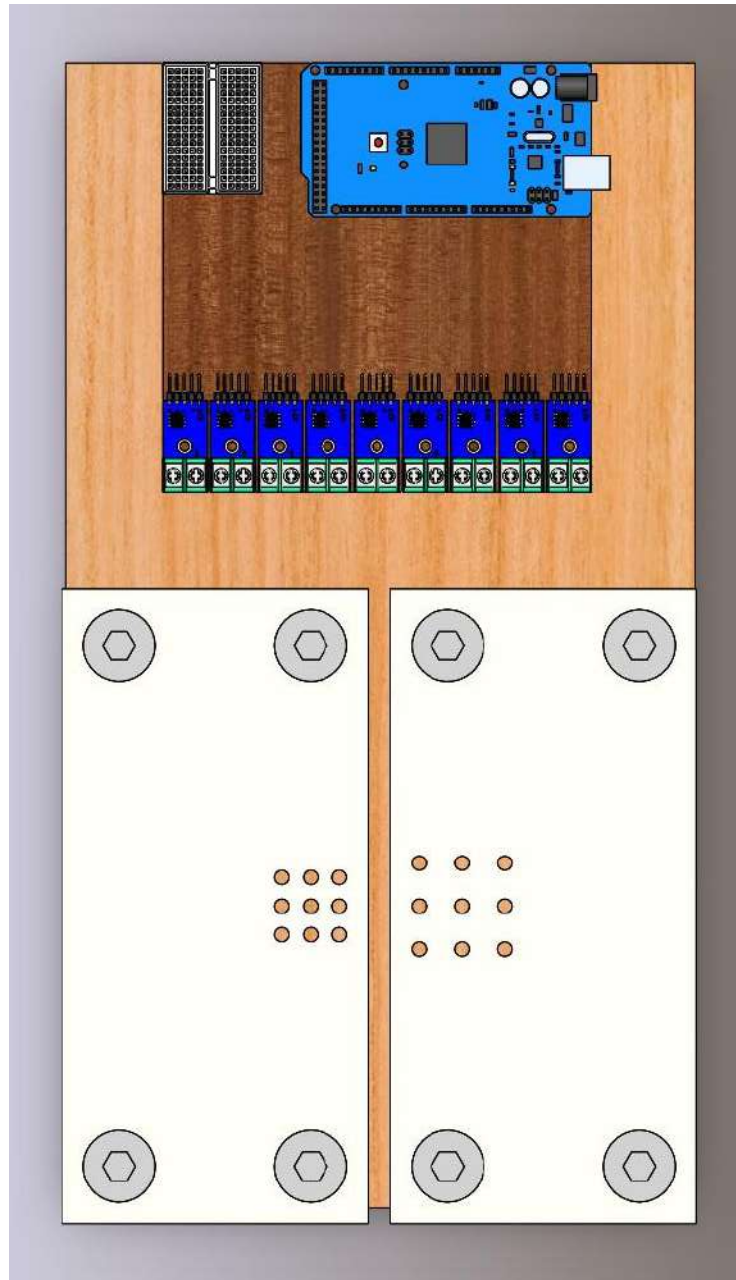


Fig:4.8 : Top View of Continuous temperature monitoring system for high temperature CAD model of the test rig.

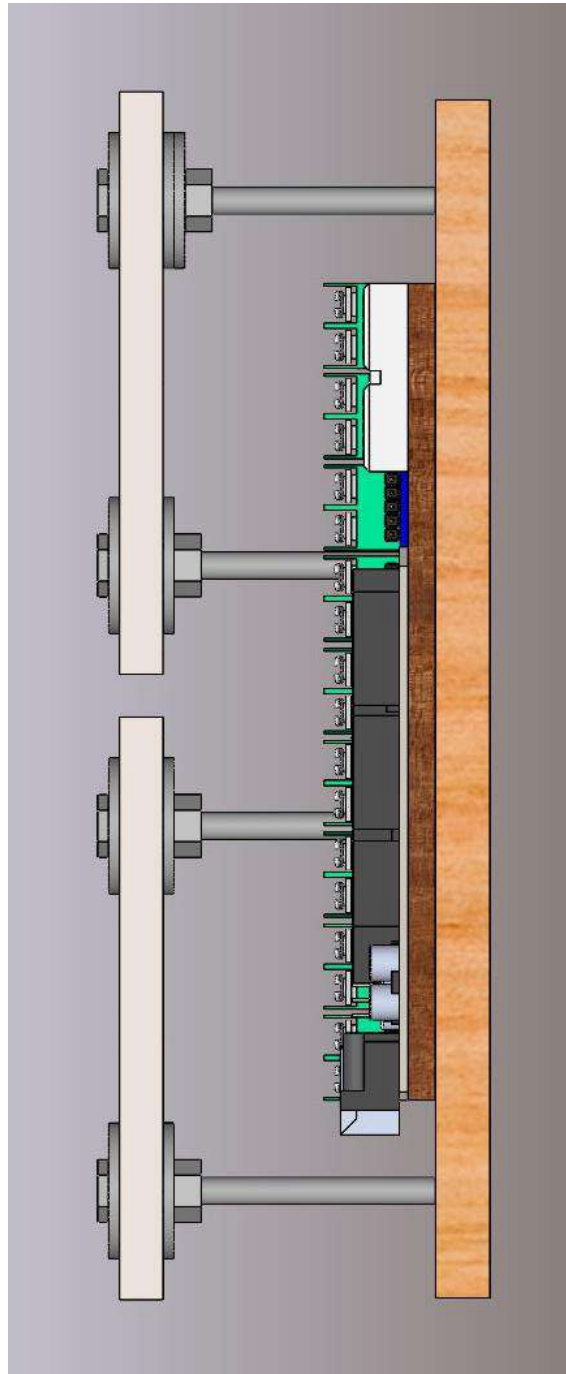


Fig:4.9 : Front View of Continuous temperature monitoring system for high temperature CAD model of the test rig.

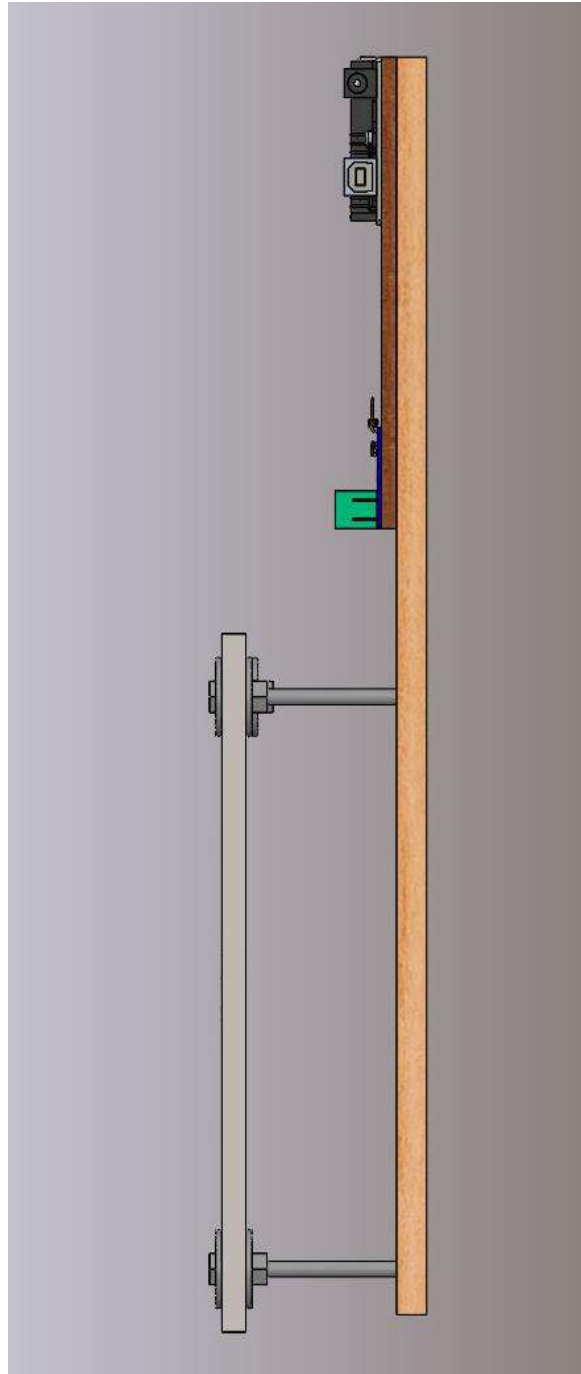


Fig:4.10 : Side View of Continuous temperature monitoring system for high temperature CAD model of the test rig.

CHAPTER 5

RESULTS AND DISCUSSION, PERFORMANCE ANALYSIS

5.1 THERMOCOUPLE SAMPLE READINGS:

The K-type Thermocouple has a maximum temperature withstand of 1260 °C. The sample temperature reading is taken for the test of k-type thermocouple.

The K-type thermocouple is heated with the boiling water, blue flame and the matchstick flame. The temperature readings recorded by the different experiments are shown in the table below.

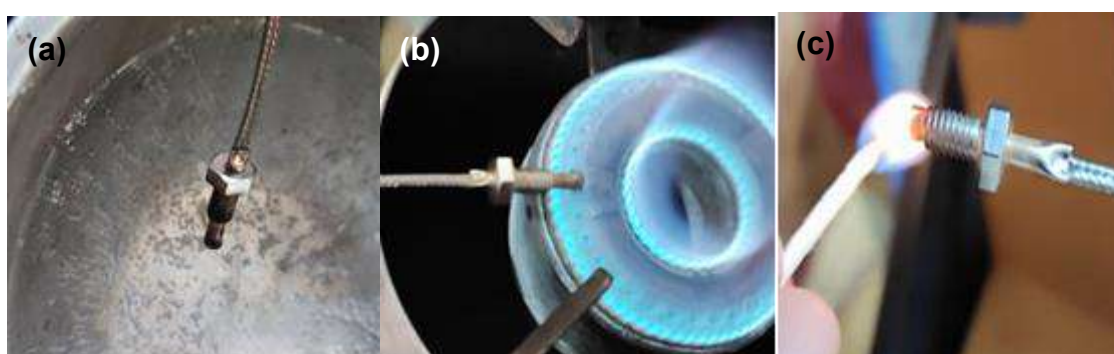


Fig:5.1 : Thermocouple in (a)Boiling Water, in (b)LPG gasflame, in (c)match stick flame

Table 5.1 : Sample output readings of the thermocouple

S. No	Sensor Used	Heat Source	Temperature
1.	K-Type Thermocouple	Boiling Water	99.9
2.	K-Type Thermocouple	LPG gas flame	590
3.	K-Type Thermocouple	Match stick flame	70

5.2 CORTEN STEEL:

Corten steel, also known as weathering steel, is a type of steel that is designed to develop a protective layer of rust on its surface when exposed to the elements. It is a group of steel alloys that contain copper, chromium, and nickel, which give it its characteristic weathered appearance and enhanced corrosion resistance. The unique rust-like patina that develops on corten steel is created through a process called "oxidation." When corten steel is exposed to air and moisture, it undergoes a chemical

reaction that forms a layer of rust on its surface. This rust layer acts as a protective barrier, preventing further corrosion and protecting the underlying steel from the effects of weathering, such as rusting and degradation. Corten steel was developed in the 1930s by the United States Steel Corporation and has since gained popularity in architecture, landscaping, and other outdoor applications due to its unique appearance and durability. When exposed to the environment, corten steel forms a protective layer of rust on its surface, which acts as a barrier to further corrosion and protects the underlying steel from the effects of weathering. The rust-like patina that develops on corten steel varies in color and texture, ranging from deep brown to orange brown with a rough, textured surface. This weathered appearance gives corten steel a distinct aesthetic appeal, often used in modern and industrial designs. One of the main advantages of corten steel is its resistance to atmospheric corrosion, which makes it suitable for outdoor applications without the need for additional protective coatings or paints. However, it is important to note that corten steel is not entirely corrosion-proof and may still experience some degree of corrosion, especially in aggressive environments or when in contact with water for extended periods of time. Corten steel is commonly used in architectural elements such as building facades, roofs, and decorative features, as well as in landscaping and outdoor sculptures. It is also used in structural applications such as bridges and retaining walls, where its high strength and corrosion resistance are advantageous.

It's important to work with qualified professionals when using corten steel, as proper design, fabrication, and installation techniques are critical to ensure its long-term performance. Maintenance and care, such as periodic cleaning and inspection, may also be required to maintain the desired appearance and performance of corten steel over time. Corten steel is popular in architecture, landscaping, and outdoor art installations due to its distinctive appearance and durability. It is commonly used in building facades, bridges, sculptures, and outdoor furniture. Corten steel is known for its long lifespan and low maintenance requirements, as the rust layer acts as a protective coating, eliminating the need for additional painting or surface treatments. One of the key benefits of corten steel is its high resistance to atmospheric corrosion compared to traditional carbon steel. However, it is important to note that corten steel is not completely immune to corrosion and will still corrode over time, albeit at a slower rate than regular steel. Proper installation and maintenance are still

important factors in ensuring the longevity of corten steel products. Additionally, corten steel should not be used in applications where it may come into direct contact with saltwater or chemicals, as these can accelerate corrosion. Overall, corten steel is valued for its unique appearance, durability, and weathering characteristics, making it a popular choice for various outdoor and architectural applications.

In summary, corten steel is a unique type of steel that forms a rust-like patina on its surface when exposed to the elements, offering distinctive aesthetic appeal and enhanced corrosion resistance. It is widely used in various outdoor applications for its durability, weathering characteristics, and industrial aesthetic.

For Corten steel with a thickness of 2mm, it is important to note that the temperature tolerance may be lower compared to thicker Corten steel plates. Thinner plates may heat up more quickly and may not be able to withstand temperatures as high as thicker plates. Additionally, the rate of corrosion and rust formation on Corten steel can also increase with higher temperatures. To ensure that Corten steel performs optimally in each application, it is recommended to consult with a qualified engineer or materials specialist who can consider the specific environmental conditions and usage requirements to determine the appropriate temperature tolerance for Corten steel with a 2mm thickness.

The chemical properties of Corten steel, also known as weathering steel, are primarily attributed to its composition, which typically includes iron, chromium, copper, and nickel, among other elements. The key chemical properties of Corten steel are:

- **Corrosion resistance:** Corten steel forms a protective rust-like surface when exposed to the elements, which acts as a barrier against further corrosion. This protective layer, known as patina, develops over time and helps to inhibit the penetration of moisture and oxygen into the steel, reducing the rate of corrosion.
- **Weathering characteristics:** Corten steel is designed to weather naturally and develop a unique, rustic appearance over time. The weathering process is influenced by the local climate and environmental conditions, and it results in a characteristic orange-brown hue that is highly sought after for its aesthetic appeal.

- Alloying elements: Corten steel typically contains small amounts of chromium, copper, and nickel, which contribute to its weathering properties. Chromium enhances the formation of the protective patina, while copper and nickel help to promote the adhesion of the patina to the steel surface.
- Carbon content: Corten steel has a relatively low carbon content compared to other types of steel, typically ranging from 0.12% to 0.22%. This low carbon content contributes to the steel's enhanced weathering characteristics and helps to reduce the risk of cracking and splitting during fabrication.
- Weldability: Corten steel can be welded using conventional welding methods, although special care may be needed due to the presence of alloying elements and the development of the protective patina. Proper welding techniques and compatible filler materials are typically used to ensure good weldability and maintain the corrosion resistance of the steel.

Overall, the chemical properties of Corten steel are what make it unique and highly suitable for outdoor applications where weather resistance and aesthetics are desired. However, it's important to note that Corten steel is not suitable for all environments or applications, and consultation with a qualified engineer or materials specialist is recommended for proper specification and usage. Welding Corten steel, also known as weathering steel, requires careful consideration due to its unique composition and weathering characteristics. Here are some key points to consider when welding Corten steel:

Pre-weld preparation: Prior to welding Corten steel, it is important to ensure that the surfaces to be welded are clean and free of rust, mill scale, paint, or other contaminants. This can be done by wire brushing, grinding, or using other suitable cleaning methods. Proper surface preparation helps to achieve a sound weld and promotes good fusion between the base metal and the filler material. **Welding process:** Corten steel can be welded using common welding processes such as shielded metal arc welding (SMAW), gas metal arc welding (GMAW), and flux-cored arc welding (FCAW). However, it's important to note that Corten steel has a lower thermal conductivity compared to carbon steel, which means it requires slower welding speeds and careful control of heat input to avoid excessive heat-affected zone (HAZ) and potential distortion. **Filler material:** The choice of filler material is critical when welding Corten steel. A compatible filler material should be used that has similar weathering

characteristics to Corten steel and forms a weld with comparable corrosion resistance. Commonly used filler materials for Corten steel include carbon steel, stainless steel, and weathering steel electrodes or wires that are specifically designed for this type of steel. Welding technique: Proper welding techniques should be employed to minimize the potential for cracking and promote good fusion. Techniques such as backstepping, peening, and avoiding sharp changes in direction can help to reduce stress and distortion in the welded joint. Post-weld treatment: Corten steel typically requires no post-weld treatment, as the weathering process will continue after welding and the protective patina will develop over time. However, if appearance is a concern, the welds can be cleaned and treated with chemicals to accelerate the weathering process and achieve a more uniform appearance. Safety precautions: As with any welding process, proper safety precautions should be followed, including the use of appropriate personal protective equipment (PPE) such as welding helmets, gloves, and clothing, and adequate ventilation in the welding area.

It's important to note that welding Corten steel requires skill and expertise due to its unique properties, and consulting with a qualified and experienced welder or materials specialist is recommended to ensure proper welding procedures are followed to maintain the integrity of the steel and achieve desired results

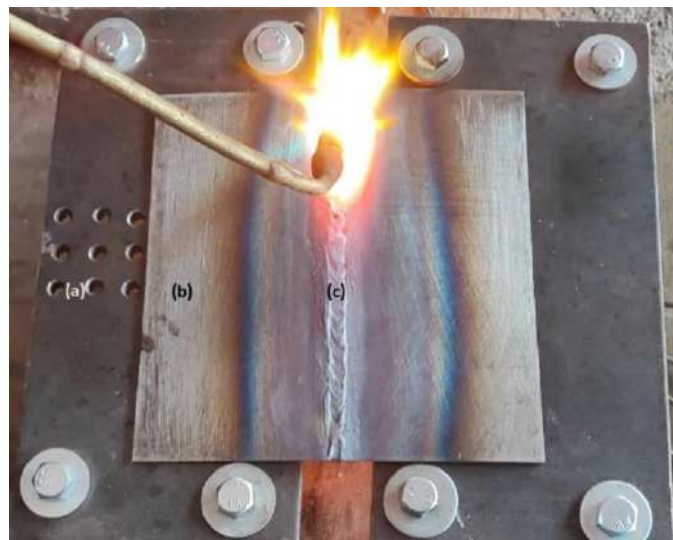


Fig:5.2 : (a) weld bed (b)weld metal of 2mm thickness (c)weld zone

With the help of a high-Temperature monitoring kit, the heat dissipated in the weld metal was collected and analyzed. The 1.6 mm thick weld metal (Corten steel) was polished with the help of the buffing process, to remove the rust particles on the

surface and to get a better weld joint. The weld bed and the weld metal are cleaned well before the welding operation. The Corten- steel with the thickness of 1.6 mm is placed above the weld bed and the Gas welding process carried out in the weld metal (Corten steel). With the help of the K-Type Thermocouple, the temperature values are captured.

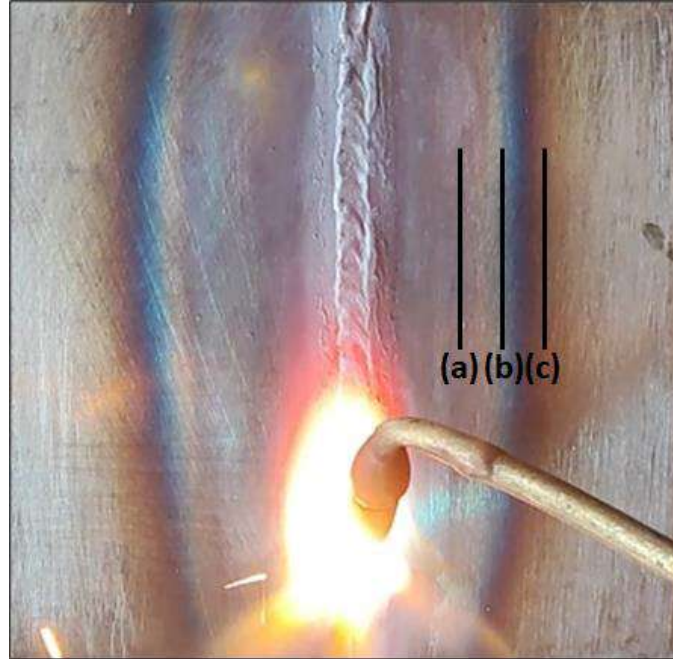


Fig:5.3 : (a) Sensor region 1(b) Sensor region 2 (c) Sensor region 3

In the beginning stage of the welding process, the weld metal is kept in such a way that the distance between the weld zone and the sensor region (a) is 1.8 cm. The maximum temperature evolved at sensor region (a) is 140°C. The distance between the weld zone and the sensor region (b) is 2.8 cm. The maximum temperature evolved at sensor region (b) is 102°C. The distance between the weld zone and the sensor region (c) is 3.8 cm. The maximum temperature evolved at sensor region (c) is 82°C.

The distance from the weld zone can be adjusted to maximum till the weld metal fuses with the test rig and the minimum operational distance is 0.5 cm. The temperature developed will vary according to the distance between the weld zone and the sensor region (fig 7).

Table 5.2 : Maximum temperature developed in the weld metal.

Sensor no	Sensor Region	Thickness of the weld metal (mm)	Distance from the weld zone(cm)	Time (Sec)	Temperature (°C)
1	1	2	1.8	166	100.5
4	1	2	1.8	166	148.75
7	1	2	1.8	166	114.75
2	2	2	2.8	166	96.5
5	2	2	2.8	166	102
8	2	2	2.8	166	80.75
3	3	2	3.8	166	82
6	3	2	3.8	166	74
9	3	2	3.8	166	78.2

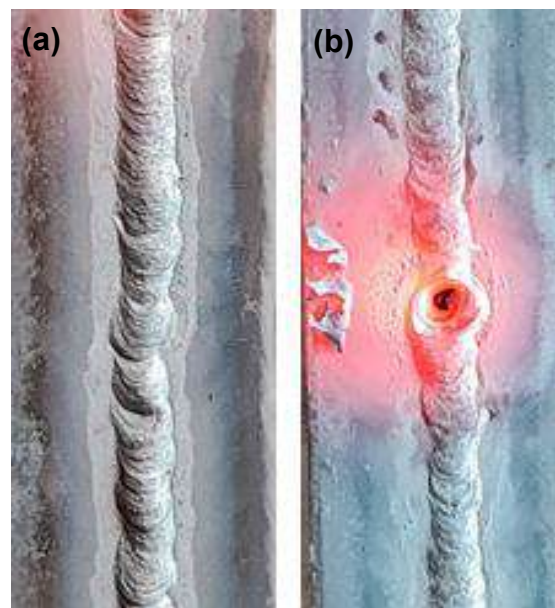


Fig:5.4 : (a)Proper weld at 302°C (b)overheated weld zone at 497°C

Similarly, 3mm thick Corten steel is welded in gas welding process and the weld zone of the weld metal is kept at a distance of 0.5 cm from the sensor region 1 to capture the temperature value closer to the weld zone. During Gas welding process of 3mm

thick Corten steel plate, a maximum temperature of 302 °C is observed on the thermocouple which is placed at 0.5cm apart from the weld zone. The maximum temperature of 497 °C caused due to continuous heat applied excessively on the weld zone is observed (Fig 8). At that point the weld metal does not fuse, and a hole is formed in the weld zone. Hence the Corten steel of 3mm thickness has a maximum temperature withstand of 497°C, above which the metal deformation occurs.

Table 5.3 : Maximum temperature captured during deformation of the Corten Steel.

Sensor no	Sensor Region	Thickness of the weld metal (mm)	Distance from the weld zone(cm)	Time (Sec)	Temperature(°C)
4	1	3	0.5	221	497
5	2	3	1.5	221	238
6	3	3	2.5	221	152

5.3 MILD STEEL:

Mild steel, also known as carbon steel or low carbon steel, is a type of steel that is widely used in various industries and applications due to its unique properties and versatility. In this essay, we will explore the different aspects of mild steel, including its composition, properties, uses, and advantages.

Composition of Mild Steel: Mild steel is primarily composed of iron (Fe) and carbon (C), with small amounts of other elements such as manganese (Mn), sulfur (S), phosphorus (P), and silicon (Si). The carbon content in mild steel typically ranges from 0.05% to 0.30% by weight, which is much lower compared to other types of steel. **Iron (Fe):** Iron is the main component of mild steel, typically accounting for over 95% of its composition. Iron provides the basic structure and strength to the steel, making it suitable for various applications.

Carbon (C): Carbon is a critical element in mild steel, typically ranging from 0.05% to 0.30% by weight. The amount of carbon in mild steel determines its properties, such as strength, ductility, and weldability. Higher carbon content can result in higher

strength but reduced ductility, while lower carbon content can result in increased ductility but reduced strength.

Manganese (Mn): Manganese is often added to mild steel in small amounts (typically up to 1%) to improve its strength, toughness, and hardenability. Manganese can also help in reducing the occurrence of brittleness and cracking during fabrication and welding processes.

Sulfur (S) and Phosphorus (P): Sulfur and phosphorus are impurities that are typically present in mild steel in small amounts. Sulfur is usually limited to a maximum of 0.05% to avoid adverse effects on weldability, while phosphorus is limited to a maximum of 0.12% to prevent brittleness in the steel.

Silicon (Si): Silicon is often present in mild steel in small amounts (typically up to 0.5%) to improve its strength, hardness, and resistance to oxidation and corrosion. Silicon can also act as a deoxidizer during the steelmaking process, helping to remove impurities and improve the overall quality of the steel.

The composition of mild steel can be controlled during the manufacturing process to achieve specific properties and performance characteristics desired for a particular application. This can include adjusting the carbon content, adding alloying elements such as manganese, chromium, or nickel, and using different processing techniques, such as hot rolling or cold rolling, to achieve the desired properties.

It's worth noting that mild steel is distinct from other types of steel, such as high carbon steel, stainless steel, or alloy steel, which have different compositions and properties. Mild steel is specifically characterized by its relatively low carbon content, which gives it its unique properties of affordability, ease of fabrication, and versatility in various applications.

Properties of Mild Steel: Mild steel possesses several properties that make it a popular choice in many industries. Let's explore some of the key properties of mild steel:

- **Strength and Ductility:** Mild steel has moderate tensile strength, which makes it suitable for a wide range of structural and mechanical applications. It can withstand moderate loads and stresses without deforming or breaking. Additionally, mild steel has high ductility, which means it can be easily bent,

formed, and shaped without cracking or breaking, making it easy to fabricate and work with.

- **Weldability:** Mild steel is highly weldable, which is one of its significant advantages. It can be easily joined to other materials through various welding processes, such as shielded metal arc welding (SMAW), gas metal arc welding (GMAW), and flux-cored arc welding (FCAW). This makes mild steel suitable for a wide range of fabrication and construction projects, where welding is a common joining method.
- **Machinability:** Mild steel is relatively easy to machine, allowing for various manufacturing processes. It can be readily cut, drilled, and machined using common tools and techniques, making it ideal for applications that require precision and intricate shapes.
- **Durability:** Mild steel is known for its durability and long-term performance in many indoor environments or protected applications. When properly maintained and protected from harsh environmental conditions, mild steel can resist wear, impact, and deformation, making it suitable for a wide range of applications.
- **Versatility:** One of the significant advantages of mild steel is its versatility. It can be used in a wide range of industries and applications, including construction, automotive, manufacturing, appliances, furniture, and many others. Mild steel can be easily customized and fabricated into different shapes, sizes, and forms to suit various requirements.

Uses of Mild Steel: Mild steel finds extensive use in numerous industries and applications due to its versatility and properties. Here are some common uses of mild steel:

- **Construction:** Mild steel is widely used in the construction industry for various applications such as structural framing, reinforcement bars, roofing, fencing, and other structural components. Its strength, weldability, and durability make it suitable for building structures that require strength and stability.
- **Automotive:** Mild steel is used in the manufacturing of automobiles and other vehicles for making chassis, body parts, suspension components, and exhaust systems. Its machinability and weldability make it a preferred choice for automotive applications.

- **Manufacturing:** Mild steel is used in the manufacturing industry for producing a wide range of products such as machinery, equipment, tools, and consumer goods. Its versatility and ease of fabrication make it ideal for manufacturing processes that require shaping, cutting, drilling, and machining.
- **Furniture and Appliances:** Mild steel is used in the manufacturing of furniture, appliances, and household goods due to its affordability, strength, and durability. It can be easily fabricated into different shapes and forms to create furniture frames, appliances, and another consumer



Fig:5.5 : Mild steel welded under the weld rig

Similarly, 3mm thick Mild Steel is welded using gas welding process in the weld rig, with a distance gap between the sensor region 1 and weld metal of 0.5 cm (Fig 9). While carrying out butt welding operation the temperature dissipated over the metal surface is recorded. From the recorded data the maximum temperature of 323 °C at sensor region 1 is observed. After which the metal deformation occurs at the temperature of 493°C.

CHAPTER 6

SUMMARY AND CONCLUSION

6.1 SUMMARY OF THE WELD DATA:

Table 6.1 : Temperature data of the welded metals

Metal used	State of welding	Sensor no	Sensor Region	Thickness of the weld metal (mm)	Distance from the weld zone(cm)	Temperature(° C)
Corten steel	Proper weld data	4	1	3	0.5	302
	Metal deformation data	4	1	3	0.5	497
Mild steel	Proper weld data	4	1	3	0.5	323
	Metal deformation data	4	1	3	0.5	493

6.2 CONCLUSION:

The weld Rig which is developed for monitoring the metal deformation temperature and heat dissipation in a weld metal such as Corten Steel, Mild Steel, Iron, Copper, Aluminum, etc., with the maximum thickness of 20mm. Gas welding operation is carried out on two different metals, Corten steel and Mild steel of thickness 3mm in the weld rig and the following observations are made and table 5 represents the data of both weld metals which is tested in the weld rig.

- Temperature observed in the Corten steel specimen during a proper weld is 302 °C and metal deformation is observed at the temperature of 497 °C.
- Temperature observed in the Mild steel specimen during a proper weld is 323 °C and metal deformation is observed at the temperature of 493 °C.

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ANNEXURE

- Design Patent has been applied for a Continuous monitoring test rig for high temperature(welding) application, 2023.
- Review paper on the title of " Review on Temperature Monitoring System for Welding application – A case study on thermocouple array" by J.R.Deepak, Prasanna Kumar.M., Nithishkar.M has been presented in iCAM conference conducted by Sathyabama Institute of Science and Technology, Chennai on November 4th, 2022.
- Review Paper has been Published in the Scopus index under Materials Today Proceeding.
- Research on the title of " Development of a Continuous Monitoring System for High-Temperature (Metal Joining) applications" by J.R.Deepak, Prasanna Kumar.M., Nithishkar.M has been presented in ICDTM conference conducted by Sastra University, Thanjavur on 9th April, 2023.

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Sr No.	Reference Number	Application Number	Name of Article	Amount Paid	Amount Computed
1	381441-001	381441-001	CONTINUOUS MONITORING TEST RIG FOR HIGH TEMPERATURE (WELDING) APPLICATION/15-99	1000	1000

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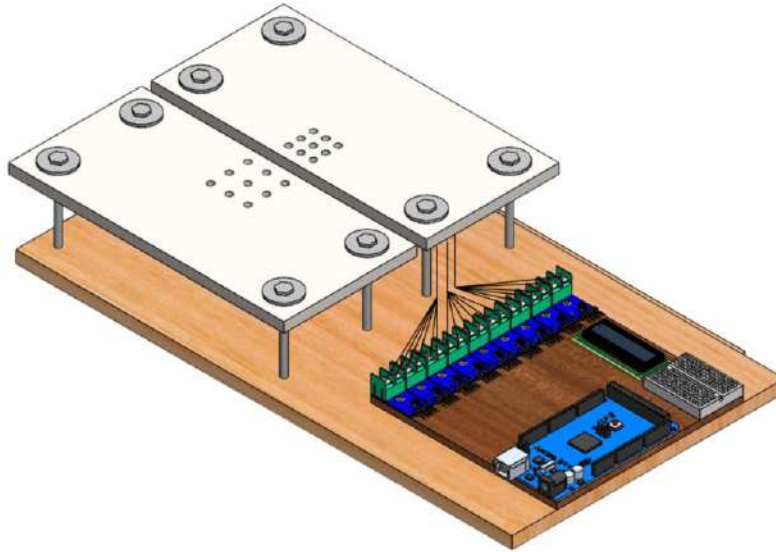
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3) Mr.Nithishkar.M

2) Mr.Prasanna Kumar.M
4) Mr.Asvin Kumar.T

No of Sheets:4
SHEET No: 1



Perspective View of Continuous monitoring test rig for high temperature(welding) application

The novelty resides in the shape and configuration of the "PERSPECTIVE VIEW OF CONTINUOUS MONITORING TEST RIG FOR HIGH TEMPERATURE(WELDING) APPLICATION" as illustrated. No Claims is made by virtue of this registration in respect of any mechanical or other action of the mechanism whatever or in respect of any mode or principle of construction of the article. No Claims is made by virtue of this registration in respect of any right to the exclusive use of the words, letters, numbers, color, color combination or trademarks as appearing in the representations.

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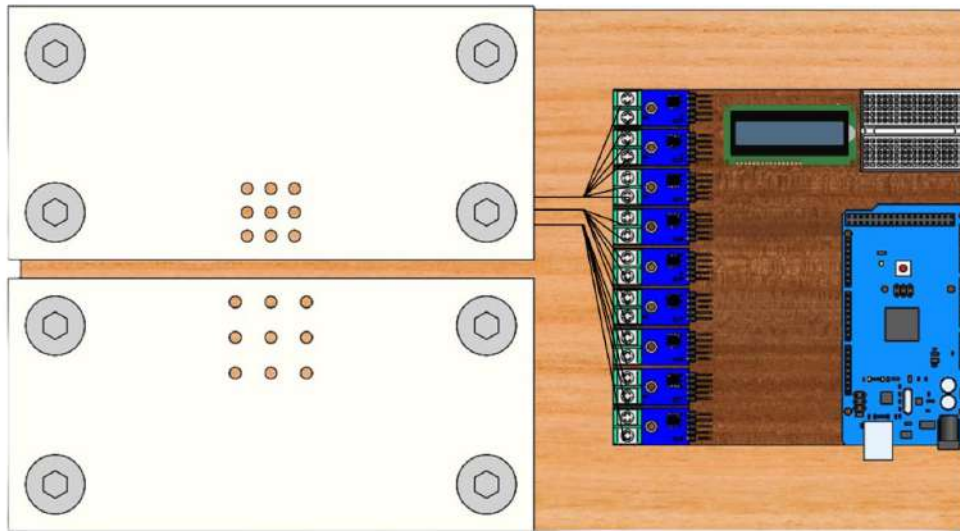
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Top View of Continous monitoring test rig for high temperature(welding) application

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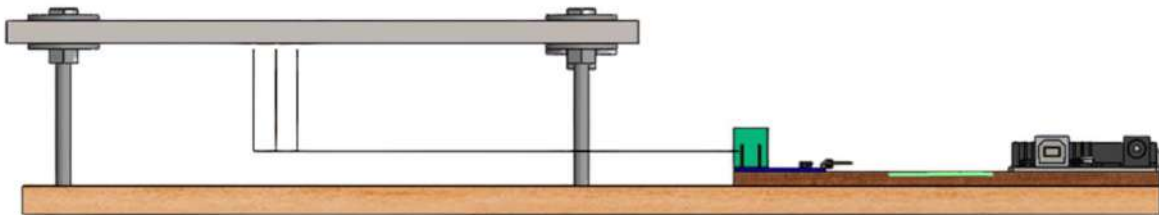
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Front View of Continous monitoring test rig for high temperature(welding) application

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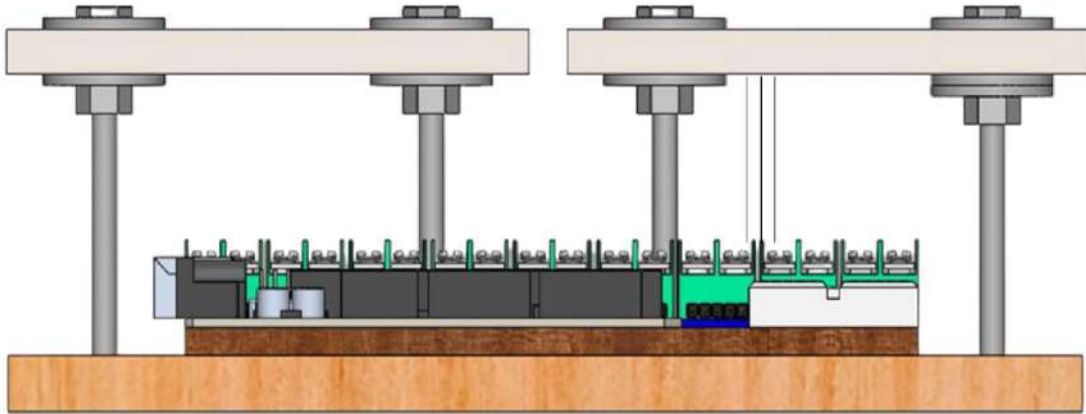
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Side View of Continous monitoring test rig for high temperature(welding) application

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PP-SS-337

CERTIFICATE

THIS IS TO CERTIFY THAT

—◆ Mr. PRASANNA KUMAR. M ◆—

School of Mechanical Engineering, Sathyabama Institute of Science and Technology, Chennai, India has presented a paper entitled *“Review on Temperature Monitoring System for Welding Application – A Case Study on Thermocouple Array”*, in the second International conference on “Advancements in Materials Science and Technology – iCAM 2022”, organized by Sathyabama Institute of Science and Technology, Chennai, India in association with Alexander Dubček University of Trenčín, Slovakia, during November 02–04, 2022.

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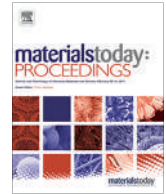


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Review on temperature monitoring system for welding application – A case study on thermocouple array

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Machining

ABSTRACT

Process Monitoring System is implemented in machining process to get the quality products, increase the precision, reduce defects, reduce machining time. The process monitoring system, involves in monitoring many parameters such as temperature, force, pressure, voltage, vibration etc., these parameters are implemented in machining process like lathe operation, milling operation, drilling operation, boring, welding etc. On a traditional way of process monitoring system, there are two techniques namely sensor-based technique and image processing technique. In sensor-based techniques different types of sensors has been used for monitoring such as thermocouple, thermistor, RTD, pressure sensor, accelerometer, vibration sensor, load cell, strain gauge etc., these sensors have been calibrated with a microcontroller for data analysis. Image Processing technique involves in capturing the radiation of the machined/machining product by using Infrared camera, ultraviolet camera, photoelectric thermoscope, optical thermoscope, thermal image camera, continuous circuit television etc., the data captured by using the image sensing devices has been processed and analysed by using machine learning algorithm. In this work monitoring system was developed for monitoring the temperature of the weld region that were welded using MIG/TIG, GTAW, GMAW, Laser, Gas Welding. It can be achieved by using Sensor-based technique. A K-Type thermocouple is fixed with a titanium alloy. This kit is placed under the welded metal and the heat distribution of the metal is studied and analysed.

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1. Introduction

Process monitoring system, continuously monitors various parameters like temperature, pressure, vibration, force, voltage, current, etc. using various sensor and image processing-based techniques. Process monitoring system are applied in industrial machining process like drilling, milling, boring, welding, cutting, lathe operations, CNC machining etc. Various parameters are monitored for various machining process that has been shown in the Fig. 1.

The work piece and the work tool-piece are monitored in every machining process for a good quality finished product and also for proper machining operation. The defects such as cracks, blowholes, overlap, undercut, slag formation, over processing, tool breakage, change in weariness of the metal etc., can be avoided by using a Process Monitoring System.

The Process Monitoring System is monitored by two methods 1. Sensor based monitoring 2. Image capturing technique. The Sensor based monitoring techniques uses different types of sensors for monitoring different parameters. These data are amplified by an amplifier and then collected for the data processing. In Image capturing technique infrared radiation camera, ultrasonic radiation camera, photoelectric camera etc., are used for the image capturing and a machine learning algorithm is used for data processing. The Fig. 2 represents the different types of sensors used to monitor different types of parameters in sensor based and image capturing technique for machining process.

In welding process monitoring system, the important parameter to be monitored is temperature. The temperature for a process monitoring system can be monitored by using various types of sensors like thermocouple, thermistor, RTD, Integrated IC. Namely in welding monitoring system Thermocouple and RTD are been used. These sensors are differed according to their properties and chemical composition.

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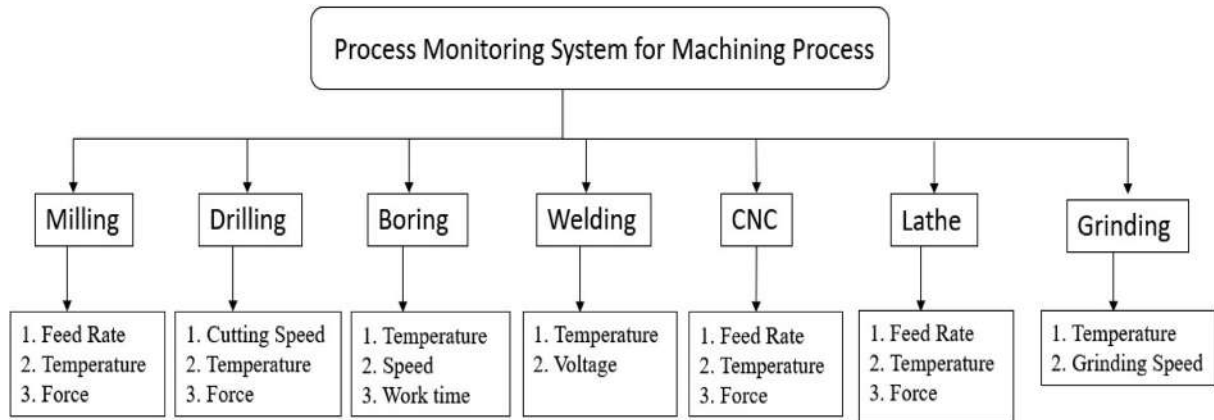


Fig. 1. Classification of Process Monitoring for various Machining Process.

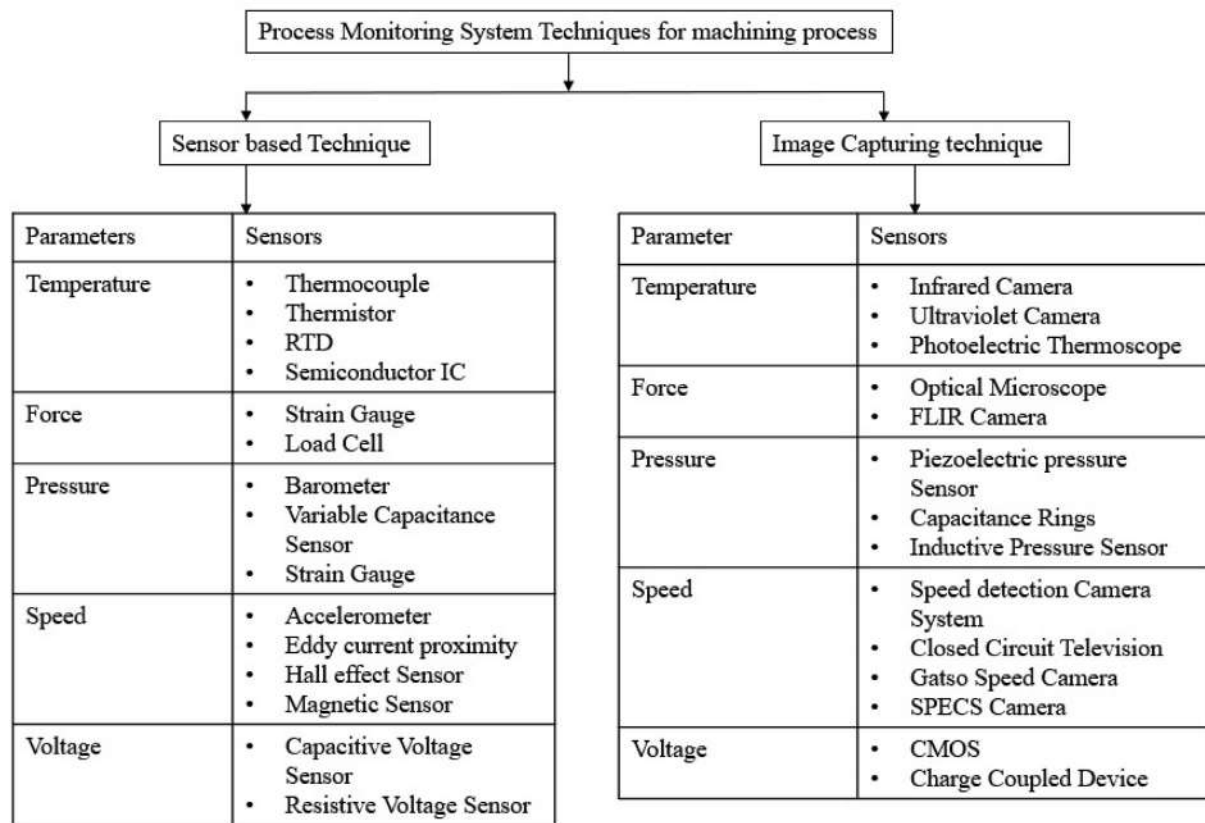


Fig. 2. Sensors used for Process monitoring techniques for machining process.

1.1. Thermistor:

Thermistor is a combination of two parameters namely "Temperature" and "Resistance". The change in temperature changes the resistance of the metal. Thermistor is a type of a resistor and its resistance is depended on the Temperature. It is classified into two types PTC (Positive Temperature Coefficient) and NTC (Negative Temperature Coefficient). In PTC the resistance increases with increase in temperature and in NTC resistance decreases with increase in temperature. PTC thermistors are prepared from barium, sodium or lead titanates. NTC thermistors are prepared from oxide families of iron group like iron-oxides, chromium, manganese, cobalt, nickel. These thermistors are been used in lithium battery circuits, 3d printers, voltage-controlled oscillators and also

in low temperature measurements. The thermistor is differentiated according to their Ohms range. The different types of thermistors are shown in the Table 1.

Table 1
Types of Thermistor and its temperature range.

Model	Resistance value(KΩ)	Temperature range (°C)
TCS605	5	–20 to + 33
TCS610	10	–8 to + 50
TCS10K5	10	–8 to + 50
TCS620	20	+6 to + 69
TCS650	50	+25 to + 92
TCS615	100	41 to 114

1.2. RTD:

Resistance Temperature Detector works in the principle of change in temperature, changes the resistance value. The RTD is made with a heat resistance ceramic core connected with a fine wire. The wire is made of using a pure material namely platinum, nickel, copper. The RTD is classified into three types UPRTs (Ultra Precise Platinum Resistance Thermometer), SPRTs (Standard Platinum Resistance Thermometer), Industrial PRTs. These types are differed according to their applications. The RTD is differed from thermistor based upon the temperature range. The average temperature range of an RTD is 600 °C – 700 °C, at 390 O the maximum temperature can be measured is 1560 °C. RTDs are used in automotive, industrial and also in high temperature measurements with high accuracy rate.

1.3. Integrated IC:

An Integrated IC is a type of temperature sensor which can measure temperature from –70 °C to 150°Celsius. Basically, an integrated IC is a semiconductor diode which consists of two similar diodes that are sensitive to temperature. Its operational temperature is about 3 V to 5 V. Most likely these types of temperature sensor are used in embedded circuit and other small applications like body temperature monitoring etc.

1.4. Thermocouple:

Thermocouple works in the principle of see-beck effect. Two different metals are bonded together in a junction to form an electrical circuit. The difference in the temperature between the junction changes the flow of electric current in the circuit. These thermocouples are classified into many types, such as B, C, E, J, K, N, R, S, T. Thermocouples are been used in various industries such as Automotive sensing, rocket and aircraft engines, food processing, electric power generation. The main difference between the thermocouple and RTD is precision and accuracy of the sensor. Thermocouples are high accurate but not precise. Thermocouples are differed depending upon the metal combination. The thermocouple temperature range and metals used are shown in Table 2.

1.5. Challenges and precautions to be followed before using thermocouple:

Thermocouples are not accurate as RTD and these types of sensors are highly corrosive when it is not insulated properly. The output signals are not linear. The accuracy level compared to RTD is less. While using the thermocouple, avoid contact with the magnetic field. If using in an electrolytic process, avoid contact with the electrode. The thermocouple needs to be periodically checked to see if it is functioning properly.

Table 2
Various Types of Thermocouple and its temperature range.

Types	Temperature Range	Metal combination
B-Type	1370–1700 °C	Platinum - Rhodium
C-Type	1650–2315 °C	Tungsten - Rhenium
E-Type	95–900 °C	Chromel - Constantan
J-Type	95–760 °C	Iron - Constantan
K-Type	–200–1260 °C	Chromel - Alumel
N-Type	650–1260 °C	Nickel - Chromium
R-Type	870–1450 °C	Platinum - Rhodium
S-Type	980–1450 °C	Platinum - Rhodium
T-Type	–200–350 °C	Copper - Constantan

2. Literature survey

2.1. Temperature measurement in friction element welding process with micro thin film thermocouples

A micro thin film thermocouple was developed for the temperature measurement of friction stir welding of Al 6005 and JSC 980 steel of 40*40 mm dimension. An array of micro thin film thermocouples (TFTC) was fabricated on top of a multi-layer insulating dielectric film on the JSC 980 Steel.

The dimension of the K-Type thermocouple is 50*50 µm and it is composed of 120 nm of chrome and 180 nm of alumel. The TFTC used in this work has a linear sensitivity of 41.3 V/°C to a temperature of 1000 °C. This method measured the temperature reading from 219 °C to 414 °C at a distance of 3.15 mm.

Study of temperature evaluation of the FEW processes is done. The microstructure analysis is done for each step of FEW for the study of temperature distribution on the weld metal.[1].

2.2. Calibration of dynamic Tool-Workpiece interface temperature measurement during Friction Stir welding

The thermocouple is configured with the FSW (Friction Stir Welding) tool for monitoring the temperature of the work tool. The machining process, where the tool-workpiece will produce a huge amount of heat, can be monitored using this technique.

The tool used in friction stir welding is typically spun at 1000RPM, which will produce high heat in the work piece. In this FSW process, the K-Type thermocouple is placed between the probe and the shoulder of the tool for the measurement of temperature. The FSW tool is made of H13 steel of shoulder diameter 15 mm and tip diameter 5 mm, and the K-Type thermocouple is surrounded by magnesium oxide (MgO) and mounted using thermocouple cement (Omega Bond 600).

At the shoulder, the temperature 1 measured is 520 °C–540 °C while rotating the tool at an angle of 0°–210° and the temperature 2 measured is 545 °C–550 °C while rotating the tool at an angle of 30°–180°. The temperature measured at the probe is 498 °C–508 °C while rotating the tool at an angle of 0°–240° and 502 °C–506 °C while rotating the tool at an angle of 30°–150°. The one-dimensional model has been created using the temperature readings.[2].

2.3. Study on High-speed High-temperature adaptive fuzzy PID control system

Using a high-speed, high-temperature adaptive fuzzy PID control system in the welding process, the temperature is monitored and controlled. This control system has two parameters: the Photoelectric Thermoscope and the Fuzzy Logic PID controller. The real-time thermal image of the weld is captured by the photoelectric thermoscope, and the Fuzzy logic PID controller is used for monitoring temperature and maintaining the temperature of the welding process.

The photoelectric sensor is a device that will capture all types of heat signals in an image format. The fuzzy logic PID controller improves the response time of the photoelectric sensor and increases its precision. The photoelectric thermoscope has a range of 200 °C–1100 °C at a soldering temperature of 500 °C–800 °C.

Using this technique, the temperature is monitored and it can also be set/controlled to a particular temperature range while welding. The study of temperature is done for the welding process.[3].

2.4. Study of on-line temperature monitoring system for hull welding based on Xgboost-PSO

In this work, the temperature is monitored for the hull welding process using a K-Type Magneto-Thermocouple and the data is sent through via the internet. This data is manipulated using the Xgboost-PSO algorithm.

The output value of the magneto temperature sensor is amplified using MAX series amplifiers and filtered using a filtering-circuit with a frequency rate of 50 Hz. By using the STM-32 micro-processor, this data is shared on the internet.

The GBDT and Xgboost algorithms increase the accuracy of the thermocouple and solve non-linearity problems in it. The PSO algorithm reduces the error dynamically. The gradient lifting decision tree has high precision over the data and is used for on-line temperature monitoring. The temperature measured in the On-line temperature monitoring was 250 °C–500 °C with a reduced absolute error of 1.0 to 0.3.[4].

2.5. Peak temperatures during friction stir welding of Ti-6Al-4 V

The study of the temperature distribution of FSW (Friction Stir Welding) process in the Ti-6Al-4 V was done by using a K-type thermocouple.

The K-Type thermocouple with a diameter of 0.8 mm is configured with a Ti-6Al-4 V of 12 mm thickness. The data is communicated with the help of a GL800 digital data collector. The chemical composition of Ti-6Al-4 V is Ti-6.28Al-0.1C-0.21Fe-0.010 N-0.13O-4.05. The result shows that for 300 rev/min at 100 mm/min, the peak temperature was about 1100 °C. At a spindle speed of 300 RPM-500 RPM and a feed rate of 100 mm/min-150 mm/min, the maximum temperature reading is around 1000 °C-1200 °C.

The temperature developed in the weld metal has been studied at different spindle rates and feed rates in the FSW process of Ti-6Al-4 V metal.[5].

2.6. Development and application of a temperature measurement device using the tool-workpiece thermocouple method in turning at high cutting speeds

When the cutting speed of the tool-piece increases, the cutting temperature of the work piece also increases, and it will affect the machining process as well as the material property. Hence, to control the temperature developed in the work piece, a K-Type thermocouple is configured with the cutting tool.

In the machining process, the workpiece used is 1350 aluminium alloy and 7075-T6 aluminium alloy. These alloys are cooled in water and artificially aged at 120 °C for 24 h. The cutting operation is carried out on a CNC machine powered by 11 kW, and it has a maximum spindle speed of 300RPM. For 1350 Al, the temperature developed was 300 °C–430 °C and for 7075 Al, the temperature developed was 450 °C–660 °C.

Thus, the temperature developed in the work piece is studied and the cutting temperature is maintained.[6].

2.7. Thermoelectric measurements for temperature control of robotic Friction Stir welding

Temperature monitoring system is developed in a robotic friction stir welding by using a TWT method. The welding is taking place in the AA6082-T6 metal. The robotic FSW is ISO 25239-4 approved machine which can produce 1500 N – 7500 N of force.

In Tool Workpiece Thermocouple (TWT) the thermocouple is configured at the TTC-Probe, TTC-Shoulder and TTC-Corner of the 12 mm thick FSW tool. The average temperature developed in TTC-Corner: 594 °C–607 °C, TTC-Shoulder: 555 °C – 596 °C, TTC-

Probe: 522 °C–554 °C. At core of the weld the temperature developed is 607 °C. Using TWT method the overall temperature developed at the operating speed: applied force: temperature developed is 5 mm/s:2500 N – 7500 N:510 °C, 10 mm/s:2500 N-7500 N:560 °C.

The study of the temperature of the tool and work piece is done and controlled over the temperature developed.[7].

2.8. Workpiece temperature investigation in micromilling of titanium alloy

A technology has been developed for monitoring the temperature of the work piece as it undergoes micro milling operations. The micro milling operation is done in two different metals, namely Ti-6Al-4 V and H13 steel.

The temperature is monitored by using a T-Type thermocouple and it is fixed in the surface of the work piece. An AlCrN-coated carbide micro cutter is used for the milling operation. The temperature is studied in an experimental method using a sensor and also simulated by using Third Wave Edge software. By using 2D FEA, while using a 100 µm micro cutter with an edge angle of 90°, the maximum temperature monitored was 300 °C for H13 steel, and while using a 508 µm micro cutter, the maximum temperature monitored was 100 °C for Ti-6Al-4 V alloy.

The experiment proved that the temperature is highest at the up-milling side, and as the temperature increases, the tool weariness also increases. The study of temperature is done by using the 2D FEA method.[8].

2.9. Experimental and theoretical investigations on temperature distribution at the joint interface for copper joints using ultrasonic welding

Using K-Type thermocouples, the temperature is monitored in the ultrasonic welding of copper joints. The ultrasonic welding machine works at 2500 W, 20 kHz.

In this work, the weld metal used is Cu and its thickness is 0.2 mm-0.3 mm. The temperature measured at a low-level frequency of welding is 110 °C, and at a high frequency of welding, the temperature measured is 155 °C-250 °C. The mathematical modelling is done using FDM in MATLAB at the weld temperature of 200 °C. The temperature developed at the weld interface is simulated in the FEA software.

The temperature developed in the weld metal is studied, and the mathematical modelling is done using the FDM method. This work concludes with the increase in work time increasing the temperature of the weld metal.[9].

2.10. Cutting temperature measurement on milling process of CFRP

The cutting temperature measurement on Milling Process of CFRP is developed for monitoring the operational temperature in CFRP metal of thickness 7 mm by using K-Type thermocouple.

The machining process is done in Vertical milling machine with a maximum rotational speed of 12,000/min and the power consumed is 18.5 W. In the milling machine the cutting tool used is of 8 mm diameter. The K-Type thermocouple is fixed in the CFRP metal under the machined surface level of 0.7 mm. The thermocouple is connected with a resistor and to the data logger. The maximum temperature monitored at a cutting speed of 300 mm/min is 60 °C.

The temperature developed in the work-piece while milling operation is studied and micro structure analysis is done.[10].

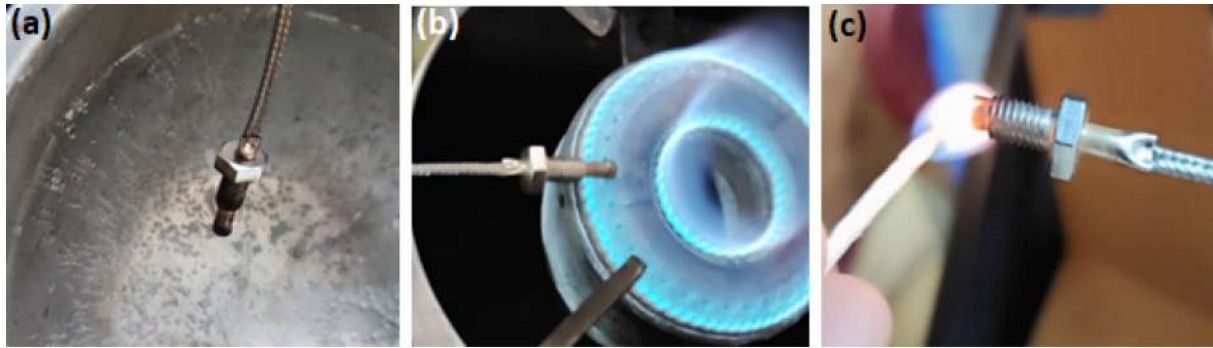


Fig. 3. Temperature Measurement using Thermocouple (a) Boiling Water; (b) LPG gas flame; (c) Match stick flame.

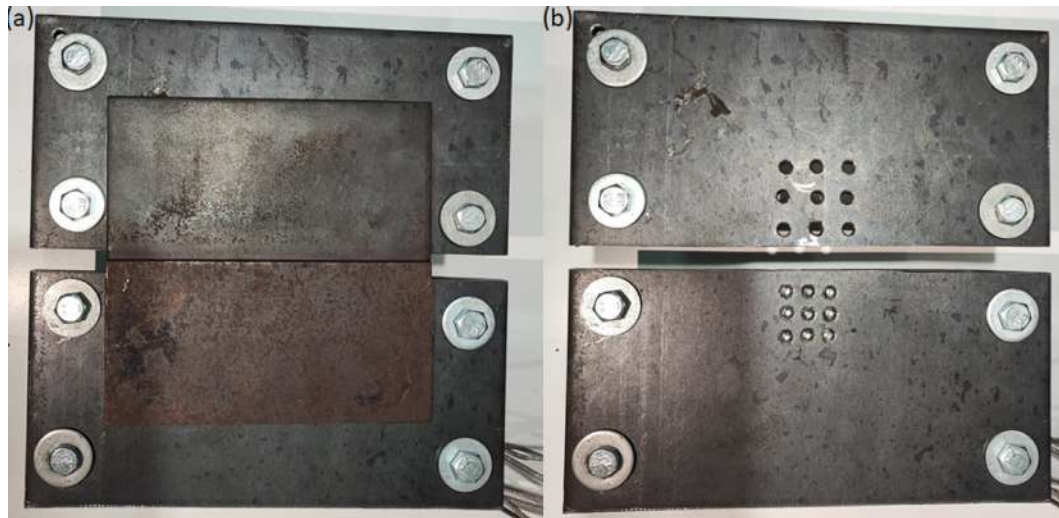


Fig. 4. (a) Weld bed with welding metal, (b) Weld bed with an array of thermocouples.

2.11. Cutting temperature measurement by a micro-sensor array integrated on the rake face of a cutting tool

Using thin film thermocouple, the temperature is monitored in the rake face cutting tool. The cutting process is done in a nylon material for medical application.

At the cutting edge of the cutting tool the Cr thin metallic line (Hot junction) and the Al₂O₃ metallic line (cold junction) is cemented by using WC-Co and named as Thermocouple A. At the chip friction is another thermocouple is been attached and named as Thermocouple B. The difference in the temperature between two thermocouples are 2 °C. While machining process the temperature measured at cutting edge is 40 °C – 80 °C and at chip formation area the temperature measured is 38 °C – 78 °C.

The temperature between two junctions is been monitored and studied. [11].

2.12. On the measurement and prediction of temperature fields in machining AISI 1045 steel

The temperature developed in the AISI 1045 steel while machined in the orthogonal cutting machine has been monitored by using an Infrared Microscope.

The AISI 1045 steel is machined at a different feed rate and different cutting speed. The infrared microscope is kept in a particular direction that captures the thermal image of the chip which is removed from the workpiece. The temperature readings are taken for four different chip thickness. (a) 48 μm – 100 °C to 800 °C (b)

40 μm – 100 °C to 800 °C (c) 31 μm – 100 °C to 700 °C (d) 23 μm – 100 °C to 700 °C.

The temperature is monitored and studied. FEA model is created. A relation between friction coefficient and temperature is obtained. [12].

2.13. An Integrated Telemetric thermocouple sensor for process monitoring of CFRP milling operations

In CFRP process drilling and milling operations are done, for both the operation the tool has a critical temperature of 180 °C to 270 °C, the temperature of the tool was monitored by using Integrated Telemetric Temperature (ITT) sensor.

The ITT sensor has been configured inside the CFRP carbide tool. The dynamic response testing and then calibration in LabVIEW has been carried out for the temperature readings obtained in the tool. The bulk temperature obtained from the tool in the milling process is 175 °C.

Table 3
Temperature readings using K-Type thermocouple.

S.No	Sensor Used	Heat Source	Temperature
1.	K-Type Thermocouple	Boiling Water	99.9
2.	K-Type Thermocouple	LPG gas flame	590
3.	K-Type Thermocouple	Match stick flame	70

The temperature of the CFRP tool has been monitored, studied and maintained.[13].

2.14. Temperature measurements during friction stir welding

Measurement of temperature of the Friction Stir Welding (FSW) Tool of aluminium alloy. The temperature of the tool is measured with the TWT method.

The TWT method is a technique in which the thermocouple is fixed in the FSW tool for the temperature monitoring. The variation of force and the spindle rate changes the temperature developed in the tool of FSW tool. Which cause defect in the work piece. Hence the temperature developed in the tool is studied for different spindle rate. The temperature developed at the probe of the tool is 300 °C to 600 °C and at the shoulder the temperature developed is 350 °C to 600 °C.

The temperature developed in the tool of FSW process was monitored and controlled over the temperature.[14].

3. Summary

Summary of Various Temperature Monitoring Systems

S.no	Machining process	Material	Metal thickness (mm)	Sensor	Temperature measured	Outcome
1	Friction Stir Welding	Al 6005, JSC 980	40*40	Thin film thermocouple	219 °C – 414 °C	Study of temperature and microstructure analysis is done.[1]
2	Friction Stir Welding (Cutting tool)	H13 steel	Shoulder dia- 15 mm	K-Type thermocouple	520 °C	One-dimensional model is created using the temperature reading.[2]
3	Welding	Any metal	—	Photoelectric sensor	200 °C-1100 °C	Temperature is studied. [3]
4	Hull Welding	Any metal	—	K-Type thermocouple	250 °C-500 °C	On-Line monitoring of temperature is studied.[4]
5	Friction Stir Welding	Ti-6Al-4 V	12 mm	K-Type thermocouple	1000 °C-1200 °C	Temperature is studied at different feed and spindle rates.[5]
6	CNC Machine	1350 Alloy and Ti-6Al-4 V	—	K-Type thermocouple	300 °C – 430 °C and 450 °C-660 °C	Cutting Temperature is monitored and controlled. [6]
7	Robotic Friction Stir Welding	AA 6082-T6	12 mm	Tool, work piece thermocouple	522 °C-607 °C	Temperature of tool and work piece is monitored.[7]
8	Micro Milling	Ti-6Al-4 V, H13 steel	100 µm 508 µm	T-Type Thermocouple	100 °C, 300 °C	Temperature is studied.[8]
9	Ultrasonic Welding	Copper	0.2 mm-0.3 mm	K-type thermocouple	135 °C – 250 °C	Mathematical model is created in FDM. [9]
10	Milling	CFRP	7 mm	K-type thermocouple	60 °C	Microstructure analysis. [10]
11	Cutting	Nylon	—	Thin film thermocouple	40 °C – 80 °C	Temperature is studied. [11]
12	Cutting	Steel	—	IR microscope	100 °C – 800 °C	FEA model is created. [12]
13	Drilling and Milling	CFRP tool	—	ITT sensor	180 °C – 270 °C	Dynamic Response.[13]
14	FSW	Aluminum alloy	—	Thermocouple	300 °C – 600 °C	Temperature in monitored and controlled. [14]
15	Cutting	AISI 4140 steel	—	Thermocouple and IR thermoscope	57 °C – 80 °C And 410 °C – 500 °C	Study of temperature is done. [15]

2.15. Thermocouple and infrared Sensor-Based measurement of temperature distribution in metal cutting

Temperature monitoring system was developed by using thermocouple and infrared sensor for the cutting process of AISI 4140 steel.

At the initial stage of the machining process AISI 4140 is heat treated with T6 to form aluminium 6082-T6 and machined by cutting tool in lathe machine. The K-Type thermocouple is configured in the work tool for monitoring the temperature developed in the work tool and infrared pyrometer is configured for measuring the cutting temperature and the temperature of the chip. The aluminium is machined with a different cutting speed and feed rate. The average temperature developed in the tool is 57 °C to 80 °C and the average temperature of the chip is 410 °C to 500 °C.

The temperature is monitored and studied with the help of ANSYS finite element method.[15].

3.1. Case study

A continuously temperature monitoring kit has been developed to monitor the temperature/heat dissipation in the welded metal during the welding process by using the GTAW, GMAW, Laser, Gas welding process as shown in Fig. 4. K-Type thermocouple is used for the temperature measurement. An array of K-type thermocouple is fixed on a 3 mm low carbon steel plate, wherein the low carbon steel plate would act as a weld table/bed during the welding process. The K-Type thermocouple is made of chrome and alumel alloy, and its operating temperature varying from $-200\text{ }^{\circ}\text{C}$ to $1260\text{ }^{\circ}\text{C}$. It has a maximum temperature measurement range upto $1024\text{ }^{\circ}\text{C}$. The thermocouple is connected to the MAX6675 amplifier for the amplification and for the conversion into digital signal. The weld bed is kept under the welded metal and the thermocouple is placed on the weld bed in a form of 3×3 matrix array. The data from the sensors is collected in the form of array using CoolTerm software, which collects the temperature data from the serial port. This kit is significant in identification of the maximum temperature the welded metal can withstand and also efficiently identifies whether the heat is dissipated properly from the weld metal. If the heat dissipation in the weld metal is improper it means that the metal was not properly welded and this can be proven by performing microstructure analysis of the welded metal. The Fig. 3 shows the Temperature Measurement using Thermocouple of Boiling Water; LPG gas flame and a Match stick flame. The temperature readings are tabulated in Table 3.

4. Conclusion

The temperature of the welded metal can be continuously monitored using various types of sensors and machine learning techniques, among which an easy and precise method of measuring the temperature can be obtained by using k-type thermocouple. Its high accuracy coupled with its ability to sense a wide range of temperature ranging from $-200\text{ }^{\circ}\text{C}$ to $1024\text{ }^{\circ}\text{C}$ making this method extremely efficient. These sensors can be easily calibrated with the amplifier and microcontroller. The heat distribution on the metal, welded by FSW, GTAW, GMAW, Laser welding, Gas welding can be identified. An array of thermocouple is used for monitoring the temperature developed in the welded metal. The matrix region reads the temperature value, processed for finding the temperature it withstand and the quality of the weld. The standard metal size of $75\times 150\text{ mm}$ is used as the weld bed. This system can be used for monitoring the weld quality of any metals without changing the position of the sensor with a maximum temperature limit of $1260\text{ }^{\circ}\text{C}$. The system does not depend on the properties of the weld metal such as ductility, rigidity, malleability, etc. To conclude the continuous temperature monitoring system has the following advantages:

- Sensor calibration is easier and it is capable of giving accurate values.

- It has a capability to withstand High temperature with minimal error.

CRedit authorship contribution statement

J.R. Deepak: Conceptualization, Supervision, Writing – original draft. **M. Prasanna Kumar:** Writing – original draft. **M. Nithishkar:** Writing – original draft.

Data availability

No data was used for the research described in the article.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Development of a Continuous Monitoring System for High-Temperature (Metal Joining) applications

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Abstract:

Defects such as micro cracks, porosity, undercut, slag inclusion, overlap, excessive reinforcement, etc are caused due to improper monitoring of the process parameters during welding process. The weld process parameters that are to be closely monitored during welding are temperature, voltage, current, shielding gas, weld speed, current time, etc. In this research work, a continuous temperature monitoring kit is developed using an array of k-type thermocouple sensors which can work up to a maximum temperature of 1260°C. Using this continuous temperature monitoring kit, the heat dissipation on the weld metal is monitored and the temperature data are captured using cool term software by data acquisition process. The heated dissipated on the weld metal is easily captured during the welding operation. This results in minimization of weld defects and also results in preparation of high-quality weld joints.

Keywords: *Temperature monitoring, Thermocouple, Welding, Metal deformation, Sensor array.*

1. Introduction:

Cracks, blowholes, slag inclusion, excessive heating are few defects that occur in both the workpiece and tool used in various machining process like lathe machining, drilling, boring, milling, welding etc., due to the improper process monitoring of the machining system. Temperature, force, pressure, speed, time etc., are few process parameters that are to be continuously monitored and maintained during the machining process. Temperature is the most important factor that needs to be monitored during welding operation. If the temperature is not monitored continuously, it leads to major defects like burn through, lack of penetration, lack of fusion, excessive reinforcement, wider heat affected zone, deformation of metal etc. Temperature can be monitored by a sensor-based technique where temperature is measured by direct physical contact and Image capturing-based technique where temperature is monitored by using an imaging sensor. Sensor-based technique is simple, cost effective, easy to adapt to any machining process and can measures very accurate temperature values. In the sensor-based technique, the temperature is monitored with the help of array temperature sensors. Types of temperature sensors vary according to their property and application. Types area 1. Thermocouple 2. RTD 3. Thermistor 4. IC. Resistance temperature detector (RTD) is highly precision and accurate in nature and can be used for very high temperature. But RTD is very expensive. The different types and applications with the maximum temperature withstand of the temperature sensor are shown in the table 1.

Sensors	Maximum temperature(°C)	Application
Thermocouple	-200 to +2300	Industrial and high temperature
RTD	-240 to +650	Automobile.
Thermistor	-20 to +114	Electric circuits.
Ic	-70 to 150	Medium-scale projects.

Table 1. Types of temperature sensors and its applications