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RELATIONSHIP OF DEW POINT AND AMBIENT TEMPERATURE VARIATION ON WELD QUALITY

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This investigation deals with the study of the effect of environmental parameters viz dew point temperature, relative humidity, ambient air temperature, and job surface temperature on robotic MAG (Metal active gas) welded joint quality. Weld samples taken were mass manufacturing welded structures of a heavy-large scale industry, which were further subjected to semi-automatic ultrasonic testing to assess defects within welded joints. The trend of defects observed and recorded after ultrasonic testing of weld joints was co-related with the trend of atmospheric parameters for a span of four years to establish a linear empirical relationship. It has been established that variations in atmospheric parameters resulted in variations in the trend of weld defects. These variations were studied to get the empirical relationship to establish the effect of variation in atmospheric parameters on weld quality or defects in joints. It has been observed that whenever there was a drop in the "difference in ambient air temperature & dew point temperature, especially less than 5," a drop in ultrasonic testing straight pass % was observed than the average value.

Keywords: Dewpoint; Atmospheric; Temperature; Humidity; Defect; Welding; Porosity.

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1. INTRODUCTION

Metal active gas welding (MAG) has been chosen for this study which is a semi-automatic process. MAG process is a member of the Gas Metal Arc welding (GMAW) family (Pires *et al.*, 2006). Detailed literature was referred to understand the effect of atmospheric parameters on weld Metal active gas welding (MAG) quality and understand the process of Metal active gas welding (MAG).

The humidity sources of welding electrode coatings, the influence of relative humidity, and the air humidity content of some types of electrode coatings for arc welding were analyzed to establish the effect on weld strength (Iocobescu *et al.*, 2019).

For A7N01S-T5 aluminum alloy welded joints, the effect of humidity on the porosity, microstructure, and fatigue strength of weld joints has been established (Iocobescu *et al.*, 2019). A study of the effect of environmental humidity on the welding of weathering steel was done to establish that the rate of fatigue crack propagation mainly depends on the microstructure of the material rather than the environmental factors such as humidity (Zhang *et al.*, 2020). MAG welding is the industry's most versatile and widely accepted welding technique. The versatility of MIG welding has enhanced the automation level of the welding technique (Zhang *et al.*, 2020). Along with automation, optimization of the weld quality is the most important requirement of time. Industrial applications always strive to achieve zero defects in welding (Pawan1 *et al.*, 2016). For the same, the assessment of input parameters, input material, and environmental parameters to determine improvement scope has been considered an important factor. Higher-quality of welding has the potential for savings in resources and materials. Robotic MAG welding has been deployed to fabricate heavy industrial machinery's structural components (Wagh *et al.*, 2014). The soundness of the weld was assessed using a semi-automatic ultrasonic testing process. Any defect recorded in ultrasonic testing of the weld needs to be repaired. The defect recorded were removed by air arc gouging technique (Das *et al.*, 2015), re-welding, followed by re-ultrasonic testing is standard practice. Defect rectification and rechecking result in loss of resources, time, and production flow delays. So, with the objective of reduction of rework loss, by assessing and eliminating the cause of welding defects, the work has been carried out and presented. The scope for the study of environmental parameters on weld quality has not been studied based on the literature available and the work done. So specifically, it has been tried to study the effect of dew point and other temperature parameters on weld quality.

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Tomkówa *et al*. (2019) investigation has shown that environmental changes cause statistically significant changes in the diffusible hydrogen content. It was established that the share of the welding process with respect to an overall product/structure life cycle impact assessment is strictly dependent on the project design choice and can be negligible for high-corrosion-resistance materials (e.g., Inconel alloy). On the other hand, using traditional metals (e.g., carbon steel) allows a large decrease in the environmental load, and the influence of the welding process becomes significant from a life cycle perspective (Claudio *et al*., 2019). Rizki *et al*. (2021). A brief description of the effect of the environment on porosity defects, the causes of porosity formation, the impact of porosity, and how to reduce porosity in aluminum welding has been discussed. In conclusion, the formation of porosity in the welding process is due to dissolved hydrogen in the weld metal, air/bubbles from the welding process, filler/filler wire, and the environment welding influence. The impact of porosity can cause cracks in welded joints, decreased ductility, and fatigue failure.

Yilong *et al.* (2019) stated hydrogen changed the feature of fracture morphology from dimples to various defects. Considering the high tensile strength as well as the fine microstructure of the welds, the hydrogen content of the ER5183 welding wires should be controlled below 0.18 μg/g. The differentiation of the shielding gas composition did not cause these regions to change, but the heat-affected zone expanded with the increase in the helium content. The hardness of the welded joint's cross-section has increased from around 60 HV to 90 HV from the welding area to the base material. 25% Argon-75% Helium gas mixtures provided an optimum combination in terms of microstructure, mechanical properties, and cost (Yılmaz *et al*., 2022).

On the other hand, Sougata *et al*. (2021) showed that an argon mixture with 3% nitrogen gas produced the best performance in terms of maximum hardness and tensile strength, with much less scatter in tensile strength. He-Ar-CO2 or tri-mix shielded samples showed a low tensile strength with wide scatter due to stabilized delta ferrite in microstructure during printing. Both tri-mix and Ar-CO2 shielded samples showed slightly higher porosity. Shaohua *et al*. (2019) investigated the results from mechanical testing and showed that the pores did not influence the mechanical properties for the low percentage of porosity in the range of near 0 to 4% but decreased the fatigue strength of the joints. EBSD results illustrated that the grain size of the fusion zone was about 74 ± 58 μm, and no obvious texture was found within the fusion zone.

Structural welding is done through an Industrial robotic welding setup in this work. The type of defect and location of weld defects within weld joints were recorded after ultrasonic testing of weld joints. The effect of atmospheric parameters on weld quality has been monitored over a span of four years to establish a linear co-relation. Various atmospheric parameters like relative humidity and dew point temperature were monitored along with job surface temperature. The trend of weld quality in terms of defects observed in ultrasonic testing was also maintained for four years. Above trends of atmospheric parameters and weld defect trend were co-related to find a suitable empirical relationship. The objective was to get suitable triggers in case of an unsuitable environmental condition during welding and to take suitable measures to avoid defects.

2. MATERIALS AND METHODS

2.1 Welded structural components for study

The structural components discussed here are fabricated hydraulic mining/earth-moving industrial equipment structures. These are earth-moving heavy machinery used for mining and construction (Das *et al.,* 2021).

These structural components were made of multiple butt-weld joints, as shown in Figure 1, welded on robots. Based on the criticality of design and application stresses, many of the welded joints were subjected to quality checks, specifically called ultrasonic testing. Configuration of butt joints of structural component welded is stated in Figure 1, where butt weld joints were made with a combination of various thicknesses of plates (T) ranging from 10 mm to 25 mm.

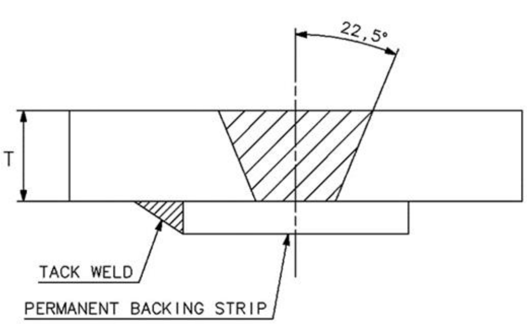


Figure 1. Type of weld joint – Butt weld joint configuration used for fabrication of mass manufacturing components

2.2 Material grade of a plate for structural components

A common grade mild steel, i.e., IS 2062 (IS Specification: 2062, 2011), was selected as the base material. The specifications for the chemical composition and mechanical properties of these mild steel plates are given in Table 1.

This grade of steel plate with a carbon equivalent of 0.4 to 0.42 are normalized without any additional requirement of pre-heating and post-heating to support the strength and quality of weld joints (Odebiyi *et al.*, 2019).

Table 1. Specifications for IS 2062 grade plate

a. Chemical composition							
Sl. No.	**Grade**	**%C Max.**	**%Si Max.**	**%Mn Max**	**%S Max.**	**%P Max.**	**CE**
1	A	0.23	0.4	1.5	0.045	0.045	0.42
2	BR	0.22	0.4	1.5	0.045	0.045	0.41
3	C	0.20	0.4	1.6	0.045	0.045	0.39
b. Mechanical properties							
Sl. No.	**Grade**	**Y.S (Mpa) min**	**UTS (Mpa) min**	**% Elongation min**	**Hardness (BHN)**	**Heat Treatment**	**Impact testing (Min Joules)**
1	A	250	410	23	120-140	Normalized	27 at room temperature
2	BR	250	410	23	120-140	Normalized	27 at 0 degrees C
3	C	250	410	23	120-140	Normalized	27 at -20 degree C

2.3 Weld technique and parameters involved

A robotic tandem welding setup was selected for having six-axis welding manipulators with trans-pulse synergized 5000 weld power source and automatic wire feed gas nozzle with arc seam tracking system for MIG/MAG welding of structural components. This welding robot has a power supply of 3 X 400 V, with a continuous current feed of 180 to 300 Amps, on a 100% duty cycle, power rating of 13.1KVA.

The tandem welding process selected involves high-performance MAG automatic welding, using two wire electrodes for increased deposition rate (Goecke *et al.*, 2001). During tandem welding, two wire electrodes were melted simultaneously and routed through two electrically isolated contact tips, i.e., the potentials were separate. As a result, the arcs could be controlled independently, and, despite differing outputs, arcs were precisely coordinated and synchronized. The separate wire electrodes were fed into a single torch hose pack via different wire feeders with a single gas nozzle and electrically isolated contact tips. Two arcs generate a single weld pool (Goecke *et al.*, 2001). For the welding purpose Argoshield (Paradowska *et al.*, 2010). shielding gas is used, a gas mix suitable for the optimized source of MIG weld shielding having excellent arc stability and high-strength welds. Argoshield composition selected was Oxygen 2%, Carbon Dioxide 12-20 %, and Argon rest %.

For welding heavy structural jobs, a robotic welding setup was used. The welding robot was equipped with a six-axis welding manipulator with a trans-pulse synergized 5000 weld power sources, an automatic wire feed gas nozzle, and an arc seam tracking system for MIG/MAG. This welding robot has a power supply of 3 x 400 V, a continuous current feed of 180 to 300 A, a 100 % duty cycle, and a power rating of 13.1 kVA.

The current and voltage ratings meet the requirement of our WPS (welding procedure specification) and are specified in Table 2a. These parameters were deployed for robotic welding of actual mass manufacturing structural jobs. The parameters mentioned in WPS (welding procedure specification) were the standard parameters adopted for welding similar components. The parameters mentioned in WPS (welding procedure specification) were derived from the best suitable range of parameters from various experimental samples, giving the best mechanical and metallurgical results.

And, if it is advised to follow the suggested range of parameters of WPS, desired mechanical and metallurgical properties of welded joints can be ensured. So, in this work, a pre-qualified WPS (welding procedure specification) parameter range was selected for welding to avoid or eliminate the effect of improper welding parameters on mechanical and metallurgical tests, and only the effect specific to the purity level of shielding gas can be addressed.

Table 2a. Parameters of welding done

Plate grade	Weld pass no.	Current in Amperes	Voltage in volts	Job to nozzle tip distance in mm	The gas flow rate in LPM (liters per minute)
Mild steel, IS2062-410 B	Root run	270-275	25-26	15	18-20
	2nd pass	277-280	26-27	15	18-22
	3rd pass	260-264	25-26	15	18-22

2.4 Investigation of the welded joint using ultrasonic testing

As per Atomic I Agency guidebook (1999), ultrasonic testing involves using ultrasonic sound waves to detect defects inside a material. The welded joints have possibilities of defects inside the welds or sometime near the weld zone. The few defects often found in welds are porosity, cracks, slag inclusion, lack of fusion, penetration, root concavity, HAZ cracks, and much more (Baughurst *et al.*, 2011).

As per the Atomic I Agency guidebook (1999), these defects, when located deep and were not viewed manually, ultrasonic scanning is utilized to detect these discontinuities. An ultrasonic testing machine with a scanning probe specification of 22.5°, 70 MHz has been used. The ultrasonic testing inspectors were qualified as per the guidelines of ASNT SNT-TC-1A, Level II (Engineering Standards Manual, 2012). All the defects observed during ultrasonic testing were assessed against the specified standard for acceptance/rejection. Rejected jobs were subjected to rework/repair. The type of defects/nature of defects were recorded for each joint.

In the investigation, A scan methodology has been deployed as per the recommendation of the manufacturer of structural components. A-Scan displays the response along the path of the sound beam for a given position of the probe. It also shows the signal's amplitude originating from the discontinuity as a function of time on the screen. The discontinuity depth (back wall echo) and time of flight are shown on the x-axis. The 'y' axis indicates the amplitude of reflected signals (echoes) and can be used to estimate the size of a discontinuity compared to a known reference reflector.

2.5 Judgment of quality standard

All the heavy structural jobs welded on the robot were subjected to ultrasonic testing. The ratio of the number of jobs recorded without any defect and the total number of jobs being tested is considered a measure of quality level and monitored as “ultrasonic testing straight pass %."

The trend of each day, each month, and the year has been monitored as a performance measurement tool for the quality of weld joints. Ultrasonic testing straight pass % is the ratio of defect-free components to the total number of components inspected.

If for a day, total '**N**' components were checked by ultrasonic testing, and '**n**' is the number of components in which all the joints have passed ultrasonic testing (i.e., no of the joints in these components have been detected with a defect in ultrasonic testing) than ultrasonic test straight pass % for the day will be calculated as expressed in Equation 1.

$$\text{Ultrasonic testing straight pass \%} = (n/N) \times 100. \tag{1}$$

The same will apply for the month straight pass % considering cumulative numbers of tested and passed jobs.

2.6 Data capturing

Data capturing was the first step of this analytical study to assess and establish the co-relation of environmental parameter effect on weld quality straight pass %. An infrared thermometer and hygrometer were basic instruments for collecting environmental parameter readings and capturing data. An infrared thermometer, as shown in Figure 2a, also called a non-contact temperature gun, is a thermometer that infers temperature from a portion of the thermal radiation, sometimes called black-body radiation emitted by the object being measured (Ibrahin *et al.*, 2009).

As shown in Figure 2b, a hygrometer is an instrument used to measure the amount of water vapor in air, soil, or confined spaces. Hygrometer based on an electronic component that absorbs water vapor according to air humidity and changes electrical impedance (resistance or capacitance). The instrument is usually in the form of a "probe" attached directly, or by a cable, to an electronics unit to display the relative humidity reading and dew point temperature (Hilton *et al.*, 2008).

Using an infrared thermometer and hygrometer, atmospheric parameters viz dew point temperature, relative humidity, ambient air temperature, and job surface temperature were monitored and recorded. The average monitored data for four years, 2018, 2019, 2020, and 2021 till October, is as mentioned in Table 2b.

Data monitoring & capturing of relevant atmospheric parameters and its effect on weld quality trend has been studied for a longer period, i.e., 4 years in the stated study, to judge the actual correlation with the environmental or weather changes. It has been tried to establish a genuine co-relation, if any, by taking all season data for multiple seasonal cycles, so taken to complete season cycle or 4 years.

(a)

(b)

Figure 2. The monitoring instrument, a. Hygrometer: Used for monitoring humidity and dew point temperature, b. Infrared thermometer: Used for measurement of surface temperature

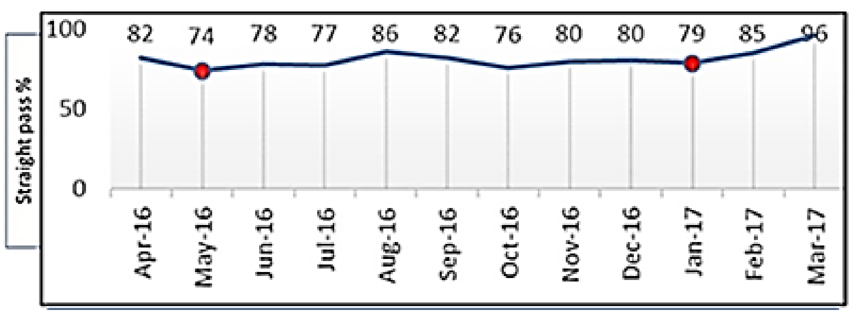
Table 2b. Average monthly data for Atmospheric Air temperature and Dew point temperature

Year	Month	Average Ambient Air Temperature	Average Dew point	Difference of ambient air and average dew point temperature
2018	January	19	11.3	7.7
	February	25	16.7	8.3
	March	28	20	8
	April	28	22.7	5.3
	May	30	24.8	5.2
	June	30	25.5	4.5
	July	29	26.4	2.6
	August	29	26.6	2.4
	September	29	26.2	2.8
	October	27	22.8	4.2
	November	25	19.8	5.2
	December	20	13.7	6.3
2019	January	20	13.7	6.3
	February	23	17	6
	March	27	21.3	5.7
	April	29	23.9	5.1
	May	31	26.9	4.1
	June	30	26.2	3.8
	July	30	26.6	3.4
	August	29	26.2	2.8
	September	28	25.2	2.8
	October	27	23.7	3.3
	November	25	20.5	4.5
	December	21	16	5

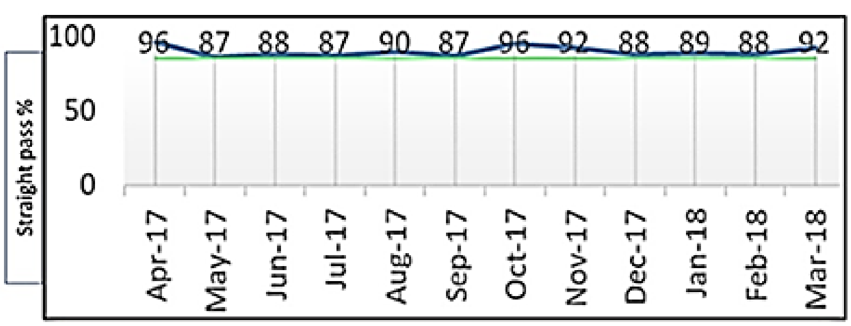
2020	January	20	14.8	5.2
	February	22	16	6
	March	26	20.3	5.7
	April	29	23.4	5.6
	May	30	25.3	4.7
	June	30	26.2	3.8
	July	30	26.2	3.8
	August	30	26.6	3.4
	September	30	26.4	3.6
	October	28	24.2	3.8
	November	25	18.2	6.8
	December	21	16.4	4.6
2021	January	21	15.1	5.9
	February	23	15.1	7.9
	March	29	21	8
	April	30	23.4	6.6
	May	29	24.5	4.5
	June	30	25.9	4.1
	July	30	26.2	3.8
	August	29	25.8	3.2
	September	28	25.4	2.6
	October	29	25.8	3.2

2.7 Recoding of Ultrasonic test straight pass data, measure for quality level

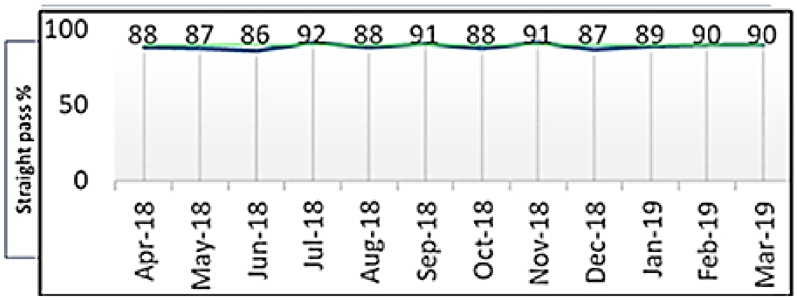
The average monthly ultrasonic welding straight pass for fiscal year (FY) 2016 -2017, 2017-2018, and 2018-2019 is shown in Figures 3a, 3b & 3c, respectively.



a. Average monthly ultrasonic welding straight for FY-2016 -2017



b. Average monthly ultrasonic welding straight for FY-2017 -2018



c. Average monthly ultrasonic welding straight for FY-2018 -2019

Figure 3. Average monthly ultrasonic welding straight; a) For FY-2016 -2017; b) For FY-2017-2018; c) For FY - 2018-2019

Sample data for daily recorded parameters viz. relative humidity, dew point, ambient air temperature & difference in ambient air temperature, and dew point temperature for the month of November 2018, at the beginning of 'A shift' start time (6:00 AM) is shown in Figure 4a, 4b, 4c & 4d respectively. Similarly, daily data monitoring was done for all the stated parameters for all the months over four years, viz. 2018, 2019, 2020, and 2021.

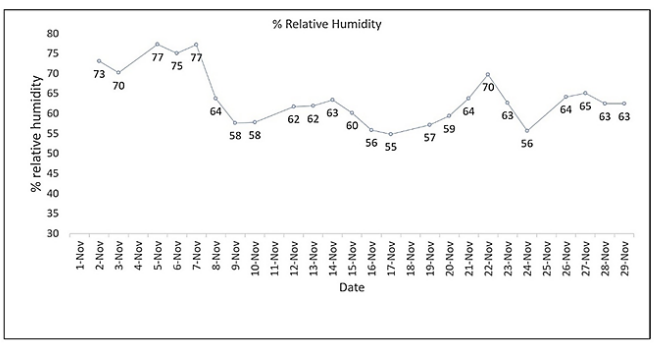


Figure 4a. % Relative humidity daily monitored data for November 2018

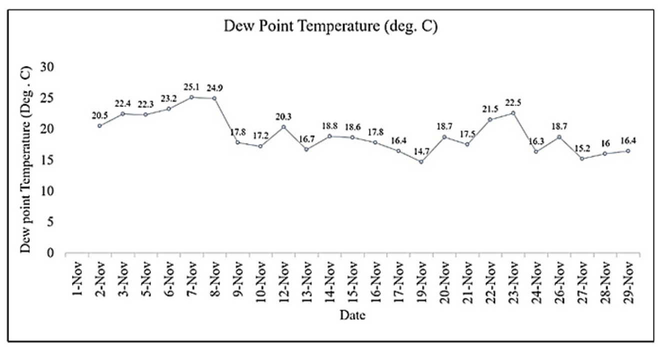


Figure 4b. Dew point temperature (deg. C) daily monitored data for November 2018

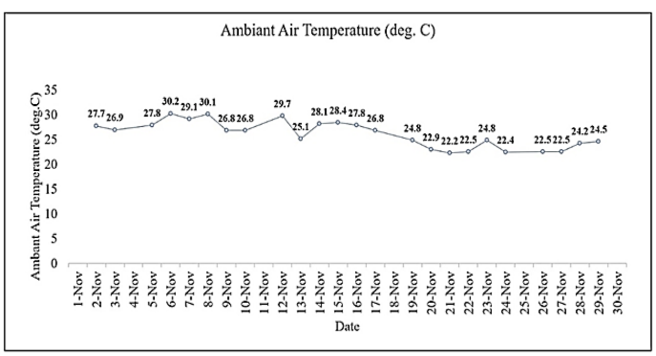


Figure 4c. Ambient air temperature (deg. C) daily monitored data for November 2018

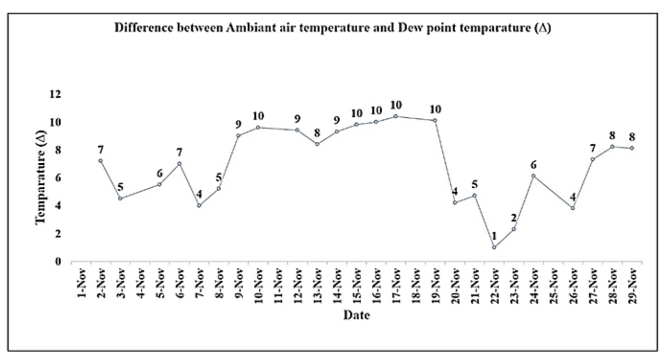


Figure 4d. The difference in ambient air temperature and dew point temperature daily monitored data for November 2018

2.8 Determination of co-relation

By monitoring atmospheric parameters and weld ultrasonic straight pass percentage on a daily basis, it has been assessed and observed points where weld ultrasonic straight pass was not within a satisfactory range of above 85%. Once the fall in ultrasonic testing straight pass trend was observed, it was tried first to analyze the type of defects observed in weld joints.

Considering November 2018 ultrasonic testing straight pass data, as stated in Figure 5, all the defects observed in non-straight pass jobs were recorded and analyzed.

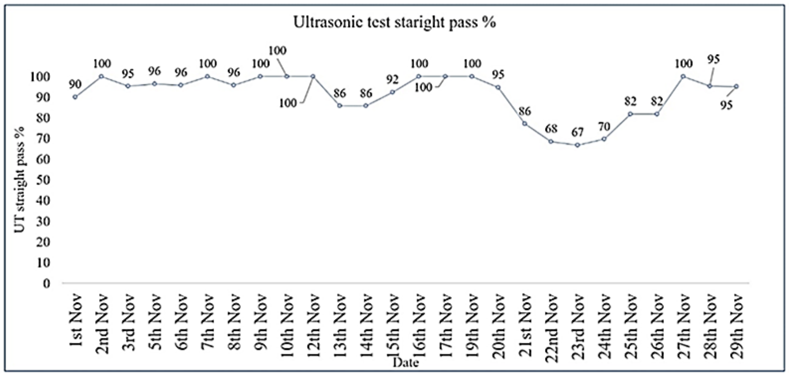
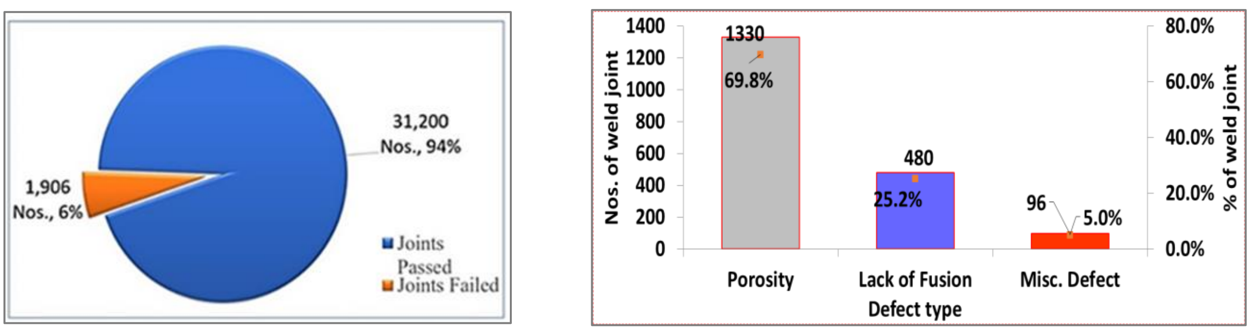


Figure 5. November 2018 daily ultrasonic testing data

Lack of fusion and porosity/pin holes were the main defects observed during the sample data assessment, as specified in Figure 6a. Out of total 33,106 numbers of joints tested with ultrasonic testing, 31200 (94%) joints had no defects, whereas 1906 (6%) joints were found to be defective. After assessing the type of defects in the above 6% defective joints, it has been observed that 1330 joints (69.8%) had porosity defects, 480 joints (25.2 %) had lack of fusion, and the rest had miscellaneous defects, as stated in Figure 6b. Similar analyses were done for data recorded each month.



a. Joint passed vs. failed

b. Defect categorization

Figure 6. Defect observation for ultrasonic testing done for November 2018; a) Joint passed vs. failed; b) Defect categorization

The above data shows that weld porosity was the major defect contributing to 69.8 % of total defective weld joints. Various contributing parameters of weld porosity were assessed to take counteractions for weld porosity, and some are specified in Table 3. It was observed that these contributing factors were within a specified limit, as various control measures were established in the manufacturing process.

Table 3. Some of contributing factors considered for porosity

• Rust on plate surface- cleaned before fabrication
• Oil or foreign material on plate surface-cleaned before fabrication
• Shielding Gas supply and quality – Observed satisfactory

By monitoring atmospheric parameters, it has been tried to assess other assignable porosity causes due to variations in atmospheric conditions. The following dates were observed to have the lowest weld ultrasonic straight pass trend in the month of November 2018 and co-related with atmospheric parameters as specified in Table 4.

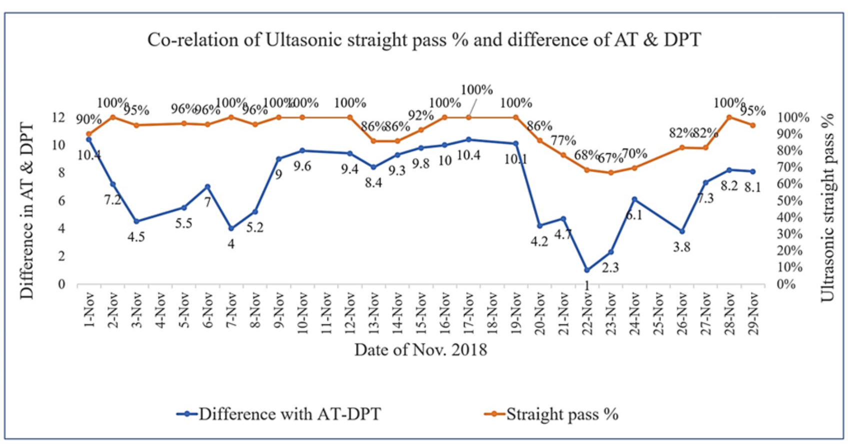
While assessing the effect of atmospheric parameters on weld quality and ultrasonic testing straight pass, a common trend of the ultrasonic straight pass was observed. Straight pass for the day was observed to be lower for dates when the local region observed rainfall, and the difference between atmospheric air temperature & dew point temperature was lower, especially less than 5. As compared to dates on which ultrasonic testing straight pass observed higher, the difference between atmospheric air temperature & dew point temperature was higher, especially above 5. The trend of ultrasonic test straight pass and the difference of ambient air temperature & dew point temperature for November 2018 is shown in Figure 7a. Two trend lines show that whenever there is a drop in the difference value of atmospheric air temperature and dew point temperature, a drop in ultrasonic testing was observed for that date.

Table 4. Dates observed with the lowest weld ultrasonic straight pass trend in the month of November 2018.

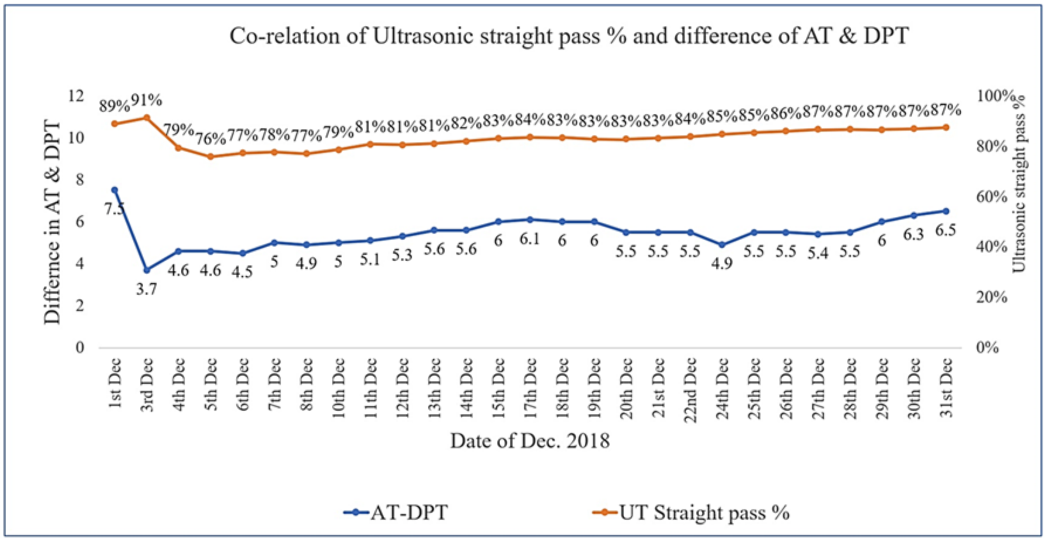
Date	Ambient Air Temperature (AT) in deg. C	Relative Humidity	Dew Point. Temperature (DPT) in deg. C	Job Temperature in deg. C (JT)	Difference (JT-DPT)	Difference with AT-DPT	Straight pass %
13-Nov	25.1	61.9	16.7	22.8	6.1	8.4	85.7
14-Nov	28.1	63.4	18.8	25.2	6.4	9.3	85.7
20-Nov	22.9	59.4	18.7	24.8	6.1	4.2	86.0
21-Nov	22.2	63.8	17.5	24.1	6.6	4.7	77.3
22-Nov	22.5	69.8	21.5	27.9	6.4	1	68.4
23-Nov	24.8	62.7	22.5	29.1	6.6	2.3	66.7
24-Nov	22.4	55.7	16.3	21.9	5.6	6.1	69.6
26-Nov	22.5	64.2	18.7	22.8	4.1	3.8	81.8

Note: AT; atmospheric air temperature, DPT; dew point temperature

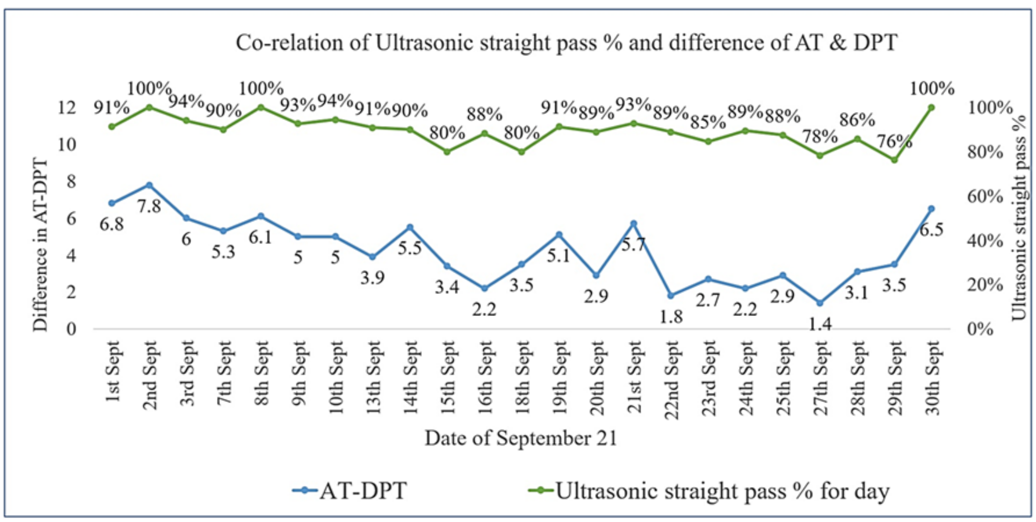
Further data were analyzed for various months and observed a similar trend of difference in ambient air temperature & dew point temperature with ultrasonic testing straight pass %. Considering the trend of Figure 7b for the month of December 2018, although the trend line shows less variation for the majority of dates when the difference in ambient air temperature & dew point temperature is less than 5, there was a drop in ultrasonic testing straight pass %, e.g., 4th to 8th December 2018. The trend graph for September 2021, shown in Figure 7c, shows a very clear correlation between two trend lines. On 2nd September temperature difference increased from 6.8 to 7.8, and the straight pass ratio also increased from 91 % to 100 %; further, when there was a drop in temperature difference on the 3rd and 7th of September, it also resulted in a drop in straight pass %. Similar trends were observed for the full month of data.



a. Co-relation for November 2018



b. Co-relation for December 2018



c. Co-relation for September 2021

Figure 7. Co-relation of Ultrasonic straight pass % and difference of Atmospheric & Dew point temperature; a) For November 2018; b) For December 2018; c) September 2021

2.9 Observation while pre-heating of jobs to avoid moisture effect on the welding

To eliminate the effect of a lower difference in ambient air temperature & dew point temperature, i.e., higher humidity in the rainy season, it has been tried to pre-heat structural components before robotic welding [17]. This weld pre-heat process is a well-established and general practice in all over fabrication industries.

As soon as pre-heating was started on components when the difference in ambient air temperature & dew point temperature was less than 5 to avoid its effect on weld quality, significant water vapor condensation over the component plate surfaces was observed in Figure 8. This observation may be attributed to higher dew point temperature near atmospheric ambient temperature.

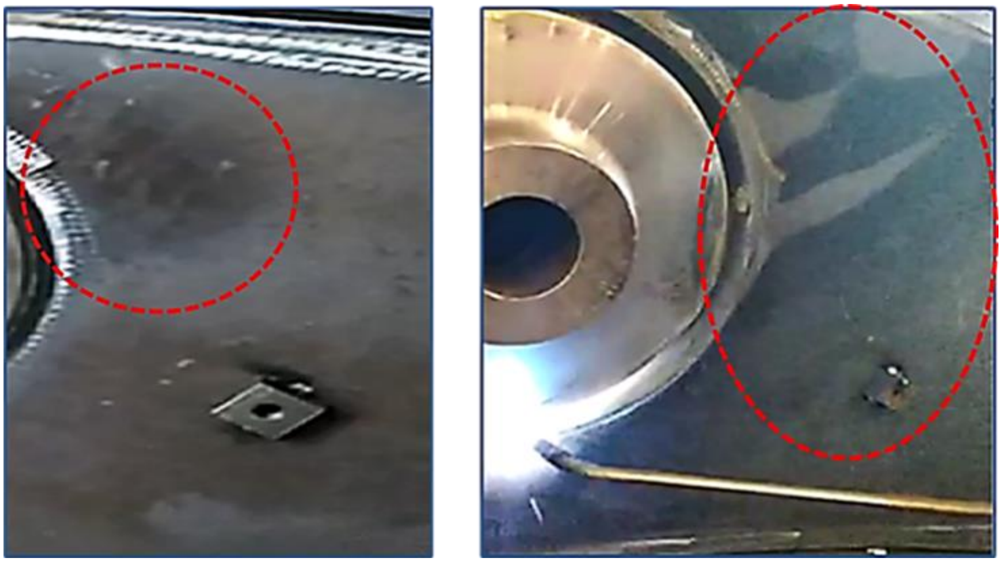


Figure 8. Traces of water condensation over the job surface while pre-heating

2.10 Validation of data and established co-relation

Karl Pearson's coefficient of correlation is defined as a linear correlation coefficient, which falls in the value range of -1 to +1. A value of -1 signifies a strong negative correlation, while +1 indicates a strong positive correlation. It determines the strength of the linear relationship between two variables. Karl Pearson's Coefficient of Correlation was used to analyze the effect of rainfall and temperature variation on tea production (Nyaio *et al.*, 2022). Pearson's method, popularly known as Pearson's Coefficient of Correlation, is the most extensively used quantitative method in practice (Manisha *et al.*, 2019). The coefficient of correlation is denoted by "r ."To give strength to the established linear co-relation limiting value of ***"difference in ambient air temperature and dew point temperature as 5"***, various sample month data were validated for Karl Pearson coefficient value (r).

Interpretation of **Pearson Coefficient** –

- **r>0** Positive Correlation
- **r>0.6** Strong Positive Correlation
- **r<0** Negative Correlation
- **r<-0.6** Strong negative correlation

Considering the significance of the Person coefficient in the judgment of linear data, the Microsoft Excel program was made, and data of sample months were plotted.

Detailed calculation of September 21 data has been plotted as shown in Table 5 and obtained calculated value as 0.720. Similarly, Karl Pearson's co-efficient of other sample months viz. November 18, December 18, and August 19 were calculated and obtained as 0.6094, 0.3098 & 0.4327, respectively, as an estimated value using stated Equation No. 2. All the values were observed to be positive.

$$r = \frac{\sum xy - N\bar{x}\bar{y}}{\sqrt{(\sum x^2 - N\bar{x}^2)(\sum y^2 - N\bar{y}^2)}} \,. \tag{2}$$

Table 5. Detailed calculation of September 21 data

AT-DPT	Fraction of straight pass	xy	x^2	y^2
6.8	0.91	6	46	1
7.8	1.00	8	61	1
6	0.94	6	36	1
5.3	0.90	5	28	1
6.1	1.00	6	37	1
5	0.93	5	25	1
5	0.94	5	25	1
3.9	0.91	4	15	1
5.5	0.90	5	30	1
3.4	0.80	3	12	1
2.2	0.88	2	5	1
3.5	0.80	3	12	1
5.1	0.91	5	26	1
2.9	0.89	3	8	1
5.7	0.93	5	32	1
1.8	0.89	2	3	1
2.7	0.85	2	7	1
2.2	0.89	2	5	1
2.9	0.88	3	8	1
1.4	0.78	1	2	1
3.1	0.86	3	10	1
3.5	0.76	3	12	1
6.5	1.00	7	42	1
where,				
N	23	**N** = number of pairs of scores $\sum$ **xy =** sum of the product of paired scores $\sum$ x^2 = sum of squared x scores $\sum y^2$ = sum of squared y scores $\bar{x}$ = average of x scores $\bar{y}$ = average of y scores		
$\bar{x}$	4.273913043			
$\bar{y}$	0.893607559			
$\Sigma(xy)$	90			
$N \bar{x} \bar{y}$	87.84162305			
Σx^2	489			
$N\bar{x}^2$	420.1256522			
Σy^2	18			
$N\bar{y}^2$	18.3662928			
AT-DPT: ambient air temperature – dew point temperature				

With positive values of Karl Pearson co-efficient for various sample month data, it has been validated that data collected, analyzed, and linear co-relation established for "difference in ambient air temperature & dew point temperature with limiting value of 5 for ultrasonic testing straight pass %'' is true. Hence, when the difference between ambient air temperature and dew point temperature was between 6 to 10 ^{0}C, the ultrasonic straight pass will be above 90 % with lesser defects. The straight pass was maximum when the difference between ambient air temperature and dew point temperature was 10^{0}C. When the difference between ambient air temperature and dew point temperature was between 1 to 4 ^{0}C, the straight pass % value was lower.

3. RESULT AND DISCUSSION

Atmospheric dew point temperature, relative humidity, and ambient air temperature have been found to correlate directly with weather conditions and rainfall. So, it has been observed that the relative humidity and dew point temperature rise whenever there is rain. This rise in dew point temperature reduces the difference between ambient air and dew point temperatures. With the drop in the difference of ambient air temperature and dew point temperature, a drop in ultrasonic testing straight pass % was observed.

The objective was to find out up to which limit drop in this temperature difference will not affect the average straight pass %. From the observation data for various sample months in 4 years from 2017 to 2021, it was established that difference in ambient air temperature & dew point temperature has a limiting value of 5. If less than 5, it significantly impacted weld quality and straight pass percentage for that date. This effect of a lower difference in ambient air temperature & dew point temperature on weld quality was due to higher moisture content in the atmosphere and condensation on cooler job surfaces which resulted in porosity defects majorly. Further, to study the effect of rainfall, sample data for July 2019 to August 2019 were taken, as stated in Figure No. 9. Difference in ambient air temperature & dew point temperature is less than 5 in the majority of dates between 18th July to 27th August 2019. For all these dates with the lower difference in ambient air temperature & dew point temperature, it has been observed that there was a drop in ultrasonic testing straight pass %, i.e., less than 80 %. But for dates when the difference in ambient air temperature & dew point temperature was more than 5, i.e., on 31st July difference in ambient air temperature & dew point temperature was 6.7. The straight pass % increased to 100 % from 85 % of the previous day's value when the difference in ambient air temperature & dew point temperature was 3.4. Similar observations were made on 20th August & 30th August 2019, with an increase in the difference in ambient air temperature & dew point temperature, and ultrasonic testing straight pass % increased.

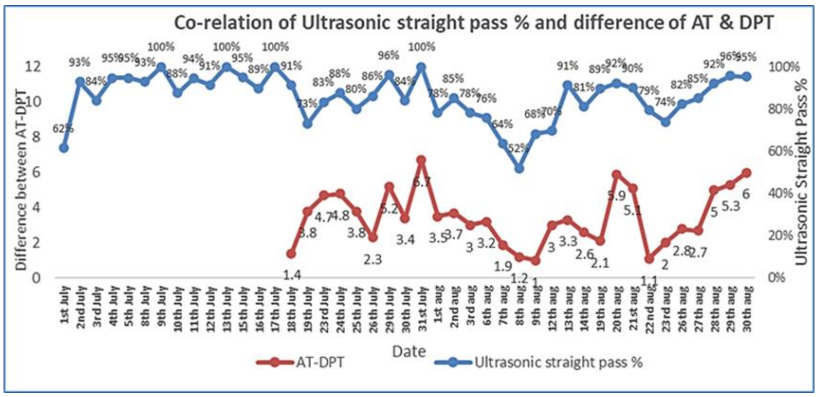


Figure 9. Co-relation of Ultrasonic straight pass % and difference of AT & DPT

While comparing of trend in Figure 9 with meteorological data for rainfall in the local region, as stated in Figure 10, a direct correlation between the rainfalls and the difference in ambient air temperature & dew point temperature can be seen. Between 19th July and 28th August 2019, the local region observed rainfall, and ultrasonic testing straight pass had a major drop between these rainfall dates. Also, between these rainy dates difference in ambient air temperature & dew point temperature was less than 5 on most days.

Hence, it was established that during rainy days, the difference in ambient air temperature & dew point temperature limiting value of 5 needs to be monitored, as below this limiting value probability of a drop in ultrasonic testing straight pass percentage due to weld porosities would be higher. If this limiting value of 5 can be considered a trigger point, necessary measures could be taken to avoid weld defects.

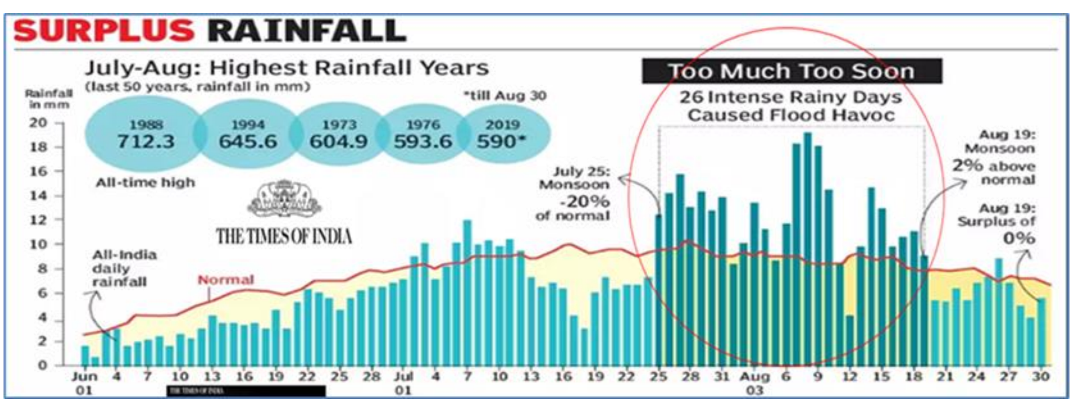


Figure 10. A co-relation with meteorological data

(Ref: https://timesofindia.indiatimes.com/india/india-sees-wettest-july-aug-in-25-years/articleshow/70917831.cms)

4. CONCLUSION

a) Considering data study for various sample months, it has been observed that whenever there was a drop in "difference in ambient air temperature & dew point temperature, especially less than 5", a drop in ultrasonic testing straight pass % was observed than the average value. This drop in ultrasonic straight pass % with the lower difference in ambient air temperature & dew point temperature was contributed due to porosity in weld joints.

b) These porosities resulted from invisible moisture content on the metal surface to be welded, as observed during the pre-heating of components.

Hence, it was established that "the co-relation of difference in ambient air temperature & dew point temperature has a limiting value of 5"; if less than 5, there is a higher probability of porosity defect in weld joints and less ultrasonic testing straight pass %. The stated co-relation was validated with positive values of the Karl Pearson co-efficient for various sample months. Having this linear correlation of difference in ambient air temperature & dew point temperature less than 5, it can be stated that weld defect would be prominent; considering this point as a trigger point, corrective action could be taken to avoid weld defect by the manufacturer to avoid loss of rework.

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