ON MEASURING THE WELDING TEMPERATURE OF CONNECTOR

Jyh-jeng Deng
Industrial Engineering Department, Da-Yeh University
Chang-Hwa, Taiwan

Abstract

The measurement of welding temperature of connector is usually performed with an infra red temperature gauge. However, the factors, which influence the temperature measurement, are rarely known. This research used the welding temperature measurement of the connector as an example, applying the experimental design, in two-phase experiments, to search the affecting factors. In phase-I experiment, we used a resolution III, seven-factor fractional factorial design with two levels for each factor. The result showed that none of the factor was significant in affecting the welding temperature when the type I error α was 0.05. Next, we did the phase-II factorial experiment with three factors and each factor had three levels. The experiment showed the experimental time was significant in affecting the temperature measurement when the type I error α was 0.05. Further Duncan's multiple range tests on the second experimental data showed that the later the experimental time, the weaker the light intensity could have on the temperature measurement and the average of the highest temperatures was lower. Moreover, the later the experimental time, the smaller was the variance of the temperature measurement and the difference between the averages of the highest and the lowest temperatures was also lower.

1. Introduction

KS connector Inc. was a mid-size enterprise that manufacturing connector, a part joining one electronic component to other. Due to the severe pressure from international competition, the company was endeavoring to obtain the approval of the Japanese QC standard, JIS 2805, even though they had acquired the approval of ISO 9002 on the connector quality. The requirement of JIS on the connector quality demanded the standardization of the welding procedures on the connector. Moreover, the JIS 2805 required KS to show the welding temperature in the operation manual. Currently the products manufactured from the KS had no problem in passing the quality tests such as hardness and tensile strength tests. However, they had problem in measuring the welding temperature, causing the failure in acquiring the JIS approval.

There were two causes in making the failure of the JIS approval. First, skilled welders performed the welding according to their personal experiences. Each master had his own way to adjust the welding process. The standard of the welding procedure was not clear. Second, it was not easy to measure the welding temperature and the variance of the temperature was too high. According to the records from the KS company, even in welding the same batch of the connectors, the difference between the highest and the lowest of the welding temperatures could be high up to 100 to 150 ℃. This indicated the measuring procedure was not standardized and there were some other factors that were not controlled during the welding.

Our purpose in this research is to focus the second problem, to discuss which factors significantly (statistically) influence the welding temperature. Also we proposed the standard welding procedures to the first problem. This research provides partial, though not all, solution for the KS in applying the JIS 2805 approval. Presently KS has adopted the suggestions proposed in this paper to set up the standard procedure of welding operations and measure the welding temperature at night or under the seclusion of light (previously all the measurements were taken at daytime, which were affected by the daylight). Moreover the KS has reapplied the JIS 2805 approval; however, the result still does not come out.

2. Phase-I experiment

In order to find out the factors that influence the welding temperature, we used a machining workshop in Da-Yeh University to perform the experiment. Our equipment included: hydrogen, H_2 and oxygen, O_2 tanks, welding gun and its wire set, copper and iron bars, portable infra red temperature gauge and a tripod.

In order to save the experimental resource, we used a two-level fractional factorial design with resolution III for 7 factors. There were 16 trials in the experiment. The factors included: A. material (copper and iron bars), B. thickness of the bar (0.5 and 1.0 cm), C. distance between welding flame and metal (10 and 20 cm), D. content of acetylene, C_2H_2, (0.2 and 0.8 rounds, 0.2 round represents that the knot controlling the volume of acetylene is turned on to 0.2 round), E. content of oxygen, O_2, (0.5 and 1.0 rounds, 0.5 round represents that the knot controlling the volume of oxygen is turned on to 0.5 round), F. welding time (5 and 10 seconds), G. measuring time (5 and 10 seconds). We repeated the experiment twice and the result is shown in Table 1.

Table 1. Fractional Factorial Trials

	A	B	C	D	E	F	G	Temp1	Temp2
1	1	-1	-1	-1	1	1	-1	297	304
2	1	1	-1	-1	-1	-1	1	278	308
3	1	1	1	-1	-1	1	-1	311	332
4	1	1	1	1	1	1	1	297	301
5	-1	1	1	1	-1	-1	1	298	301
6	1	-1	1	1	-1	-1	-1	296	300
7	-1	1	-1	1	-1	1	-1	318	292
8	1	-1	1	-1	1	-1	1	290	308
9	1	1	-1	1	1	-1	-1	298	321
10	-1	1	1	-1	1	-1	-1	283	307
11	-1	-1	1	1	1	1	-1	257	302
12	1	-1	-1	1	-1	1	1	313	311
13	-1	1	-1	-1	1	1	1	283	309
14	-1	-1	1	-1	-1	1	1	288	322
15	-1	-1	-1	1	1	-1	1	274	342
16	-1	-1	-1	-1	-1	-1	-1	251	339

The first row in Table 1 lists symbols for the experimental factors and the measured temperatures of the two experiments. Temp1 represents the measured temperature in the first experiment, while Temp2 the temperature in the second one. The meaning of the second row is that when we set the factor A at the high level (1, it means the material is iron bar), B at the low level (-1, it means the thickness of the iron bar is 0.5 cm), C at the low level (-1, it means the distance between the flame and metal is 10 cm), D at the low level (-1, it means the content of acetylene is 0.2 round), E at the high level (1, it means the content of oxygen is 1.0 round), F at the high level (1, it means the welding time is 10 seconds), G at the low level (-1, it means the measuring time is 5 seconds), the measured temperatures in the two experiments are 297 and 304 ℃ respectively.

Our experimental procedures were as follows.

1. Cut the copper and iron bars into slices with thickness of 0.5 and 1.0 cm.
2. Fixed the copper/iron bar to vise jaw, which was mounted on the bench edge.
3. Fastened the welding gun to the iron grid.

4. Lit up the welding gun and had the flame shoot at the center on the surface of the copper/iron bar.
5. Adjusted each factor to proper level.
6. Used the infra red temperature gauge to measure the surface temperature of the metal slice.

All the experimental setup is illustrated in Fig. 1.

Before we analyze the experimental data, we have to understand structure of the temperature gauge and how it measures the temperature. This will help us understand the meaning of the measured temperature.

2.1 Infra red temperature gauge

When the light quantum concentrated on the spot of the measured object, it emits energy. This energy can be detected by the infra red temperature gauge. Through the calculation of the electrical temperature inside the temperature gauge, the temperature gauge will display the temperature of the object in digits with Celsius (℃) as unit [1]. The side and 3D views of the infra red temperature gauge are shown in Figs 2 and 3. On measuring the welding temperature, we focus the measuring circle (left of Fig. 3), which is on the display window of the temperature gauge, on the front of the flame and keep the front away from the protection lens of the temperature gauge about 1 meter. During the procedure of measurement, the LED in the display window will continue to show the change of the temperature with digits (left of Fig. 3). In the end, a LCD (right of Fig. 3) on the surface of temperature gauge shows the highest measured temperature during the measurement process. Fig. 4 shows the measuring process and its result.

It is clear from Fig. 4 that the temperature changes with time. After finishing temperature measurement, the temperature gauge displays the highest temperature T_{max} on LCD. All the following analysis is based on T_{max} unless specify otherwise. T_{max} is related to the span of measuring time. Generally speaking the longer the measuring time and the bigger the variance of the measured temperature, the higher the probability of obtaining large T_{max}.

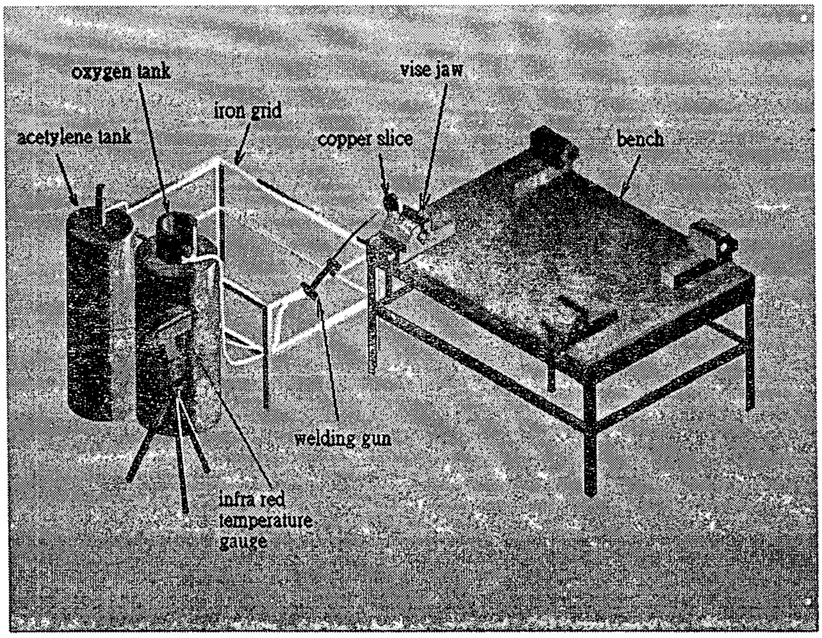

Fig. 1. Setup for the phase I experiment.

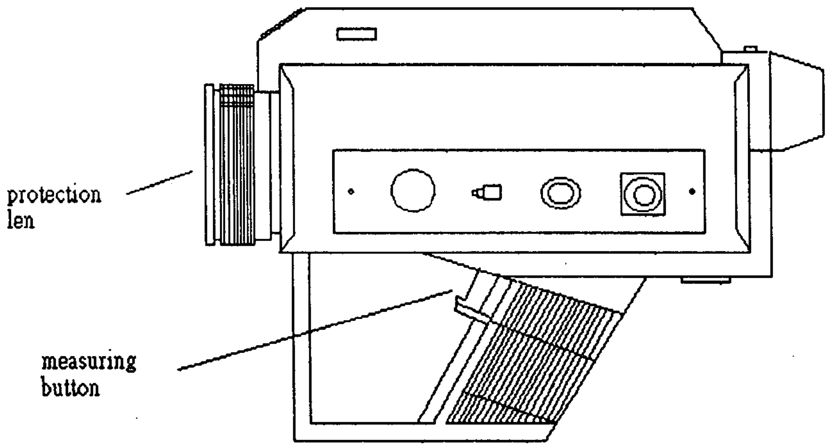

Fig. 2. Side view of infra red temperature gauge.

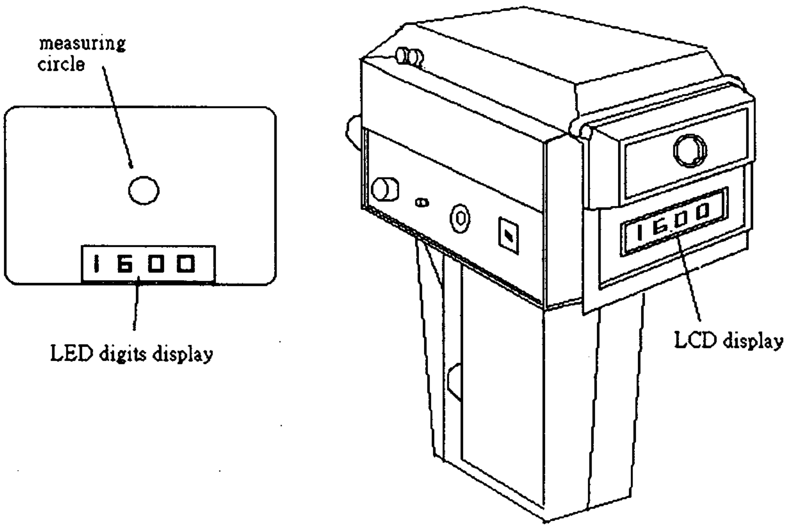

Fig. 3. 3D view of infra red temperature gauge.

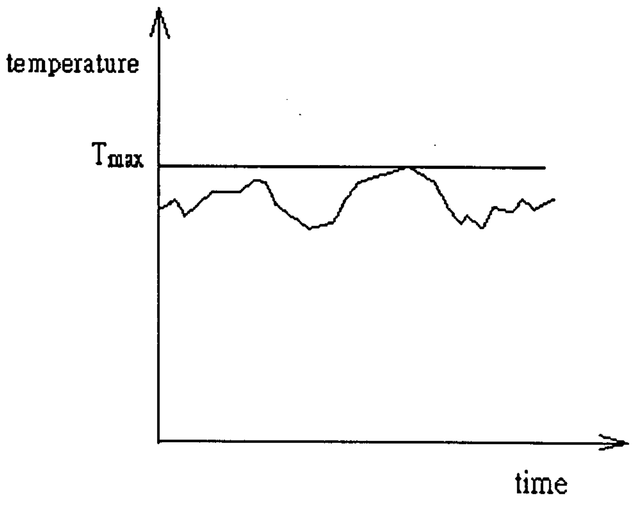

Fig. 4. Variation of measured temperature.

After doing ANOVA (Analysis of Variance), we found that all the factors did not have significant influence on the measured temperature given type I error α=0.05 (Tables 2 and 3). Table 2 is the ANOVA for Temp1. On the upper part of the rightmost column of Table 2, we see the Model's p value is 0.299. According to the Model's p value, we knew that the whole model was not significant. We broke down the Model into 7 factors and found that none of the factor was significant either. The results were shown on the lower part of the rightmost column of Table 2; the p values for factors A through G were 0.0922, 0.1735, 0.9078, 0.3262, 0.3011, 0.1894, 0.8849 respectively. Table 3 showed similar result. Both Model and seven factors were not significant either.

This result was surprising. From the principle of material science: under the same heating time and diameter of the welded metal bar, when the welding object is thicker, its surface temperature should be lower [3]. However, the experimental result showed the factor B, thickness, was not a significant factor. This revealed big variance of the measured temperature, hence covering the effect of factor B. In order to reduce the variance, we decided to mimic the welding shop in KS and redo the experiment.

Table 2. ANOVA of Temp1

The SAS System					
Analysis of Variance Procedure					
Dependent variable: TEMP1					
Source	DF	SS	MS	F Value	Pr > F
Model	7	2883.75	411.964286	1.47	0.299
Error	8	2240.25	280.03125		
Total	15	5124			
Source	DF	Anova SS	MS	F Value	Pr > F
A	1	1024	1024	3.66	0.0922
B	1	625	625	2.23	0.1735
C	1	4	4	0.01	0.9078
D	1	306.25	306.25	1.09	0.3262
E	1	342.25	342.25	1.22	0.3011
F	1	576	576	2.06	0.1894
G	1	6.25	6.25	0.02	0.8849

Table 3. ANOVA of Temp2

The SAS System					
Analysis of Variance Procedure					
Dependent variable: TEMP2					
Source	DF	SS	MS	F Value	Pr > F
Model	7	833.4375	119.0625	0.4	0.8787
Error	8	2390.5	298.8125		
Total	15	3223.9375			
Source	DF	Anova SS	MS	F Value	Pr > F
A	1	52.5625	52.5625	0.18	0.686
B	1	203.0625	203.0625	0.68	0.4336
C	1	175.5625	175.5625	0.59	0.4654
D	1	217.5625	217.5625	0.73	0.4183
E	1	7.5625	7.5625	0.03	0.8775
F	1	175.5625	175.5625	0.59	0.4654
G	1	1.5625	1.5625	0.01	0.944

3. Phase II experiment

In order to imitate the welding operation in the workshop completely, we went to the shop to do a further investigation and learned some hand on experiences from the welders in the shop. In the meantime, the KS firm also borrowed some equipment to us to help us mimic the field site welding operations. After a few trial experiments, we found that the temperature gauge was sensitive to the light intensity of the experimental environment. In order to reduce the variance caused by the light intensity, we decided to do the experiment at night.

Our experimental equipment included: natural gas and oxygen tanks, two fasteners, one step motor (with spec of 220 V and 1200 rpm), one divider (this divider controls how far can an iron disc rotate per minute), a welding gun, a portable infra red temperature gauge, a tripod, an iron disc, a power switch set, a 10 feet long electric wire, screws and two pieces of pile wood.

After analyzing the field site welding operations, we eliminated factors A, material (because the current field site welding used only copper material), B, thickness of the bar (because the thickness had small variation), C, distance between flame and metal (because the distance was fixed), D and E, the contents of acetylene and oxygen (because they used natural gas and oxygen as fuel to do the welding and the mixed ratio of them was fixed). Thus the only factors that we needed to control were welding time and measuring time. Welding time was controlled by the speed of the rotating disc. The faster the speed, the shorter the welding time is. Their relationship is explained as follows.

The connector is fixed equal-spaced on the circumference of the disc. By the transportation of the step motor, the disc rotates one segment every once a small time interval. During the interruption of the rotation, the welding gun welds the connector in front of it where the connector is fixed to the disc. Thus, when the disc rotates faster, the interrupting time interval becomes shorter and the welding time is shorter accordingly.

Concerning the effect of the light intensity on the measurement of the welding temperature, we added another experimental factor, experimental time. Thus, we had three experimental factors, A. disc speed, and B. span of the measuring time, and C. experimental time. Each factor had three levels as follows.

Factor A, rotation speed, had three levels. They were 60, 70 and 80 points per minute. There are 8 points equally spaced on the circumference of the disc. To rotate 80 points per minute means that the disc rotates 80 intervals, the distance between two adjacent points on the disc, each minute. There are 8 points on the disc; thus there are 8 intervals on the circumference. To have disc rotate 80 points per minute means that the disc rotates 10 rounds per minute. Factor B, span of the measuring time, had three levels such as 30 seconds, 1 minute and 2 minutes. Factor C, experimental time, included three different timings (levels) in two different dates. They were 10 PM on October 7, 1997, and 8 and 9 PM on October 9, 1997.

Our experimental procedures were as follows:

1. Set up the experiment as shown in Fig. 5. In Fig. 5 there were 8 points on the circumference of the disc and each point had a connector. For clarity, we only drew one connector as a representation. Fig. 5 showed the welding gun was doing the welding on the connector. The welding gun was fixed on the iron grid, but we did not draw the grid for the sake of clarity.
2. Laid out the 8 dividing points on the disc.
3. Fixed connectors to the dividing points.
4. Made the gearbox to rotate 60 points per minute.
5. Fastened the welding gun to iron grid.
6. Lit up the gas and adjusted the contents of natural gas and oxygen.

7. Measured the temperature of the contacting point between connector and the flame.
8. Changed the rotation speed of the gearbox to 70 and 80 points/minute, and repeated steps 6 and 7.

We also proposed a welding procedure for the KS in order to satisfy the requirements of JIS quality approval. Since this part is not critical in the paper here, thus we will not list the detailed operations. Interesting reader can write to the author for further information. The welding procedures, which we proposed, has been adopted by KS and put in the welding operation manual for reapplying the JIS 2805 certificate. We now turn our focus to the development of statistical modeling and data analysis of the phase II experiment.

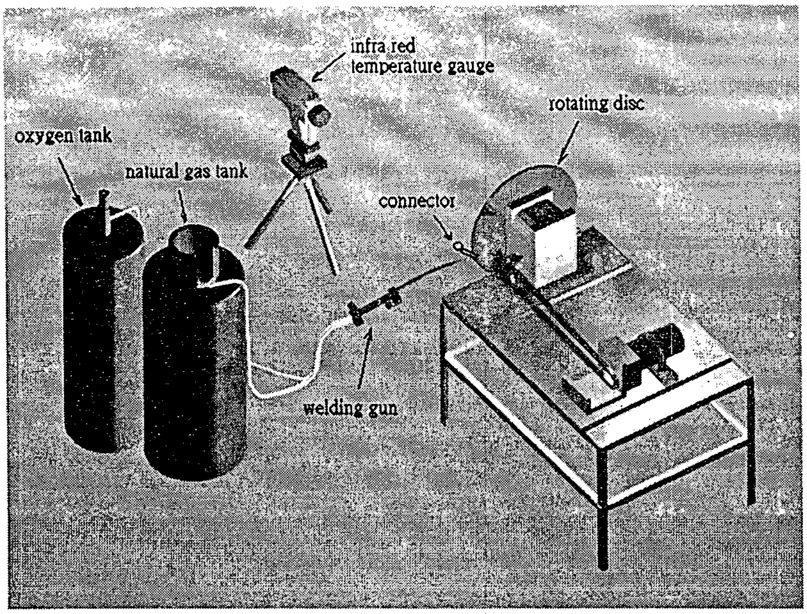

Fig. 5. Setup for the phase II experiment.

In order to find the affecting factors, we did a 3-factor study with three levels for each factor. This gave 9 sets of data and each datum contained two records: the highest and the lowest temperatures. The highest temperature came from the LCD of the temperature gauge. The lowest temperature came from the memorization of the lowest of all the digits displayed on the LED of the temperature gauge. We collected these data in order to know the difference between these two data. We described the statistical model for fitting the data and their results as follows.

3-1. Statistical Model and Data Analysis

We supposed that there was no interaction effect among the three factors, A, rotating speed, B, span of the measuring time and C, experimental time. This assumption was made according to their physical characteristics. It was obvious that there was no interaction among them. Thus, our model was: [2,4,6]

$$Y_{ijk} = \mu + A_i + B_j + C_k + E_{ijk} \quad (1)$$

Where

Y_{ijk} measured temperature when factor A in level i, B in level j, and C in level k

μ mean of the temperature

A_i effect on the temperature from the rotation speed (A) in level i.

B_j effect on the temperature from the span of measuring time (B) in level j

C_k effect on the temperature from the experimental time (C) in level k

E_{ijk} error

The error term, E_{ijk}, included other random errors. The rotation speeds were 60, 70 and 80 points per minute. The spans of the measuring time were 0.5, 1 and 2 minutes. The three experimental times were 10 PM on October 7, and 8 and 9 PM on October 9. In each trial of the experiment, the datum contained two records, the highest and the lowest temperatures. They are listed as follows.

Table 4. Experimental Data

10 PM on October 7			
Rotation Speed	0.5 minutes	1 minutes	2 minutes
60	538/513	538/511	538/507
70	531/513	543/524	545/519
80	538/516	542/520	543/515
8 PM on October 9			
60	543/499	534/472	546/504
70	543/504	541/490	546/494
80	545/508	542/486	545/484
9 PM on October 9			
60	540/501	545/504	544/499
70	545/504	546/504	545/487
80	546/500	544/490	545/501

We explain the first record (on the up-left corner, the values are 538/513) of Table 4 as follows.

538 means that on 10 PM of October 7, we used a disc with the rotation speed of 60 points/minute to do the welding and measured the temperature for a span of 0.5 minutes, then we obtained the highest temperature of 538 ℃ which was shown on the LCD of the gauge and the lowest temperature of 513 ℃ by memorization.

We used SAS (Statistical Analysis System) [5] to do the ANOVA on the highest and the lowest temperatures respectively. The results are shown in Tables 5 and 6. In Table 5, we saw the Model had degrees of freedom (df) of 6. This was due to the fact that we had three factors, each factor had three levels and there was no interaction among those factors. Since we had 27 pieces of data, thus the corrected total had df of 26 (i.e., 27 - 1). This gave a result of 20 (i.e., 26 - 6) df for the error term. These were seen on the second column of the upper part of Table 5. On the rightmost column of the upper part of Table 5, we saw the p-value for this model was 0.0197. Thus when type I error α=0.05, our statistical model, the combination of the effects of the three factors, was statistically significant. From the lower part of Table 5, we further understood that which factor caused the significance happened. In the lower part of the Table 5, we broke down the Model into three parts, Speed (Factor A, rotation speed), Time (factor B, span of measuring time) and Day Time (Factor C, experimental time). These were seen on the leftmost column of the lower part of Table 5. Due to the fact that each factor had three levels, the second column showed each factor had df of 2. The p-values of each factor were 0.1883, 0.1106 and 0.0112 respectively. The meaning of the p-value of factor A as 0.1883 was if the effect of factor A was null, then the probability for us to obtain our experimental data was 0.1883. Since α=0.05, we could not reject the null hypothesis of zero effect of factor A. Thus we declared that the effect of factor A was null. In the same way, the meaning of the p-value of factor C as 0.0112 was if the effect of factor C was null, then the probability for us to obtain our experimental data was 0.0112. Since α=0.05, we rejected the null hypothesis of zero effect of factor C and accepted the alternative hypothesis. I.e., the effect of factor C was greater than zero. In sum, we knew that the main reason that caused the Model to be significant was factor C, the experimental time. The other two factors were not significant on affecting the measured temperature.

Table 6 is an ANOVA for the lowest temperature. Its conclusion was similar to Table 5. The only difference was that it had smaller p-values. The p-values of the Model and factor C were 0.0007 and 0.0001 respectively. This showed that the effect of factor C on the measured temperature was more significant in the lowest temperature than in the highest temperature.

Table 5. ANOVA for the Highest Temperature

Analysis of Variance Procedure					
Variable : TEMP1 (the highest temperature)					
Source	DF	Sum of Squares	Mean Squares	F value	Pr > F
Model	6	195.1111	32.51851	3.32	0.0197
Error	20	196.074	9.8073		
Corrected Total	26	391.1851			
Source	DF	Anova SS	Mean Squares	F value	Pr > F
Speed	2	35.6296	17.8184	1.82	0.1883
Time	2	48.2962	24.1481	2.46	0.1106
Day Time	2	111.1851	55.5925	5.67	0.0112

Table 6. ANOVA for the Lowest Temperature

Analysis of Variance Procedure					
Variable : TEMP2 (the lowest temperature)					
Source	DF	Sum of Squares	Mean Squares	F value	Pr > F
Model	6	2594.4444	432.4074	6.43	0.0007
Error	20	1344.2222	67.2111		
Corrected Total	26	3938.6666			
Source	DF	Anova SS	Mean Squares	F value	Pr > F
Speed	2	48.2222	24.1111	0.36	0.703
Time	2	208.6666	104.3333	1.55	0.2362
Day Time	2	2337.5555	1168.7777	17.39	0.0001

Next, we wanted to know which level of factor C was significant different from others in terms of affecting the measured temperature. We did a Duncan's multiple range tests on the highest and the lowest temperatures respectively. The results are shown in Tables 7 and 8.

Table 7. Duncan's Multiple Range Test On the Highest Temperature

Analysis of Variance Procedure

Duncan's Multiple Range Test for variable: TEMP1

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 20 MSE= 9.803704

Number of Means	2	3
Critical Range	3.079	3.232

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	DAY
A	544.444	9	3
A			
A	542.778	9	2
B	539.556	9	1

Table 8. Duncan's Multiple Range Test On the Lowest Temperature

Analysis of Variance Procedure

Duncan's Multiple Range Test for variable: TEMP2

Alpha= 0.05 df= 20 MSE= 67.21111

Number of Means	2	3
Critical Range	8.062	8.462

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	DAY
A	515.333	9	1
B	498.889	9	3
B			
B	493.444	9	2

From Table 7, we knew that when α=0.05, the effects of experimental time on the highest temperature were clearly divided into two sets. The first set was composed of label A under the column of "Duncan Grouping" in the lower part of Table 7. It included effects of Day 3 (9 PM on October 9) and Day 2 (8 PM on October 9). The averages of the highest temperatures were 544.444 and 542.778℃ respectively. The second set was composed of label B under the same column of the first set. It included the effect of Day 1 (10 PM on October 7). The average of its highest temperature was 539.556℃, which was lower than the counterpart of the first set.

Table 8 shows similar result. The effects of experimental time on the lowest temperature were clearly divided into two sets. The first set was composed of label A under the column of "Duncan Grouping" in the lower part of Table 8. It included effect of Day 1 (10 PM on October 7). The average of the lowest temperatures was 515.333℃. The second set was composed of label B under the same column of the first set. It included the effects of Day 3 (9 PM on October 9) and Day 2 (8 PM on October 9). The averages of its lowest temperature were 498.889 and 493.444℃ respectively, which was lower than the counterpart of the first set.

Summarizing the results of Tables 7 and 8, we concluded that the effects of experimental time on both the highest and the lowest temperatures were divided into two groups. The first set was of Day 3 and Day 2. They were done on October 9. The other set was composed of Day 1, which was done on October 7. On the surface, we know that different date affects the measured temperature. However, further investigation shows that in the experiment on October 9, there were two sets of data done at 9 and 8 PM, while on the October 7, the data was from 10 PM, which was later than the counterparts of the former set. Thus, the difference between the measured temperatures of these two days might come from the timing of experiment. Of course, further experiments are needed to prove this point. We explained one step further of how the timing of the experiment affected the measured temperatures as follows. Due to the effect of the light intensity, the timing of the first set experiment was earlier (the light was stronger in intensity), thus the averages of the highest temperature (544.444 and 542.778℃ respectively) were higher than the counterpart of the second set (539.556℃). Moreover, the later the timing, the variation of intensity was smaller, so the difference between the averages of the highest and the lowest temperature (539.556 - 515.333 = 24.223℃) of the second set was smaller that the counterparts of the first set (544.444-498.889=45.555℃ and 542.778 - 493.444 = 49.334℃).

4. Conclusion

KS connector's company wanted to improve the international competition; thus they decided to apply the JIS 2805 quality approval. On the process of obtaining approval, they needed to solve two problems. First, they needed to decide the welding procedure and standardize it; second, to measure the welding temperature and search the factors that influences the welding temperature. Through two experiments, we proposed partial, but not all, solutions for the problems. First, we proposed a welding procedure such that every new hand can operate welding according to instruction manual. This operation procedure has been adopted by KS and put in the welding operation manual for reapplying the JIS 2805 certificate. Moreover, we did a detailed investigation of the characteristics of the infra red temperature gauge and found the light intensity of the experimental environment significantly affected the measured temperature. We suggest the KS to measure the welding temperature under the seclusion of light. KS also took this suggestion.

On the phase II experiment, we found the light intensity of the experimental environment was significantly affecting the measured temperature given type I error $\alpha = 0.05$. The p-value of its effect on the highest temperature was 0.0112 and on the lowest temperature, 0.0001. The meaning of p-value as 0.0112 was if the effect on the highest temperature was zero (null hypotheses), then the probability of obtaining the experimental data was 0.0112. Since we used $\alpha = 0.05$ in the hypothesis testing, we refused the claim of null hypothesis and declared that the experiment time had effect on the measured highest temperature.

We speculate that the later the timing of the experiment, the lower was the influence of the light intensity and the average of the highest temperature was also lower. However, this guessing needed to be validated by further experiments. In the experiment of 10 PM, the average of the highest temperature was 539.556℃, while the counterparts of 9 and 8 PM were 544.444 and 542.778℃ respectively. The later the timing of experiment, the smaller was the variance of the effect of light intensity. The difference between the averages of the highest and the lowest temperatures was also smaller. In the experiment of 10 PM, the difference was 24.223℃, while for the 9 and PM, the differences were 45.555 and 49.334℃.

5. Acknowledgements

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