Temperature correction of hot stamping parts based on infrared thermal imager

Fangfang Li, Bo Yin, Haobin Tian, Xuelei Li and Jianping Lin†
School of Intelligent Manufacturing, Shanghai Polytechnic University, Shanghai, 201209, China
†E-mail: jplin58@tongji.edu.cn

Using thermal imager in hot stamping production enterprises to measure the temperature of steel sheet has the characteristics of high automation, fast response and convenient control. However, in the practical application, infrared temperature measurement generally exists the problem of inaccurate temperature measurement, resulting in the quality of stamping parts cannot be accurately controlled. The main reason for the inaccuracy of temperature measurement is the inability to calibrate the infrared thermal imager and set the correct emissivity. Therefore, this paper analyzed the relationship between emissivity and boron steel sheet temperature, and derived corresponding equations to quantitative define this relationship. The research results indicate that as the sample temperature decreases, the influence of emissivity on the temperature of the thermal imaging instrument gradually decreases. At the same temperature, as the emissivity increases, the display temperature of the thermal imager gradually decreases. Based on experimental testing, the relationship between emissivity and sample temperature is obtained, which is used to correct errors in high and low temperature ranges and improve actual measurement accuracy.

Keywords: Hot stamping; Infrared thermal imager; Temperature correction; Emissivity.

1. Introduction

The final performance of hot stamping part depends on the microstructure and its distribution after quenching. The formation of the microstructure is based on the temperature and deformation during the forming process. The deformation is applied by the press, and the temperature is affected by the temperature of the furnace, the transfer time of the steel sheet, the temperature of the die, the contact pressure, etc. Therefore, the non-contact monitoring of the temperature before and after the hot stamping process using the infrared thermal imager can be used without affecting the production. At the same time, it can judge whether the temperature in the forming process is reasonable in real time, and find the location of the unreasonable temperature area, etc., and provide a basis for temperature correction. However, the accuracy of the temperature obtained by the infrared thermal imager is difficult to guarantee in different temperature ranges and different use scenarios, and it needs to be debugged in advance. Therefore, by welding thermocouples on the sheet and using thermocouples at the same time, the emissivity of the infrared thermal imager can be corrected to ensure the accuracy of the temperature measurement of the infrared thermal imager.

At present, thermal imagers have been used in many experimental scenarios. Hao Xin et al [1] recorded the temperature change of sheet metal through thermal imager, and

Y. Zhang and M. Ma (eds.), *Proceedings of the 7th International Conference on Advanced High Strength Steel and Press Hardening (ICHSU 2024)*, Atlantis Highlights in Materials Science and Technology 3,
https://doi.org/10.2991/978-94-6463-581-2_62

derived the value of heat transfer coefficient through reverse analysis, thus established the relationship between heat transfer coefficient and contact surface roughness, hardness, material thermal conductivity, interface pressure and other parameters. Xue Fei et al [2] used infrared thermal imager as a tool to study the application of electrode heating and local covering shielding material to implement partial heating of hot stamping. Song Gao et al [3] conducted the bulging test to obtain thermal forming limit diagram with the M-K model for Ti-6Al-4V alloy, and the temperature of dies were monitored and regulated using an infrared thermal imager. Yang Chen et al [4] conducted Q&P hot stamping of a U-cap part, while the infrared thermal imager FLIR A615 was used to record the temperature change of the blank. Jing Zhou et al [5] conducted microwave heating and welding experiments with an infrared thermal imager (FLIR A310), located on the top surface of the cavity, which was used to capture the in-plane temperature distribution of the specimen.

Therefore, by welding thermocouples on the sheet and using thermocouples at the same time, the emissivity of the infrared thermal imager can be corrected to ensure the accuracy of the temperature measurement of the infrared thermal imager.

2. Experiment

In order to obtain correct emissivity of infrared thermal imager during hot stamping, the Al-Si coated boron steel sheet was used. The specimen was processed to 50 mm*100 mm size. One end of thermocouple was spot welded to the center of specimen, and the other end was connected to the temperature display of thermocouple to record the real temperature change of the specimen. During the experiment, the specimen was heated and kept in a heating furnace preheated at 950°C for 5 minutes, and then manually transferred to the upper surface of the cooling system with tongs. The infrared thermal imager was mounted above the front of the specimen using a tripod, as shown in Fig. 1.

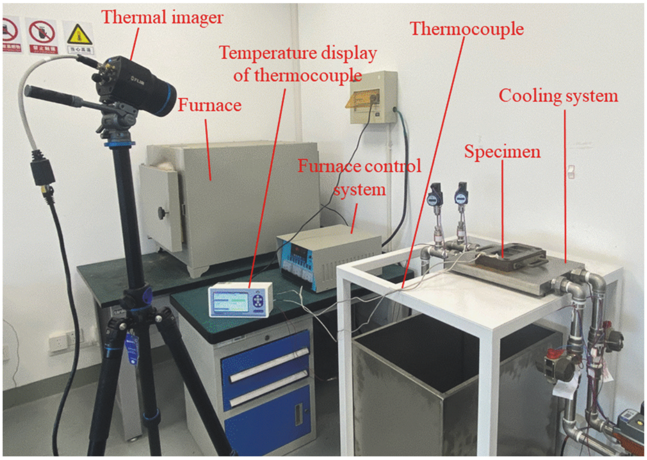

Fig. 1. Experimental setup.

The working principle of the infrared thermal imager is to convert the infrared radiation energy emitted by the sheet metal into temperature information. Experimental thermal imagers can record 30 frames of data per second, and the default emissivity is 0.95. The cooling system can change the cooling rate of the specimen by controlling the water flow.

3. Results and discussion

The cooling processes recorded by the thermal imager and thermocouple respectively was shown in Fig. 2. At the high temperature segment, the temperature difference between the thermal imager and the thermocouple is large, and the temperature difference gradually decreases with the decrease of the specimen temperature, but the difference always exists. Therefore, it is necessary to correct the emissivity of the thermal imager and determine the emissivity matching the temperature segment, so as to achieve correct non-destructive temperature monitoring.

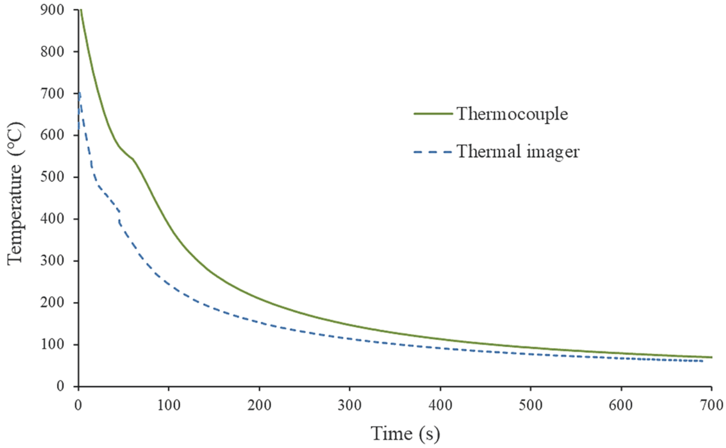

Fig. 2. Temperature comparison of cooling process between thermocouple and thermal imager.

In the hot stamping process, the state of the steel sheet at different temperature segments is very different, so the forming process can be distinguished according to the temperature segment, which is the main high temperature segment (600-900 °C), the middle temperature segment (300-600 °C) and the low temperature segment (0-300 °C). The high temperature segment is referred to the temperature between the steel sheet removed from the heating furnace until the die closed. This temperature segment can be photographed by the thermal imager, and also determines the time required for cooling in the die, the temperature at which the deformation begins and the final microstructure, which is the most important part of the entire cooling process. The medium temperature segment is the temperature at which the steel sheet is quenched in the die, which cannot be photographed by the thermal imager during the actual forming process, and in the case of sufficient cooling speed, the temperature is determined by the high temperature segment and the die design. The low temperature segment is the temperature range of the steel sheet from die opening to room temperature. In this temperature segment, the phase transformation has been completed, the microstructure and mechanical properties have been fixed, but the temperature distribution of part after die opening can reflect its deformation. Unreasonable die opening temperature distribution means that the cooling and pressure holding modes of the die need to be adjusted. Thus, accurate geometry can be obtained while ensuring the performance of the parts. The influence of emissivity on different temperatures in the three temperature segments is shown in Figs. 3-5.

It was found that with the increase of emissivity, the temperature of the thermal imager gradually decreased in the high temperature segment. The thermocouple temperature was used to check the thermal imager. It is found that when the actual temperature is 867.5℃, the temperature of thermal imager is 866.4℃, which is the most accurate one, when emissivity is 0.65. Similarly, when the thermocouple temperature is 618 ℃ and emissivity is 0.68, the corresponded thermal imager temperature is 618.3℃. In general, with the decrease of specimen temperature, the emissivity of obtaining accurate specimen temperature gradually increases, from 0.65 to 0.68. In addition, as the temperature of the specimen decreases, the emissivity influence on the temperature of the thermal imager gradually decreases. For example, when the specimen temperature is 867.5℃, emissivity increases from 0.63 to 0.68, the temperature of the thermal imager decreases from 886 to 839℃, with a difference of 47℃. Similarly, emissivity increased from 0.63 to 0.68. When the specimen temperature was 673.7℃, the thermal imager temperature was reduced from 698.7 to 662.8 ℃, with a difference of only 35.9℃.

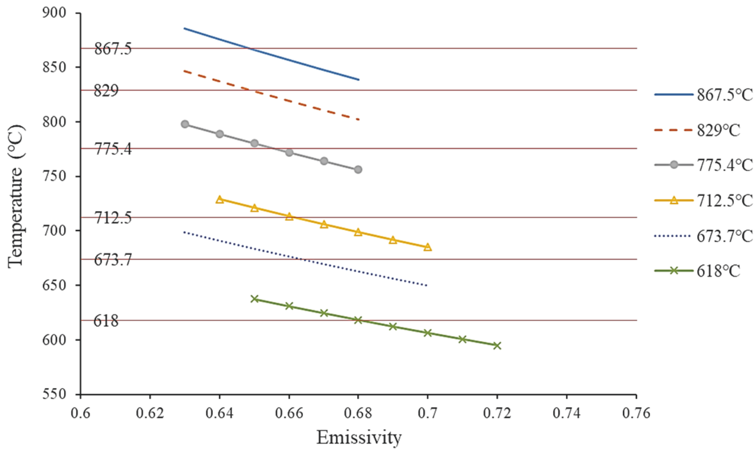

Fig. 3. Influence of emissivity on temperature in the high temperature segment.

In the middle temperature segment, with the increase of emissivity, the temperature of thermal imager also gradually decreased. With the decrease of specimen temperature, the emissivity of accurate thermal imager temperature first increases and then decreases. As the temperature of the specimen decreases, the emissivity influence on the temperature of the thermal imager gradually decreases. For example, when the specimen temperature is 469.5℃, emissivity increases from 0.63 to 0.68, and the temperature of the thermal imager decreases from 481.7 to 456.8℃, with a difference of 24.9℃. When the specimen temperature is 331.2°C, the temperature of the thermal imager decreases from 339 to 322.9 °C at the same emissivity range, and the difference is only 16.1°C.

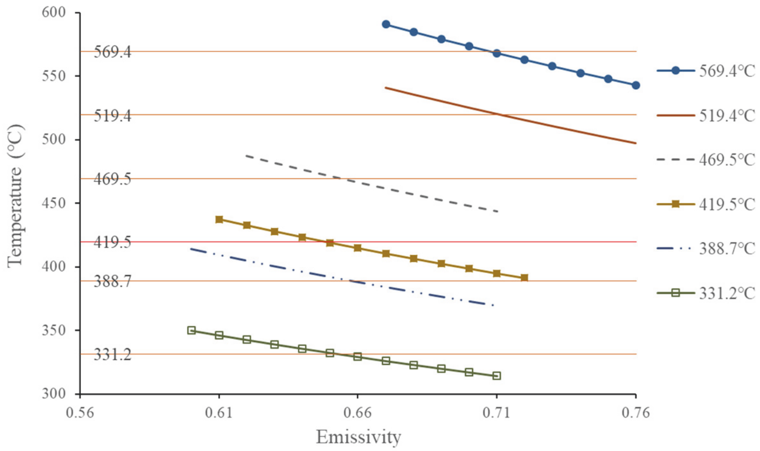

Fig. 4. Influence of emissivity on temperature in the middle temperature segment.

In the low temperature segment, the emissivity of obtaining accurate thermal imager temperature gradually increases with the decrease of specimen temperature. Similar to the high and medium temperature segments, the emissivity influence on the temperature of the thermal imager gradually decreases with the decrease of the specimen temperature. This may be because as the temperature decreases, the color of the specimen changes from red to black, which indicates that the infrared radiation of the sheet material decreases, and the influence of changing emissivity on the thermal imager temperature decreases continuously.

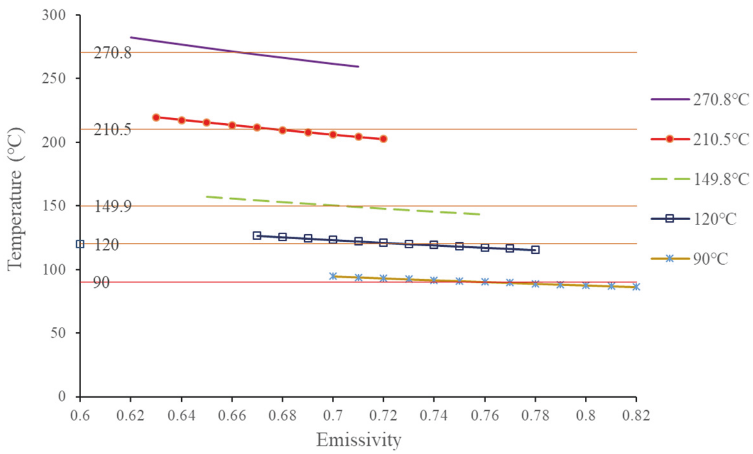

Fig. 5. Influence of emissivity on temperature in the low temperature segment.

In order to better determine the relationship between emissivity and specimen temperature, high, medium and low temperature segments were fitted respectively, and the results were shown in Eqs (1) - (3). The comparison of experimental and calculated results was shown in Fig. 6. The fitting accuracy of the high temperature segment and the low temperature segment is higher, R^2 is 0.9085 and 0.9546 respectively, but the fitting accuracy of the middle temperature segment is lower, R^2 is only 0.7921. However, in the actual hot stamping process, the steel sheet is quenched in the die during the middle temperature segment, and the thermal imager can not capture the specimen temperature, so it has little significance for temperature detection.

$$T_H = 118948 * e^2 - 166179 * e + 58598 \quad (1)$$

$$T_M = 240617 * e^2 - 324122 * e + 109603 \quad (2)$$

$$T_L = 458685 * \exp(-11.31 * e) \quad (3)$$

Where, e is emissivity, T_H is the fitting temperature of the high temperature segment, T_M is the fitting temperature of the middle temperature segment, and T_L is the fitting temperature of the low temperature segment.

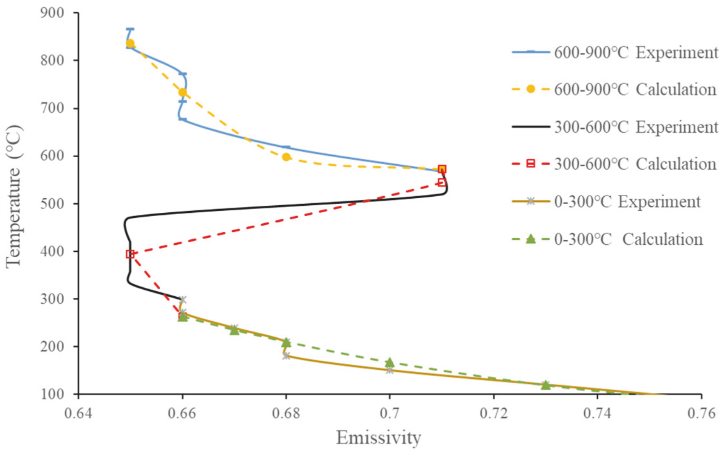

Fig. 6. Emissivity Relationship of specimen temperature.

4. Conclusions

Using thermocouple and thermal imager to observe the specimen temperature simultaneously, it can be found that:

(1) As the temperature of the specimen decreases, the influence of emissivity on the temperature of the thermal imager gradually decreases.

(2) At the same temperature, with the increase of emissivity, the displayed temperature of the thermal imager gradually decreases.

(3) According to Eqs (1) - (3), the relationship between emissivity and specimen temperature can be obtained. The fitting accuracy is higher in the high and low temperature segments, while the fitting accuracy is lower in the middle temperature segment. However, specimens in this temperature segment cannot be directly photographed in the die.

References

1. X. Hao, X. H. Han, K. Yang, et al. Theoretical and experimental research on heat transfer phenomena in hot stamping. *J. Plast. Eng*, **98-101**, 2 (2014).
2. F. Xue, X. L. Liu, Y. S. Zhang, et al. Hot forming technology of high strength steel with tailored properties by partial heating. *Hot Working Technol.*, **41-44**, 47(2018).
3. S. Gao, G. T. Wang, Y. Sang, et al. Research on the thermal forming limit diagram (TFLD) with the M-K model for Ti-6Al-4V alloy. *Int. J. Adv. Manuf. Technol*., **3713–3728**, 131 (2024).
4. Y. Chen, H. Z. Zhang, J. Tang, et al. Integrated Modelling of Microstructure Evolution and Mechanical Properties Prediction for Q&P Hot Stamping Process of Ultra-High Strength Steel. *Chin. J. Mech. Eng.*, **45**, 33 (2020).
5. J. Zhou, Y. G. Li, T. Yang, et al. Microwave heating and processing of solid metals using electromagnetic resonators. *Int. J. Adv. Manuf. Technol*., **1111–1121**, 123 (2022).