



## EXPERIMENTAL AND NUMERICAL ANALYSIS OF METAL RADIATED BY AN INFRA-RED HEATER

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### ABSTRACT

For heat assisted bending process, an irradiation of the whole bend line together with optimum temperature gradient between two adjacent surfaces is most favorable. However, it's depends on type of the used heat source with high intensity heat energy into the workpiece is very importance. In this paper, an experimental and numerical technique have been used to study an efficiency of the infra-red heater to radiate a mild steel plate. Initially, an experiment has been conducted to determine temperature distribution at the selected points on the workpiece. The result indicates that the infra-red heat is not suitably used as a heat source for the heat assisted bending process. Then, a finite element model (FEM) has been developed to replicate the conducted test. Thermal distribution results from FEM shows good agreement with the experiment results. The result proves the validity of all the input parameters in the developed FEM model.

**Keywords:** finite element analysis, experimental analysis, heat transfer.

### INTRODUCTION

Heat-assisted bending is one of latest technology has been applied in metal forming processes. One of the advantage of this process is to reduce bending force and increase part stiffness. The process is performed by applying controlled heating on plate surface prior to bending process. Heat generates thermal stresses (without melting) inside the workpiece as additional to contribute to reduce forming forces. The part stiffness is increased due to development of thicker bending region after the forming process. This fact could be achieved with producing distant temperature gradient inside the plate during the bending process. The most crucial heating technique is from a laser heating system that seems to be the best type of heat source for the heat-assisted bending process. This due to an establishment of a huge temperature gradient along the part thickness [known as temperature gradient mechanism (TGM) (Geiger,2004).

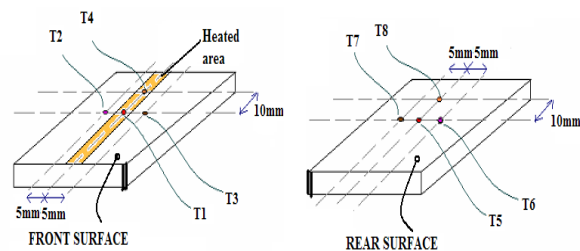
Instead of using laser, heat-assisted bending could be established by using different type of heat source, including the infra-red heater. Considerable research were carried-out numerically and experimentally to investigate heat generation on the metal surface under localised heating condition. Researches by Hao and Li was focused on numerical analysis that used to determine on how to model power input based on Gaussian distribution (Hao & Li, 2009). Meanwhile, Cheng *et. al* conducted similar research as Hao and Li to determine heat generation inside the workpiece under localised heating condition (Cheng *et. al*, 2006). Beside Gaussian distribution model, the other assumption for heat intensity such as a uniform square, and a point heat source as described (Vollertsen, 1994) The uniform square heat source uses the same peak intensity, while the point heat source was obtained by assuming that the radius of the Gaussian heat source approaches zero. In this paper, a finite element method has been used to replicate experimental result to model temperature contour inside

the metal plate, with intention to establish TGM profile using infra-red heater as a heat source.

### EXPERIMENTAL WORK

#### Specimen preparation

In experiment, the test pieces were cut to size 100 mm x 30mm. The primary measurements were involved temperature investigation at different locations, from which temperature gradient can be obtained as a function of time. The eight channels data acquisition device was used to cater all the planned data points required in this experiment. Thermocouples type K placed in eight locations where four of them were fitted on the front plate (heated area) and the others on the rear plate (cooled area) The location for every thermocouple and their distance from the centre line are shown in Figure-1.



**Figure-1.** Thermocouple locations on both sides of specimen.

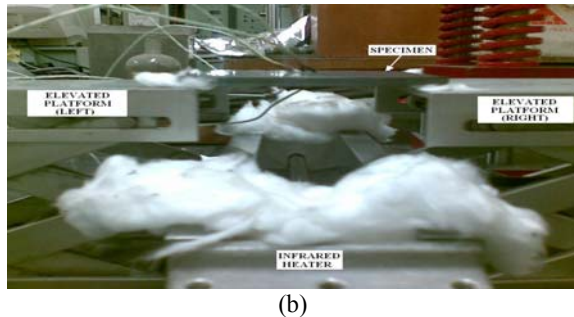
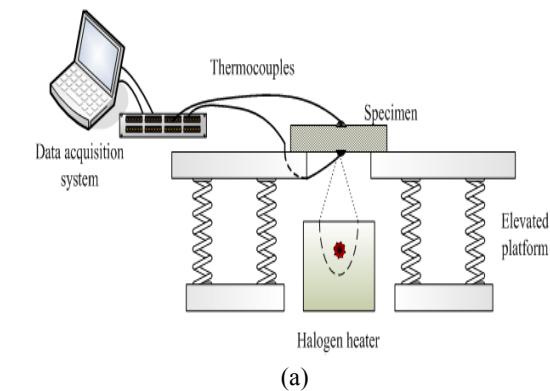
In this experiment, halogen heater model LineIR 5209-10, manufactured by Research Incorporated, USA has been used (Research inc, 2009). The main components of the heater comprises of the heating module, cooling system and electrical system. The heating module or halogen lamp used are composed of a coiled tungsten filament (length 254 mm), contained in a quartz tubular enclosure (diameter 10 mm) filled with Argon gas and coated on its back with a aluminum



reflector in order to increase the heat flux received by the product.

### Test setup

The experimental setup for heat transfer test is shown schematically in Figure-2. It includes an electrical halogen heater as a heat source, elevated platforms and the corresponding data acquisition system. The bar was held in two flexible platform supports, isolated by asbestos cord, and heated electrically at one end by a electric heater. To reduce heat loss from the testpiece to the surrounding, fibre glass sheet is used to cover both side of heater opening.



**Figure-2.** (a) Full arrangement for heat transfer test (b) Actual setup for heat transfer test.

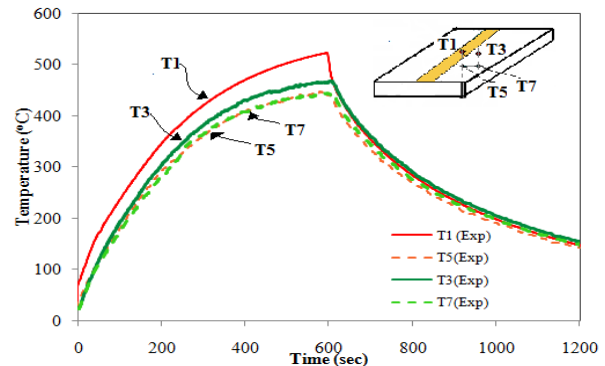
### Test procedure

This test was held in at ambient temperature in open lab environment. In such conditions, the loss energy to the surrounding was varied. The initial test was performed to show the quality of the applied heat on metal surface at selected distance between the heater and testpiece. In this case, the distance between the testpiece and heater was adjusted by using the elevated platform. Based on the first result, correct specimen positioning has been identified and was used in the second experiment was held. Similar procedure by choosing the optimum distance between workpiece and heater, i.e. 50mm. Number of tests have been established to develop the good test data. Fibre-glass foam was used to reduce heat loss to the surrounding and also from plate to the

platform. To avoid inconsistent of the results, only single testpiece has been used along the experiment.

### RESULTS AND DISCUSSIONS

The result is plotted in a graph as shown in Figure-3. It reveals how temperature changes at the four selected point during the simple heat transfer test. As we can see from the  $T_1$  curve, the temperature increases quickly for the first 5 minutes before slowly decreasing to the maximum achievable temperature. In this experiment, the total heating time was fixed for 10 minutes since temperature almost at the peak value and more at the steady state condition. After the heat was removed, temperature initially drops very fast and later slowly decreases to original ambient temperature. Similar characteristic is determined on the other points but at different temperature history as revealed from the similar graph below.



**Figure-3.** Thermal evolution extracted from the experiment

From this test, it was found that the temperature difference at the centre point ( $T_1$  &  $T_5$ ) is only  $50^{\circ}\text{C}$ . This difference is too low to create enough bending line deformation with higher thickness at the corner region. It occurs due to low capacity of the infra-red heater that produces the low heat flux density on the metal surface. It takes longer heating time to for metal to heat the surface. As a result, the temperature has more time to uniformly distribute inside the workpiece and reduces the temperature gradient between the front and the back surface. Hence, it generates small temperature gradient along the part thickness. For instance, this condition is not so conducive in term of suitability of the infra-red heater to be used as a heat source to study the hybrid roll forming process. The main contribution of this experiment is to provide the available data to be adopted in the future numerical analysis.

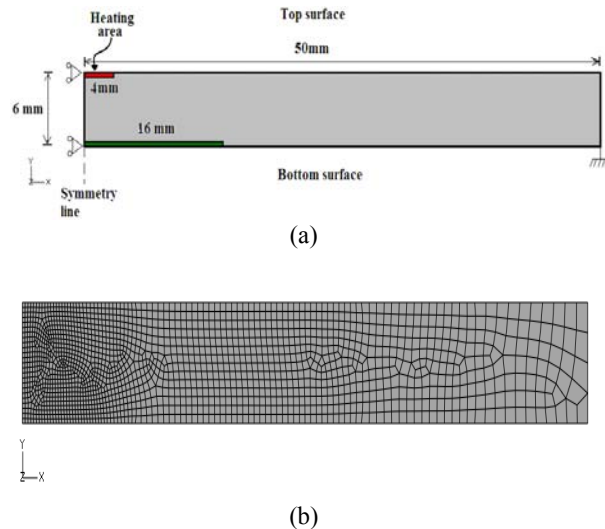
### NUMERICAL ANALYSIS

#### Geometrical model

The 2D finite element model was developed to analyze the heat transfer and temperature distribution in a



line heating process as shown in Figure-4. The main objective is to find the nodal temperatures inside the plate over a time domain.



**Figure-4.** 2D model of heat transfer analysis (a) Geometrical sketches (b) Meshes.

The specimen is modelled as a single work piece of mild steel with 6 mm thickness. A schematic of a spot heating situation and the specimen dimension are shown above. The blank model consists of 1741 linear quadrilateral elements type DC2D4.

### Input parameters

Boundary conditions on the thermal model have been set as fixed temperature at 28°C on external surfaces. The value of the heat transfer coefficient in the first analysis was defined at 600 W/m<sup>2</sup>.K which determined based on the forced evaporative condition as acquired from the study by (Felde, 2001). Also, a natural convective heat transfer coefficient for interaction between the workpiece and the surrounding was set at 20W/m<sup>2</sup>.K. The boundary conditions used include that all surfaces is cooled through free convection and radiation with ambient temperature around the plate is set as 22°C. The interaction between the work piece surfaces with the surrounding is accounted by the calculation where film convection coefficient is obtained from (Biswas, 2007). The temperature dependent material properties of mild steels from previous hot tensile test were used for the transient heat transfer analysis. Physical and thermal properties of workpiece materials as function of temperature have been found in literatures.

In the developed symmetrical model, a middle heating area with 2 mm width was considered. It was determined based on recommendation of manufacturer's technical manual, which stated the maximum width of the focal line is about 4 mm (Research Inc, 2009). Instead of using the Gaussian distribution method, the heat flux distribution is divided into four zones inside the heating

area. Therefore, the maximum temperature exists at the middle and drastically small when it move to the outer heating zone. The total heat flux for the entire zone is equal to the supplied energy was estimated mathematically as shown in Table-1.

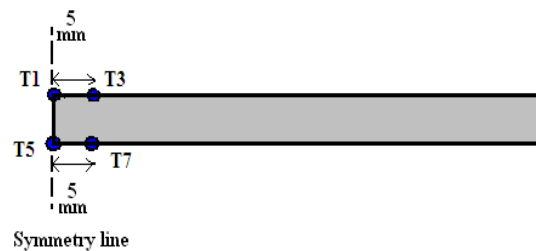
**Table-1.** Heat flux value on the respective heating zone.

Top Surface	Width (x10 <sup>-3</sup> ) - (m)	Length (x10 <sup>-3</sup> ) - (m)	Heat flux (W/m <sup>2</sup> .C)
1st row	0.25	15	1.8x10 <sup>6</sup>
2nd row	0.25	15	1.4x10 <sup>6</sup>
3rd row	0.25	15	1x10 <sup>6</sup>
4th row	0.25	15	5x10 <sup>5</sup>

Selection of the time increments to use in calculating the behavior of the roof will affect the run time of the model and its accuracy. In this model, the total time of heating is 1200 sec through single heating step. The time frame for this analysis is equal to allocated heating time during the experiments. After applying the heating power, the temperature increases until a maximum value is reached. This temperature is defined as the transient-state value.

### Result and validation

The observed points were generated based on similar test arrangement discussed in previous chapter. However, not all of the test points will be analysed in this section. By referring to the cross-section own in Figure 5, the used test results only consider look on the selected 6 thermocouple points; i.e. T<sub>1</sub>, T<sub>3</sub>, T<sub>5</sub> and T<sub>6</sub> was redraw in the Figure-5. The other points have been omitted since they provide redundant that have been used for checking any misalignment between the workpiece and the infra-red heater during the process.



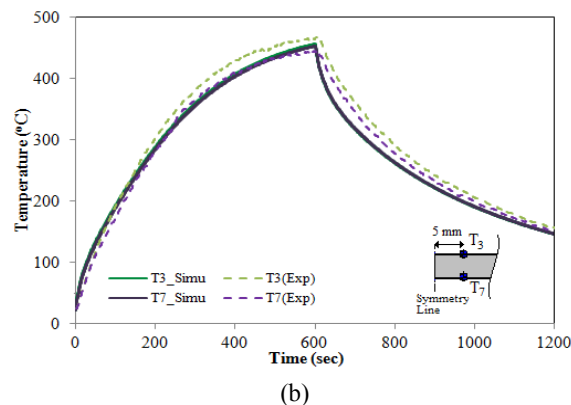
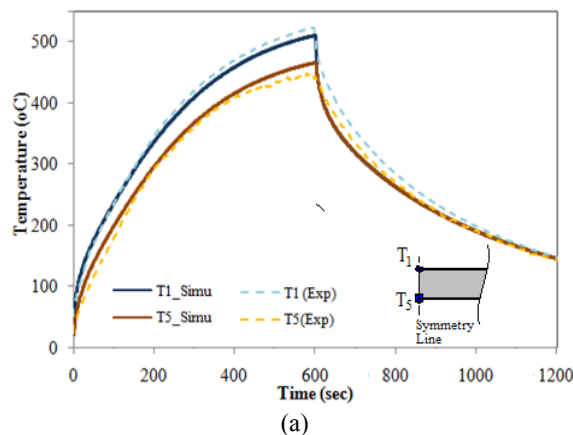
**Figure-5.** The measurement points in the heat transfer experiment.

To validate the numerical model, the numerical results of temperature have been compared with the experimental results. The temperatures histories from the four selected points are shown in Figure-6 (a) & (b). From the figure, it shows the temperature as a function of time at the selected point based on the experiment and simulation results. It can be seen that the temperatures rise tardily and fall sharply. According to the graph 6(a), it shows that in the first heating stage, the numerical temperature at T<sub>1</sub> consistently higher than those obtained



from the experiment. The peak temperature occurs at  $T_1$  was obtained from simulation is  $511^\circ\text{C}$ , which a little bit lower than the experimental result at  $523^\circ\text{C}$ .

At the point  $T_5$  which is located on the back surface of metal plate, the different between the simulation and the experiment more obvious close to the peak temperature value. Percentage of error at this point is calculated about 3%. For the point  $T_3$  and  $T_7$  in the Figure 6(b), the temperature history was found at the same pattern with very small discrepancy. In particular, the maximum error was determined during the cooling stage which is about 10% different between the simulation and the experiment results. For the case of this study, this accuracy can be accepted to show all the adopted thermal and interaction properties are fit for the future finite element analysis.



**Figure-6.** (a) Temperature history on the symmetry line  
(b) Temperature history 5 mm away from the symmetry line.

Small deviation in the current analysis can be explained due to the two main factors, i.e. the heating zone definition and the selection of the thermal interaction properties. In the simulation model, the heating was divided to four zones, in which not as accurate as the gauss's normal distribution. Therefore, small error in the simulation analysis has been expected. For more accurate

results, the model can be improved by adopting smooth heat flux distribution. The second factor is due to the estimated value used in the model likes the heat transfer coefficients and the interaction properties that produce the determined errors in the analysis.

At the end, though there is a small deviation between the two analyses, but still within an acceptable range for the case of heat transfer analysis. This proves the effectiveness of the finite-element model to be developed for the hybrid roll forming process study. The most important outcome from this analysis is the validity of all thermal properties, which will be used in investigation of the heat-assisted bending process. This analysis proves that the actual heat transfer incident in experiment was successfully remodelled on the computer using the finite element analysis.

## CONCLUSIONS

This study successfully determines a reliability of the infra-red heater to be used as a heat source in the heat-assisted bending process. It is found that the infra-red heater fails to generate good temperature gradient between top and bottom surface. The obtained temperature gradient is about  $50^\circ\text{C}$  is too low to create thickening effect during the hot bending process. A higher capacity heating source must be used to produce greater temperature gradient inside the plate.

Beside that, this study successfully validate all the required input parameters of the FEM model of the heat-assisted bending process. It shows that the generated temperature in FEM similar to the experiments. It indicates that all the adopted input parameters are reliable to be used in further investigation on high intensity heating in hot bending process.

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