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Controller Performance of Air Blowing Heater Applicable on Forming Process of UHMW Sheet Material

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***Abstract* - This paper presents the performance of an air-blowing heater controller used with UHMW sheet material. Temperature control is implemented within the range of 80°C to 110°C to achieve the re-crystallization temperature of the UHMW sheet material. A PID controller was applied, and its performance was analyzed by varying the temperature set point (SET VALUE), the fan's flow capacity, and the use of dual heaters to heat both surfaces of the UHMW sheet simultaneously. This paper also examines the effects of auto-tuning and self-tuning PID methods on control performance. The test results indicate that balancing the fan's flow capacity and the heat generation of the heater unit is the dominant factor in PID controller performance. In addition, with the use of double heaters, the material's energy accumulation becomes the main factor, causing a slower PID controller response in reaching the target temperature. Implementing self-tuning PID constants yielded better controller performance compared to the auto-tuning method.**

Keywords: PID Temperature Controller, sheet plastic forming, UHMW.

I. INTRODUCTION

The use of materials from the plastic family is growing rapidly, not only in terms of aesthetics and basic properties but also in terms of meeting operational requirements. One example is ultra-high molecular weight polyethylene (UHMWPE), a thermoplastic semi crystalline polymer with exceptional mechanical properties, a low friction coefficient, excellent wear resistance, and high resistance to corrosive chemicals [1].

Unlike most thermoplastics, UHMWPE does not become a liquid when heated above its "melting point." Due to its high melt strength, it can be handled and shaped above its crystalline melting temperature of 265°F (129°C). Although UHMWPE can also be shaped below this temperature, doing so introduces residual stress into the part. The optimal forming temperature for UHMW P1000 is approximately 280 to 300°F (138 to 149°C). At these temperatures, the plastic becomes translucent. Methods for heating UHMWPE include air-circulating ovens, conventional ovens, heat lamps, radiant heating panels, and oil baths.

The thermal-forming process of UHMWPE sheets typically involves a warm forming process to reach the desired forming temperature. The UHMW sheet is heated to its re-crystallization temperature, after which it is shaped using dies. During the pressing phase, the UHMWPE temperature must be rapidly reduced to room temperature to permanently retain the desired shape.

The effect of temperature on spring back in warm sheet metal forming has been investigated for aluminum alloys 1050 and 5052 [2]. They conducted bending tests in a furnace at temperatures up to 350ºC and concluded that temperature significantly influences the amount of spring-back. In addition to affecting spring-back, increasing the temperature enhances form ability. The determination, realization, and maintenance of an optimal temperature gradient are key process parameters for improved form-ability [3]. In aluminum alloy 1050, the effect of temperature on spring back, concluding that the forming rate is another factor influencing the spring back effect [4].

Various methods for die manufacturing and construction have been studied, including the production of forming dies through Additive Manufacturing (AM). AM is considered to significantly improve material utilization and reduce total production time and energy consumption compared to traditional metal forming or casting methods [5]. Typically, AM methods are used to produce parts; however, the production of casting molds and metal forming dies shows tremendous potential. AM has found many applications in the production of sheet metal forming dies. Among the types of AM processes, die manufacturing using Laser Powder Bed Fusion and Wire Arc Direct Energy processes [6].

Given the critical role of temperature management in the success of the sheet plastic forming manufacturing process, it is essential to evaluate the effectiveness of temperature controllers. This paper presents an evaluation of a commercially temperature controller as a temperature control mechanism in the sheet plastic forming process of UHMW material.

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II. MATERIAL AND RESEARCH METHODS

2.1 Design of Air Blowing Heater Applicable to UHMW Sheet Forming Process

The design of the air-blowing heater was based on the product's dimensions, which is made from UHMW P1000 sheet material with a thickness of 5 mm. Figure 1 shows the design of air-blowing heater use in the experiment's setup. Four air-blowing heaters, whose horizontal positions can be adjusted to achieve the appropriate heating placement. To orient the heating area of the specimen, the table is hollowed in two configurations with varied dimensions. The specification of air fan and heater shows in Table 1.

To control the airflow of the heaters, each heater is installed within ducting, with a fan positioned above each heater unit. The specimen then passes over the table, aligned with the air-blowing heater's direction. The gap between the table surface and the heater ducting is 30 mm. Two commercial temperature controllers use to control the temperature of specimens during heating. Each controller used to control 2-unit heater which parallel configuration. The controller is completed feature of auto-tuning PID constants and also self-tuning with the step response method. Table 2 shows the specification of the controller. The schematics wiring diagrams which connecting the controller with fan-heater shown in Figure 2.

Specimen positions during heating are fixed by two-axis stoppers installed on the upper surface of the table. Additionally, the stopper serves to block the airflow, preventing heated air from reaching the opposite side of the heating unit through the table's openings.

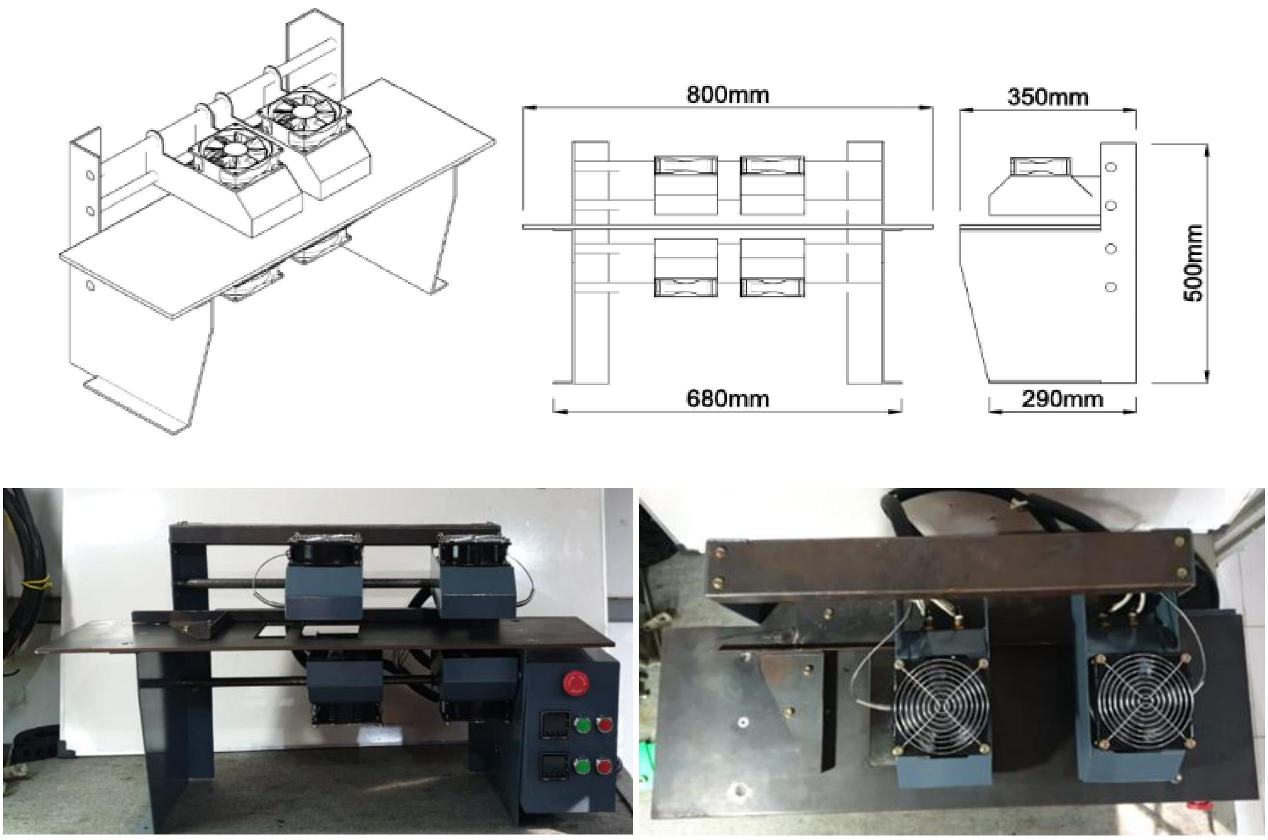

Figure 1: Air Heating Blower Bench

Table 1: Technical Specification of Fan and Heater

Specification of Axial Fan		Specification of Electrical Heater	
Dimension	Outside Diameter : 12 cm Inner Diameter : 6 cm	Power	1600 Watt
Voltage	220 V	Voltage	220 Volt
Flow		Type of Heater	
Flow Velocity			

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Table 2: Specification of Temperature Controller

Series Number	Digital Temperature Controller Omron E5CC QX2ASM-800
Power Supply Voltage	100 – 240 VAC, 50/60 Hz
Dimension	48mm x 48mm
Number Input	1 Input
Number Output	2 Output
Output Type	Analog
Input Type	RTD, Thermocouple
Control Methods	On-Off Control, or 2-PID Control (with Auto-tuning)
Operating Temperature	(-200) Celsius up to 2300 Celsius
Display Type	11 Segment, 4 Digit

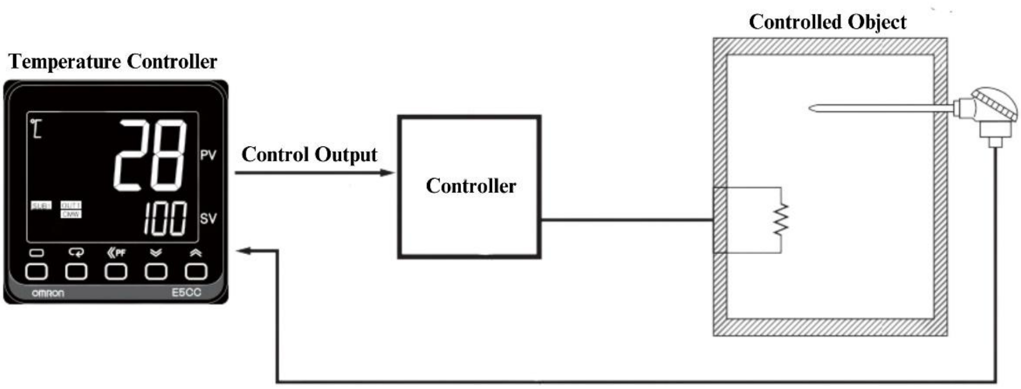

Figure 2: Wiring Diagram of Temperature Controller

2.2 Experimental Set-up

The performance of controller was tested in two ways which is single side heater and double side heater. The single heater experimental set-up is depicted in Figure 3. In single heater the operational of axial fan and heater unit were controlled by temperature controller. Variation of the air flow capacity of fan was arranged by a voltage regulator in variation of 160V – 220V. The RTD sensor was installed in air flow area beyond specimen. The surface temperature of specimen was monitored periodically using an infrared thermometer. In double heater experiments, the top and bottom surface specimen was heating simultaneously. The controller configuration is depicted in Figure 4. Two fans and two heaters are reconfigured using single temperature controller, in which the temperature sensor was installed beyond the upper surface of the specimen.

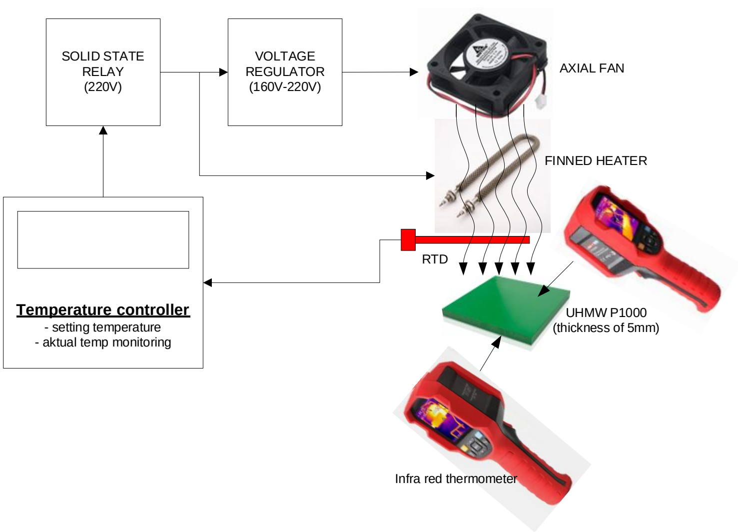

Figure 3: Experimental Set-up of Single Side Heater Configuration

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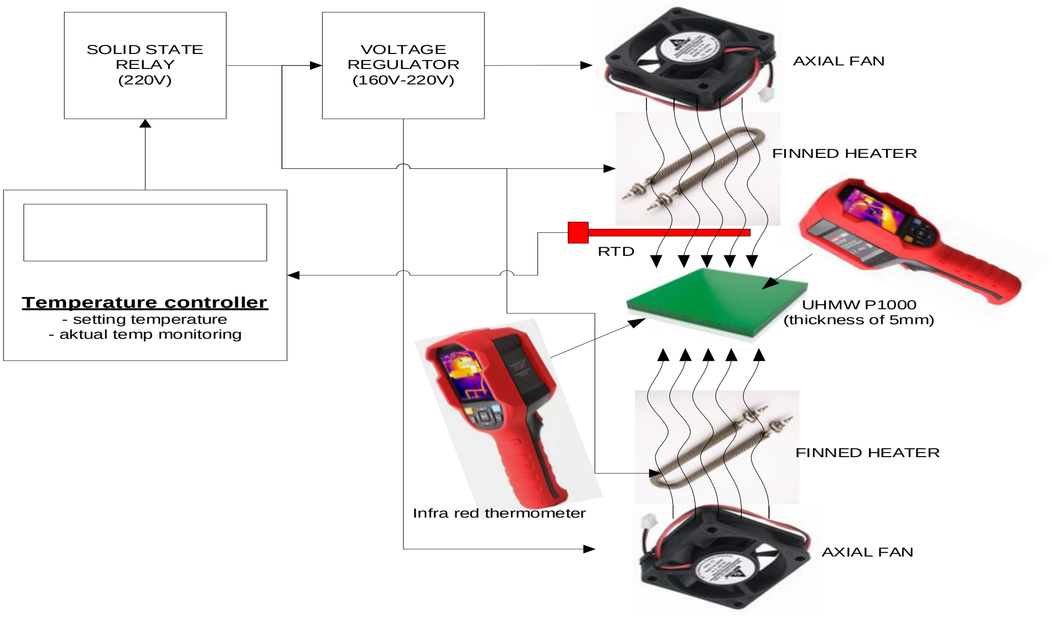


Figure 4: Experimental Set-up of Double Side Heaters Implementation

2.3 Experiment Parameters

Controller system performance was tested by varying the setting value (SET VALUE) includes 80, 90, 100 and 110oC. The experiments were conducted by auto-tuning method to yield the PID constants and the flow capacity of fan was fixed of 0.054 m3/s. The tests were carried out along 900s, and then the SET VALUE, actual controlled temperatures and temperatures of top and bottom surface were plotted in each parameter variation.

The second experiments were objected to observe the influence of the flow capacity of fan toward the performance of the controller. The flow capacity of fan was varied by adjusting input voltage. The plot of correlation between voltage and flow capacity of fan is depicted in Figure 5. The experiments were conducted in variation of flow capacity including 0.055 m3/s, 0.054 m3/s and 0.0505 m3/s.

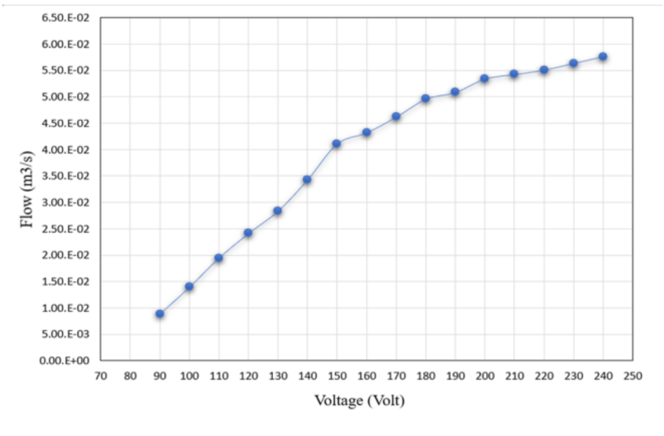


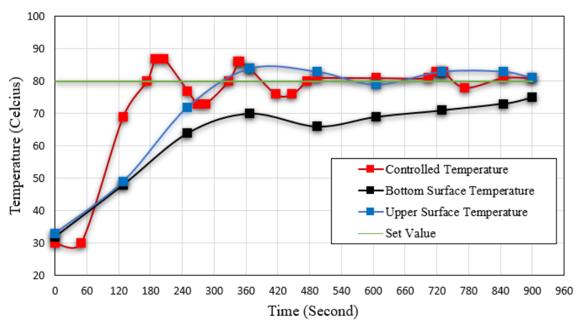
Figure 5: Characteristic of Fan Flow Capacity toward the Input Voltage

III. RESULT AND DISCUSSION

In the air-blowing heater system, temperature stability in control is determined by the balance between the airflow capacity generated by the fan and the heat produced by the electric heating system. Stable control temperature received by the work piece material is achieved not only through the application of a PID controller but also by maintaining a balance between the fan's airflow capacity and the heat generated by the electric heater. Therefore, fan speed control is essential. The fan speed is adjusted by regulating the voltage. Figure 6 shows the fan's airflow capacity curve in relation to its input voltage.

3.1 Experimental Result of Single Side Heater

This test was conducted to evaluate the performance of the temperature control system by determining the PID constant values using the auto-tuning method. The test utilized a single heating system with a fan flow capacity of 0.055 m³/s, and the setpoint was varied. The test results are shown in Figure 6.



(a)

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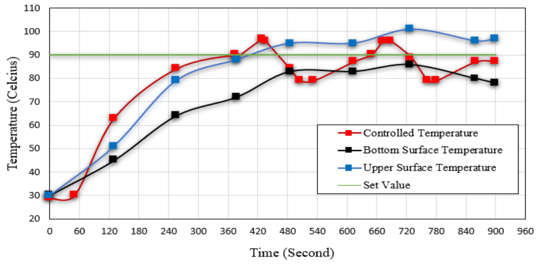

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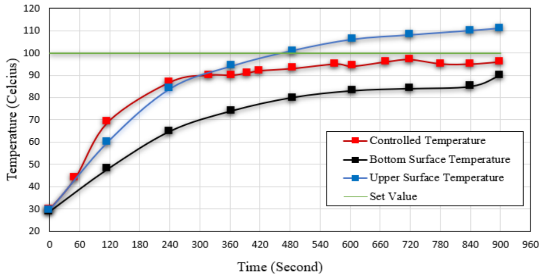

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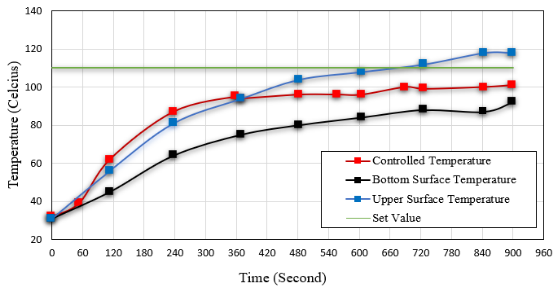

(d)

Figure 6: Temperature PID Controller performance by varying SET VALUE (flow capacity of Fan 0.055 m^3/s): a. SET VALUE=80°C, PID constants are 15, 101, 17, respectively, b. SET VALUE=90°C, PID constants are 21.3, 149, 25, respectively, c. SET VALUE=100°C, PID constants are undefined, d. SET VALUE=120°C, PID constants are undefined

At a set-point of 80°C, the controller demonstrated satisfactory performance with PID constants of 15, 101, and 17. The target temperature on the work piece was reached in approximately 5 minutes (Figure 6a). The overshoot was 5°C above the set-point, and steady-state conditions were achieved after 480 seconds. Figure 6b shows that at an SET VALUE (set value) of 90°C, the controller's performance exhibited a relatively large steady-state error, and steady-state conditions were not reached even after 900 seconds. However, PID constants could still be determined at 21.3, 149, and 25. The work piece temperature reached the set-point approximately 7 minutes after heating began.

Starting from an SET VALUE of 100°C, the controller's performance failed to achieve the target, as evidenced by the failure to reach the target temperature, as shown in Figures 6c and 6d. Under these conditions, PID constants could not be determined. Nevertheless, the work piece temperature did eventually reach approximately 100°C in about 8 seconds and 120°C in 11 seconds.

In general, the upper surface temperature of the work piece was ultimately higher than the control temperature due to energy accumulation within the work piece. Additionally, the upper surface temperature was higher than the lower surface temperature, which is related to the heater's position above the work piece surface.

The controller's inability to achieve the target performance may be due to excessive airflow from the fan, which disrupts the balance between the generated and transferred energy.

To address this issue, tests were conducted to identify the flow capacity needed to reach set value of 100°C and 110°C. A set-point of 100°C was achieved by adjusting the flow capacity to 0.053 m³/s, as shown in Figure 7. However, a flow capacity of 0.053 m³/s was insufficient to reach the setpoint of 110°C, as shown in Figure 8.

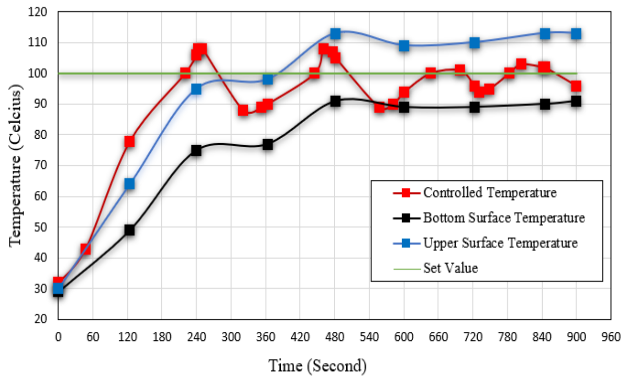

Figure 7: Temperature PID Controller performance by SET VALUE 100° C, Fan Voltage 200V (flow capacity of Fan 0.053 m^3/s) which defined PID constants are 24.7 , 143, 24 after auto tuning process completed

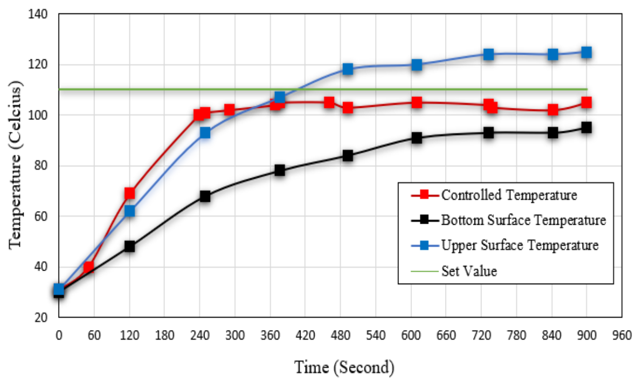

Figure 8: Temperature PID Controller performance by SET VALUE 110° C, Fan Voltage 200V (flow capacity of Fan 0.053 m^3/s) which couldn't define PID constants during Auto-tuning process

3.2 Effect of PID Auto-tuning and Inserting PID Constant

For the implementation of PID controllers, commercial temperature control systems are equipped with an auto tuning

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method to determine PID constant values. How much influence the method of determining the PID constant using the auto tuning and inserting value method has on achieving steady state temperature is shown in Figures 9 and Figure 10. Testing was carried out at setting value 110°C, fan flow capacity 0.054 m^3/s. From the figure curve, it can be seen that with the auto tuning method, the percent overshoot that occurs is relatively greater so that reaching the steady state temperature tends to take longer compared to implementing the inserting fixed value method.

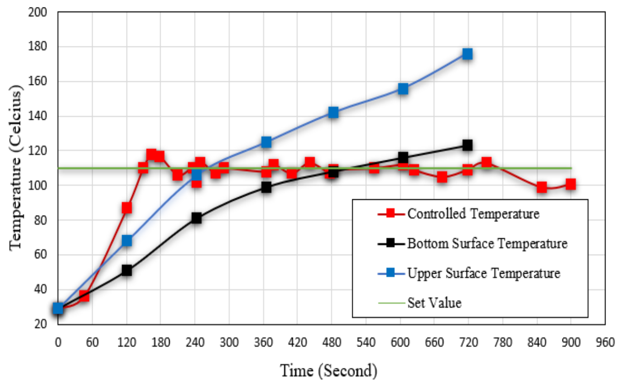

Figure 9: Temperature PID Controller performance by SET VALUE 110 C, Fan Voltage 180V (flow capacity of Fan 0.049 m^3/s) which defined PID constants are 8, 42, 7 after auto-tuning process completed

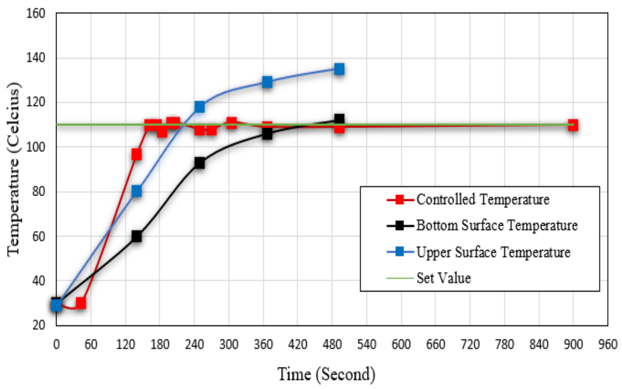

Figure 10: Temperature PID Controller performance by SET VALUE 110 C, Fan Voltage 180V (flow capacity of Fan 0.049 m^3/s) and inserted PID constants are 8, 42, 7.

3.3 Experimental Result of Double Side Heater

Testing was conducted using two heater units placed on each side of the work piece surface, with each heater positioned approximately 3 cm from the work piece surface. Both heaters and their fans were controlled by a single control system with an RTD sensor placed on the upper surface of the work piece in the heating area. Figure 11, 12 and 13 shows the change in temperature over time in the experiment with dual heaters.

The test results, which involved varying the fan's airflow capacity, showed that with the above control system configuration, PID control was ineffective. This ineffectiveness was evident as the temperature of the work piece rose more quickly than the control temperature. Due to the cumulative energy effect in the work piece, the actual temperature could no longer be controlled by the system. The temperature difference between the upper and lower surfaces of the work piece was relatively small, with an identical upward trend, indicating better temperature uniformity in the work piece. Adjusting the fan's airflow capacity affected the heating rate: at a flow capacity of 0.054 m³/s (220V), the re-crystallization temperature of UHMW was reached in approximately 420s, whereas with fan settings at 200V and 180V, this temperature was reached in about 300s.

Given this phenomenon, using heaters on both sides of the work piece surface is likely effective without a control system. The heating process can be managed with a timer. The re-crystallization temperature of the UHMW sheet material can be achieved in approximately 5s with fan flow capacity settings of 200V and 180V.

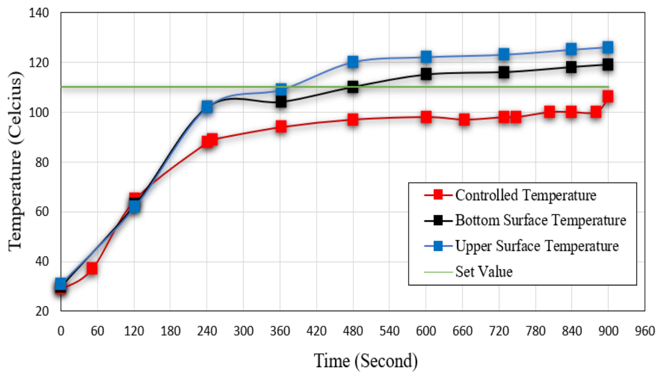

Figure 11: Temperature PID Controller performance by SET VALUE 110 C, Fan Voltage 220V (flow capacity of Fan 0.055 m^3/s) using double side heater which couldn't defined PID constants during Autotuning process

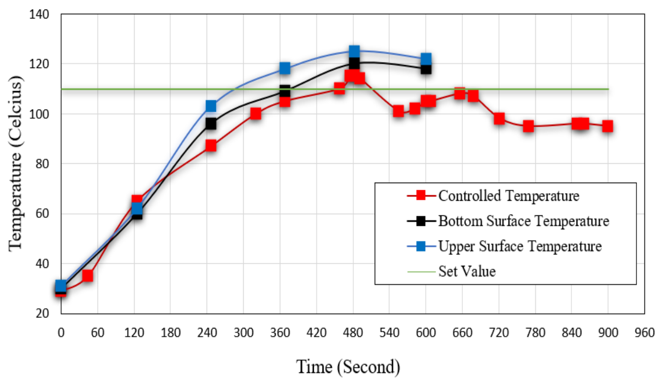

Figure 12: Temperature PID Controller performance by SET VALUE 110 C, Fan Voltage 200V (flow capacity of Fan 0.054 m^3/s) using double side heater which couldn't defined PID constants during Auto-tuning process

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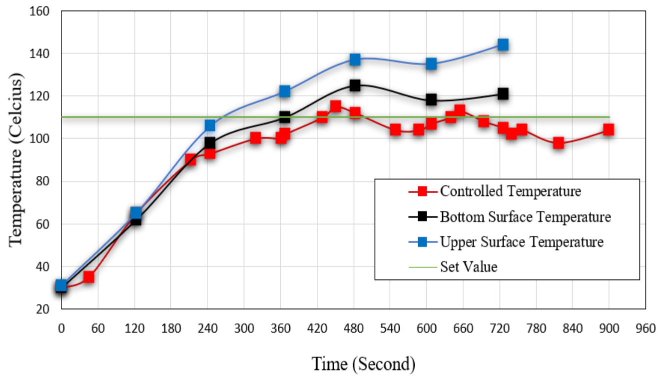

Figure 13: Temperature PID Controller performance by SET VALUE 110 C, Fan Voltage 180V (flow capacity of Fan 0.049 m^3/s) using double side heater which defined PID constants are 11.4, 116, 20 after auto-tuning process completed

The difference in heating performance between the single and double heaters on the work piece is shown in Figure 14. The temperature curve of the work piece measured represents the average temperature between the upper and lower surfaces of the work piece. The figure demonstrates that with the use of double heaters, the re-crystallization temperature of the UHMW material, which is 110°C, cannot be achieved with a fan flow capacity of 0.054 m³/s.

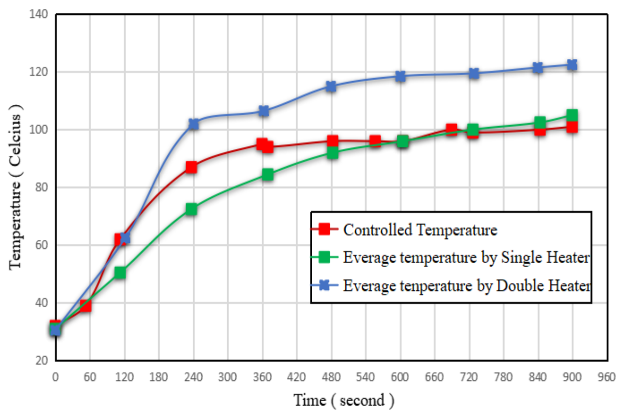

Figure 14: Heating performance comparative between single and double heater performance by SET VALUE 110 C, Fan Voltage 200 V (flow capacity of Fan 0.053 m^3/s

IV. CONCLUSION

The evaluation of the performance of a commercial temperature controller for use in heating UHMW has been successfully conducted. The controller is not always able to reach the specified set-point temperature. At the crystallization temperature of UHMW, which is 110°C, the controller failed to achieve this temperature. This is because, at 110°C, further heating does not result in an increase in temperature. Adjusting the airflow rate is necessary to achieve the specified set-point.

REFERENCES

[1] Khalil, Y.,; Hopkinson, N.,; Kowalski, A.,; Fairclough, J P A. Characterisation of UHMWPE Polymer Powder for Laser Sintering. Materials 2019, 12(21), 3496.

[2] Keum, YT.,; Han, BY. Springback of FCC sheet in warm forming. Journal of Ceramic Processing Research, 2002, 3(3), 159-165.

[3] Kim, HS.,; Koc, M.,; Ni, J. Determination of Proper Temperature Distribution for Warm Forming of Aluminum Sheet Materials. Journal of Manufacturing Science and Engineering, 2006, 128, 622-633.

[4] Moon, YH.,; Kang, SS.,; Cho, JR.,; Kim, TG. Effect of Tool Temperature on the Reduction of the Springback of Aluminum Sheets. Journal of Materials Processing Technology, 2003, 132, 365-368.

[5] Rasiya, G.,; Shukla, A.,; Saran, K. Additive Manufacturing-A Review. Materials Today Proceedings, 2021, 47(4).

[6] Alimov, A.,; Sviridow, A.,; Sydow, B.,; Jensch F.,; Hartel, S. Additive Manufacturing of Hot-Forming Dies Using Laser Powder Bed Fusion and Wire Arc Direct Energy Deposition Technologies. Metals, 2023, 13, 1842.

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