

Examine temperature field at sealing surfaces treated by laser sealing using Ansys software

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Abstract. Upon deposition of laser irradiation on sealing surface, energy build-up heats up the structural radiation area, significantly and rapidly changing the mechanical properties of the materials in the irradiated area. Consequently, the change of material properties leads to the liquidation of the radiated surfaces which is responsible for the binding efficacy of EVA glue. It is therefore important to investigate the temperature field during the transient sealing period. In our study we demonstrate a method of temperature field investigation by finite element analysis using Ansys software. Three-dimensional finite element simulation is employed to investigate the temperature fields and heat flux in a 0.2mm-thick adhesive layer on surface of a sealing edge with total thickness of 0.5mm x 22mm width. The laser beam was emitted by a device with laser power of 3kw, scanning speed 100mm/s, 980nm wavelength, induced temperature ranging from 100°C to 160°C. Results proved optimal temperature of 135°C, inducing total heat flux of 8731.8 w/m² which is suitable for melting adhesive for optimized binding efficacy. Our study introduced the optimal temperature, heat flux generated by the laser beam yet retaining performance of adhesive, as well as ascertaining binding efficacy and durable linkage between EVA glue and surface of wooden boards.

1. Introduction

In accordance with recent development of furniture industry, there have been considerable advances in research and application of thermoplastic sealing edges. Materials with improved heat resistance, water resistance, higher durability and elasticity, and reduced thickness have been increasingly introduced in manufacture of furniture in living rooms, kitchen and bathrooms. Advanced edge EVA glue correspondingly lead to improvement in sealing technology. Up to date technologies in edge sealing have been employing laser beam to treat the surface of wood panels (MFC, MDF) to melt on-site



adhesive on the surface of sealing edges, avoiding disadvantages associated with current technologies based on heated adhesive [1-4].

The light emitting diode is the key component of a laser-based edge sealing equipment. The millivoltage ray emitted by the diode is enhanced by polarization process, which uses a collector to “collect” multiple laser beams and forms a single laser beam field. The appropriate size and speed of the outlet laser beam can be adjusted according to input parameters such as width of the sealing edges. Upon absorbance of energy from the laser beam, the adhesive polymer on sealing edge surface melts and, with pressure from the edge roller, gradually cover and penetrate panel sides to provide improved adhesiveness with excellent bonding strength and durability. The technology also allows more throughout distribution of adhesive to the gap between panels and sealing edges, minimizing gaps in final products.

Major challenges in edge sealings mainly arises from melting adhesive by heat. Conventional sealing technologies melt adhesives by heat, which requires heating and storage devices dedicated to hot melt adhesive, consumes time and energy in the heating step, reduces sealing efficacy and increase risk of pollution. In addition, sealing equipment needs to be cleaned and serviced regularly, adding costs for labor and spare parts. As alternative for the heat-melting processes, laser beam sealing technology was introduced in 2009 as a protected edge sealing equipment by the Germany company HoMa. Apart from the significantly improved adhesiveness, equipment using laser sealing technologies are able to be programmed with multiple sealing edges, including sealing colours, allowing faster and safer modification in manufacture processes. Laser beam sealing does not require preheat equipment and produce zero excessive adhesive, eliminating risk of equipment contamination [5].

The energy load and emission speed of functional layers of laser, which depends on the nature of the sealing edges and panels, is one of the most important parameters of laser sealing. Sealing edges materials provided to factories or workshops usually come with recommended energy loads and emission speed. Yet in practical production, changes in equipment and other manufacturing conditions lead to manufacturers using non-recommended parameters, which in many cases does not fit the existing equipment and therefore provide suboptimal results. Fine tune assessment is therefore essential to recommend best fit energy value for sealing edges. In an attempt for such fine-tune, we use the ANSYS software to simulate the heating process upon absorbance of laser beams and subsequent temperature increase in adhesive in sealing edges [6].

In this study we focus on establishing optimal thermal distribution and temperature movement in adhesive as well as variation of temperature inside adhesives upon absorbance of energy from laser beam. Our modelling approach have successfully generated data of thermal fields on edge sealing surfaces in laser sealing machine without requiring excessive time and money as in conventional experimental approach

2. Material and method

2.1. Finite element method

Based in Canonsburg, Pennsylvania, Ansys is a joint stock company established in 1970 by a research team led by Dr. John Swanson, namely Swanson Analysis System. The company focused on development and promotion of technical modelling softwares which are used in designing semi-conductive products and materials and testing of product durability by modelling temperature distribution, flow-rate and electromagnetic properties in products. The applied finite element analysis enables dimensional and mathematical modelling in solving specific issues of high degree of freedom in mechanics, thermo-hydraulics and electromagnetics. Based on those advantages, and due to high accuracy, Ansys has become an important software which finds its use and development in numerous institutions in mechanical and engineering. The abovementioned background justified our study.

2.2. Mathematical model of melting

The modeling of laser melting is a highly non-linear thermo-mechanical phenomenon. The moving heat source results in localized heat generation and large thermal gradients. In addition, the thermo-physical properties of the material depend on the temperature.

2.2.1. Thermal analysis. In Fig. 1 depicts the schematic diagram of laser melting process. As the laser beam irradiated the top surface of the glue, a fraction of laser energy was reflected and the remainder was absorbed. The absorbed laser energy melted the glue, thereby yielding a small-sized molten pool. During the process, besides the consideration of the thermal conduction, the heat losses due to convection and radiation should also be taken into account, in order to make a correct description of the thermal behaviour.

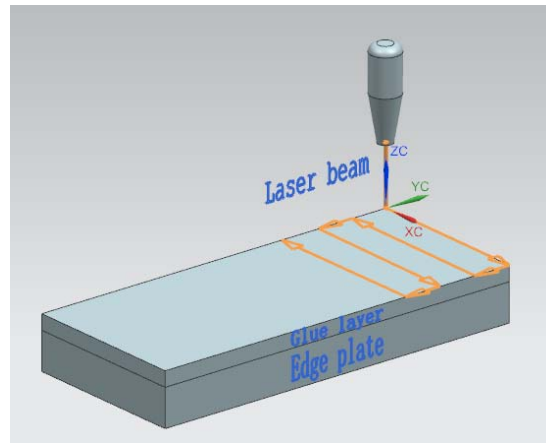


Figure 1. View of laser melting process

The spatial and temporal distribution of the temperature field satisfies the differential equation of 3D heat conduction in a domain D , which can be expressed as [7, 8]:

$$\rho c \frac{\partial T}{\partial t} = Q + \frac{\partial}{\partial x} \left(k \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y} \left(k \frac{\partial T}{\partial y} \right) + \frac{\partial}{\partial z} \left(k \frac{\partial T}{\partial z} \right) \quad (1)$$

Where ρ is the material density (kg/m^3), c is the specific heat capacity (J/kg K), T is temperature (K), t is the interaction on time (s), Q is the heat flux per unit volume (W/m^3) and k is the thermal conductivity (W/m K).

Boundary conditions;

The initial condition of uniform temperature distribution throughout the powder bed prior to laser melting at time $t = 0$ s can be applied as,

$$T(x, y, z, t) |_{t=0} = T_0(x, y, z) \in D \quad (2)$$

Where T_0 is the ambient temperature taken as 20°C (293K).

The natural boundary condition can be expressed as [9]:

$$k \frac{\partial T}{\partial n} - q + q_c + q_r = 0 \quad (x, y, z) \in S \quad (3)$$

Where S represents the surfaces which are attached to impose heat fluxes, convection and radiation, n is the normal vector of surface S , the input heat flux q is presented in the following by Eq. (6'), Q_c is the heat convection and can be defined by:

$$q_c = h(T - T_0) \quad (4)$$

q_r is the heat radiation and can be expressed by:

$$q_r = \sigma \epsilon (T^4 - T_0^4) \quad (5)$$

In Eqs. (4) And (5), h is the coefficient for heat convection, σ is the Stefan–Boltzmann constant, and ϵ is the emissivity

2.2.2. Basic setup of the finite element model. Numerical simulation was performed using the ANSYS Multi-physics finite element package. The finite element model and laser scanning pattern during the selective laser melting process are present in Fig. 2. The laser scan area on the glue edge banding had a length of 22 mm, a width of 22 mm and a thickness of 0.2 mm. The edge banding with the dimensions of 22mm x 22mm x 0.5 mm was taken as the substrate for the glue. Considering the calculation efficiency and the computational precision, the solid 70 hexahedron elements with the fine mesh were used in the edge banding, while a relatively coarse tetrahedron mesh was adopted in the substrate. The three- mensional simulation model was meshed into 17300 elements and 2401 nodes.

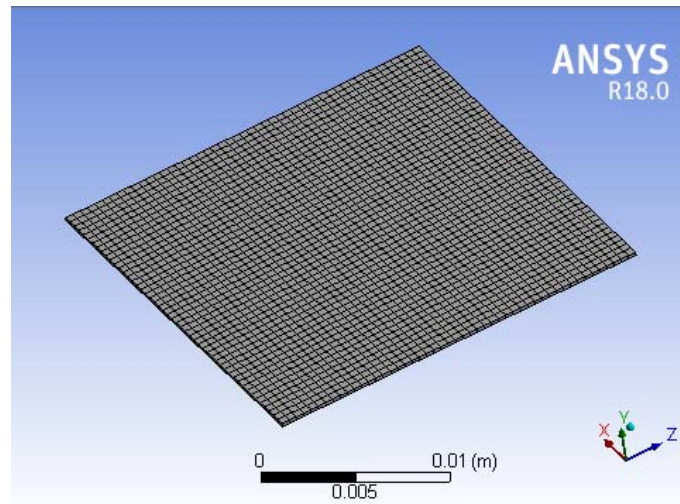


Figure 2. Finite element model

In the present model, some assumptions were made as follows:

- (1) The whole glue was assumed to be a continuous and homogeneous media.
- (2) During the melting process, the thermal physical parameters of the material such as thermal conductivity and specific heat capacity were considered to be temperature - dependent.
- (3) The coefficient of convection between the glue and the environment was assumed to be a constant.
- (4) The moving laser heat source acting on the glue was modelled as the Gaussian distribution of heat flux and was input directly on the surface of the powder layer.

2.2.3. Heat source model. Proper modelling of the heat source is crucial as it controls the thermal load. During the selective laser melting process, the induced fusion of material was usually achieved using a laser beam as a thermal energy source. The distribution of the laser intensity followed nearly a Gaussian relationship, which was mathematically presented as:

$$q = \frac{2AP}{\pi R^2} \exp\left(-\frac{2r^2}{R^2}\right) \quad (6)$$

where P is the laser power, R denotes the effective laser beam radius at which the energy density reduced to its $1/e^2$ at the center of the laser spot, and r is the radial distance from a point on the powder bed surface to the center of the laser spot, and A is laser energy absorptance of a material affected by the wavelength of laser, the surface conditions and the physical properties of the material.

Considering the melting and solidification phenomenon that occurred in the SLM process, the latent heat could not be negligible for the phase change. To define the latent heat, the enthalpy was expressed as a function of temperature:

$$H = \int \rho c dT \quad (7)$$

Where q is the material density, c is the specific heat capacity, and T is the temperature of the molten pool formed in the edge banding.

Fig. 3 shows heat source model, where the power density deposited region is maximum on the top surface along the edge banding, and is minimum at the inner surface. Along the edge banding thickness of the power density distribution region is linearly decreased. Results, presented by Arif (2010), show that varying various laser parameters the above volumetric heat source model has the ability to depict actual heating phenomenon in the heating region.

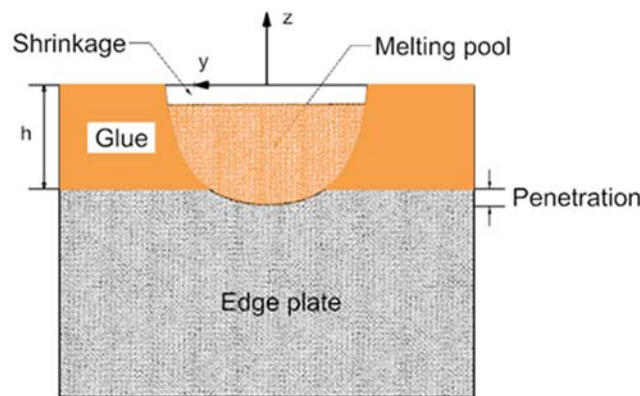


Figure 3. The heat distribution in the volumetric heat input model

3. Results and discussion

3.1. Characteristics of temperature distributions

The temperature distribution in the layer is very much affected by the energy density which is a function of laser power, spot size, scanning speed, hatch spacing and scanning strategy. Additionally, the temperature gradient in the layer is similarly influenced by conductivity of the material underneath the deposited layer being a loose glued, support structure or a solid substrate. The temperature distribution in the glued and consolidated layers changes rapidly with time and space.

Fig. 4. Shows the temperature at the beginning of the laser scanning, from which, the very high temperature gradients in the vicinity of the laser spot on the glued can be clearly seen due to an applied Gaussian heat source. The temperature of the glue particles is elevated rapidly under the action of absorbed energy, causing a molten pool when the temperature exceeds the melting temperature and heat affected zones in the surrounding loose glue. Note that the energy intensity of the source might also be high enough to cause the material to evaporate [10].

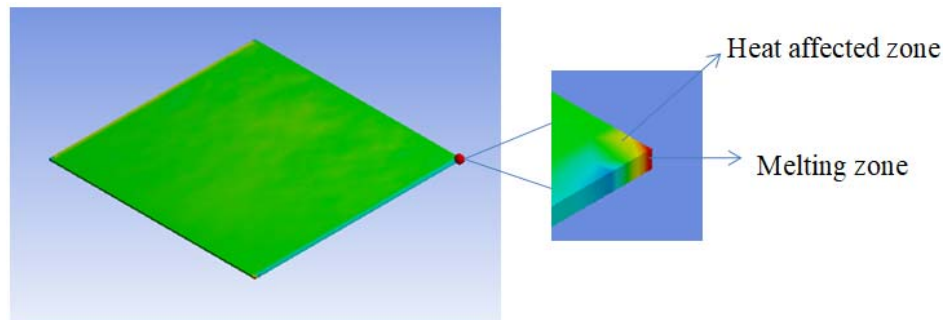


Figure 4. at the beginning of first track scan

Fig.5. shows the temperature distribution process when generating temperature of the laser beam power $P = 3000\text{W}$ and a scan speed $V = 100\text{mm/s}$ on the surface of the material, The results show that colors can be used: Red is the highest temperature and the temperature is decreasing in turn according to the yellow, green, skyblue and blue is at ambient temperature 20°C .

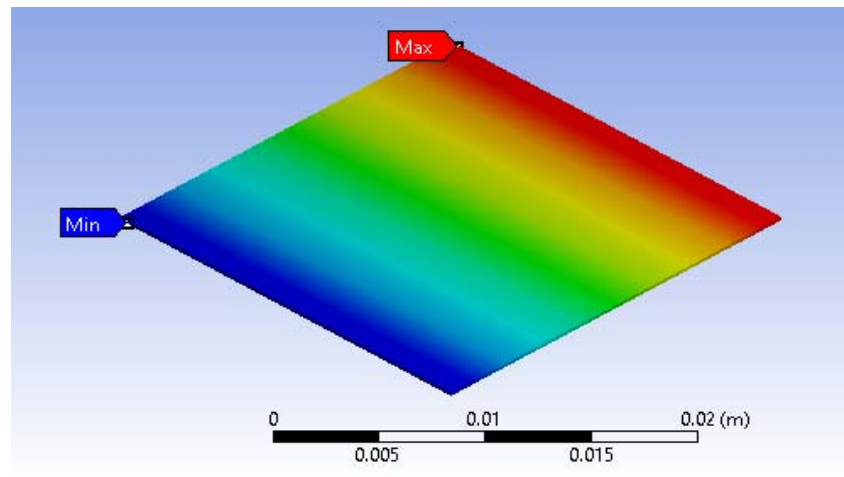


Figure 5. Steady state temperature distribution during layer melting

3.2. The results of simulated temperature distribution

After establishing the model then setting material properties with parameters (isotropic thermal conductivity $= 1, 7 \text{ W/m/K}$) and constraint conditions in the model, the results are as follows;

Model progress temperature and level: 100°C , 105°C , 110°C , 115°C , 120°C , 125°C Results the temperature distribution of treatment was reflected in the shows Fig. 6. (a, b, c, d, e, f).

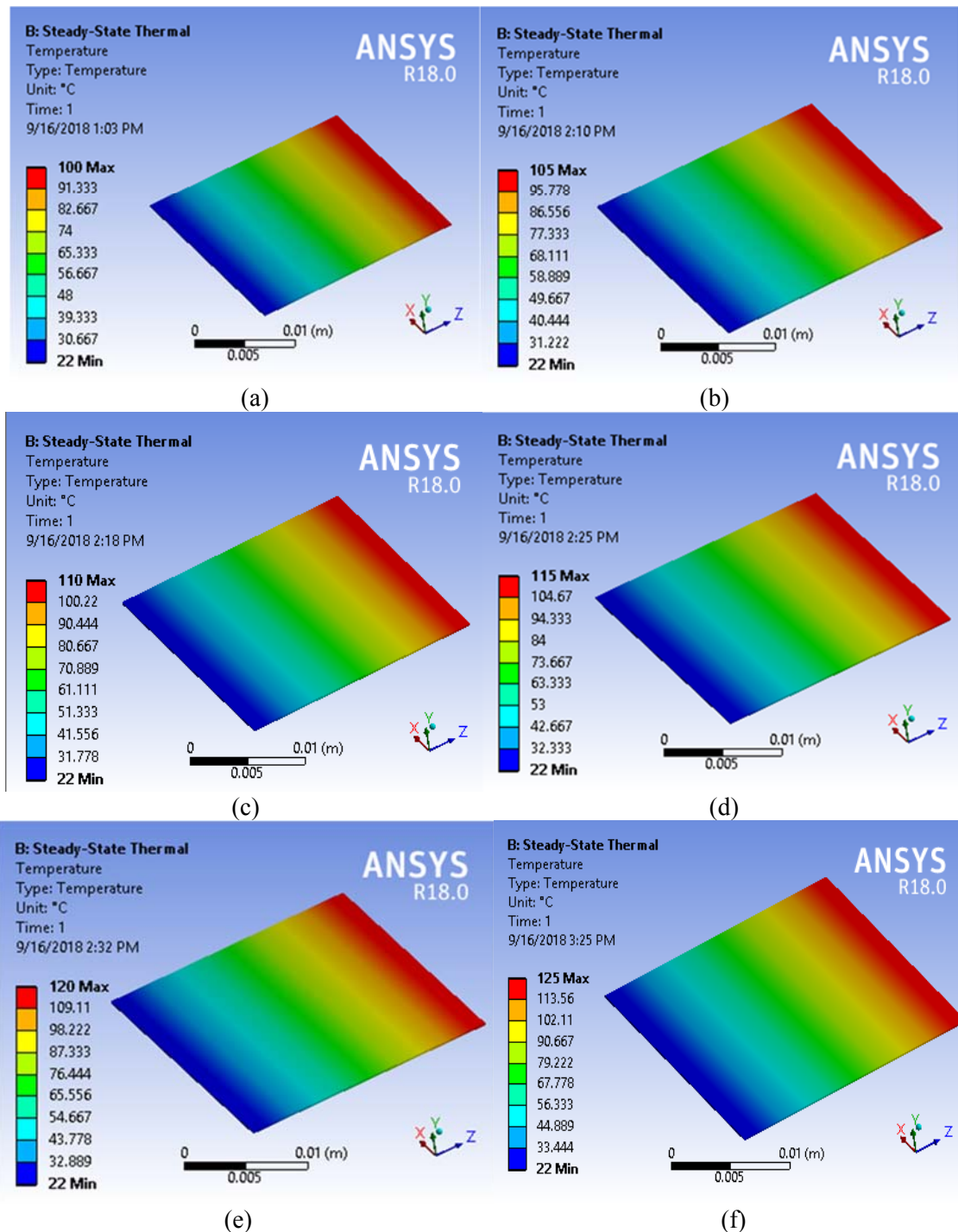
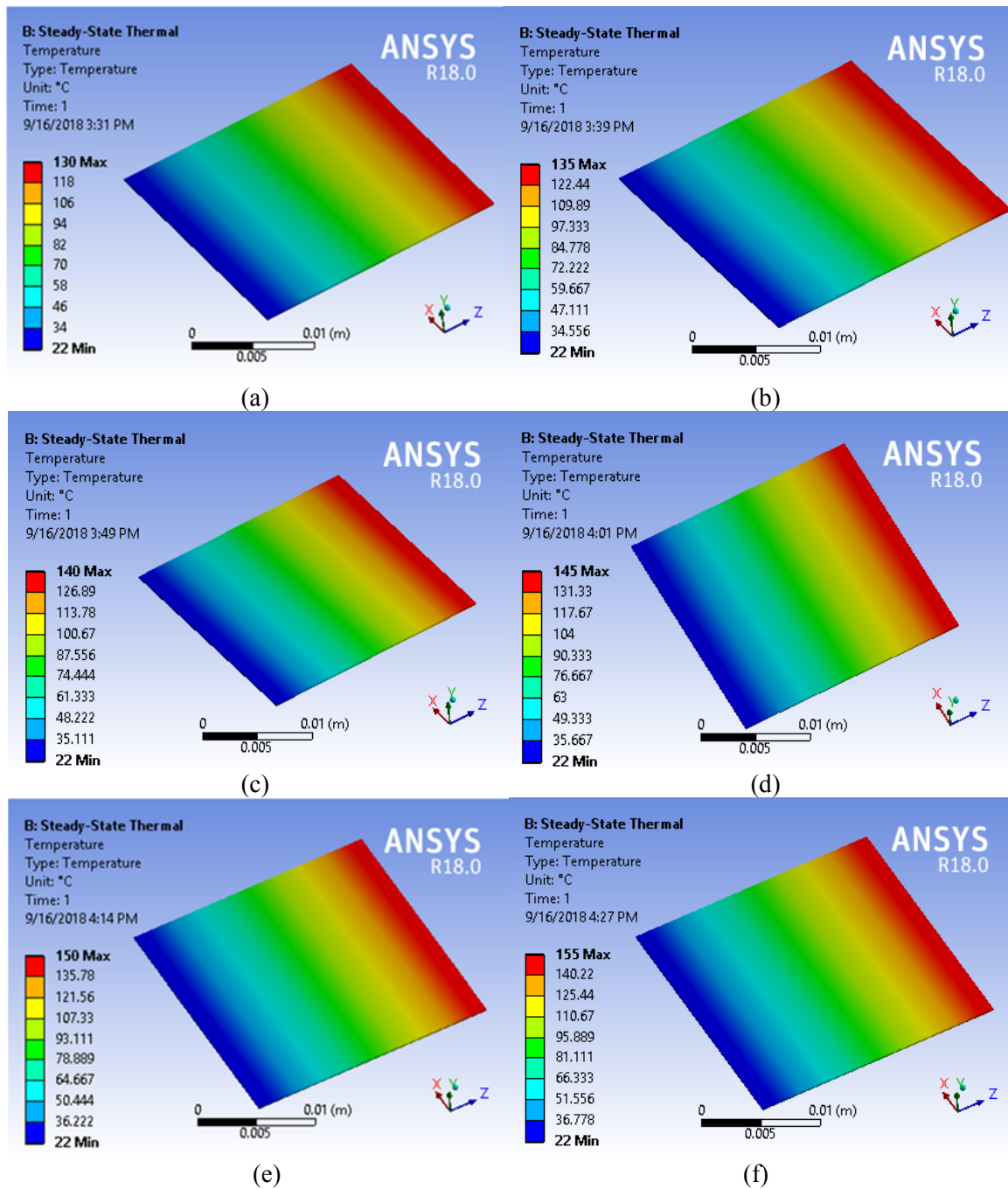


Figure 6. Steady state temperature distribution: (a) temperature is 100°C, (b) temperature is 105°C, (c) temperature is 110°C, temperature is 120°C, (d) temperature is 125°C

Model progress temperature and level: 130°C, 135°C, 140°C, 145°C, 150°C, 155°C, 160°C. Results the temperature distribution of treatment was reflected in the shows Fig. 7. (a, b, c, d, e, f, g).



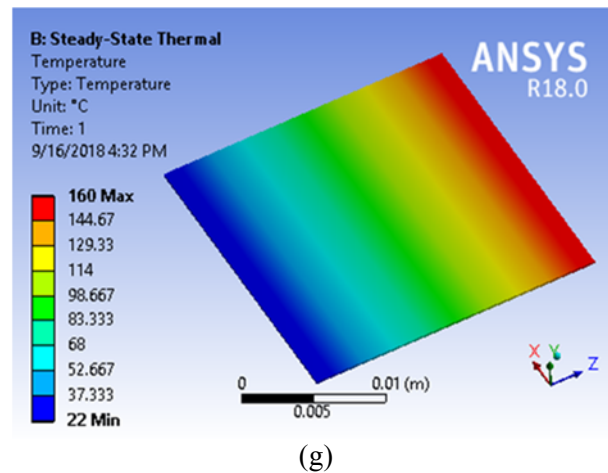


Figure 7. Steady state temperature distribution: (a) temperature is 130°C, (b) temperature is 135°C, (c) temperature is 140°C, (d) temperature is 145°C, (e) temperature is 150°C, (f) temperature is 155°C, (g) temperature is 160°C.

3.3. Heat flux

Heat flux dependant temperature, as show in Table 1. The experiment is conducted using an Ansys Workbench 18.0. The results show that the collected temperature at 135°C is 8731 (W/m^2), Value is the most suitable glue melting. Under these operating conditions, the penetration and width of the glue melting predicted by the modeling show a good agreement with the experimental results.

Table 1. Heat flux dependant temperature

Temperature (°C)	100	105	120	125	130	135	140	145	150	155	160
Total heat flux (W/m^2)	6027	6413	6800	7959	8345	8731.8	9118	9504	9890	10277	10664
Thermal conductivity (w/m/k)	1,7										

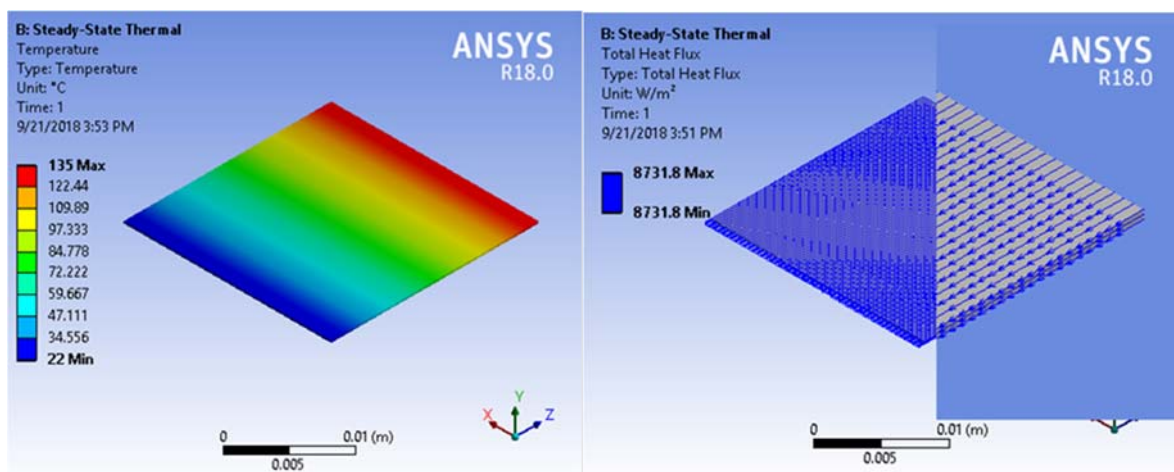


Figure 8. Steady state temperature distribution at total Heat flux at temperature is 135°C

4. Conclusion

1) Our study showcased a novel approach in investigation and forecasting changes in temperature field on surface of sealing edges in laser sealing machine, using ANSYS software.

2) Data illustrating temperature, thermal flows and thermal distribution in adhesives upon absorbance of energy from laser beam was generated based on modelling.

3) The presented data can be applied in designing and manufacturing sealing edges and laser beam control panel matching in-situ production, which eventually improve productivity and quality of sealing surfaces with lower quality control cost.

4) Towards reducing time and cost intensive experimental approach, the illustrated results successfully proved that temperature fields on sealing edges surface in laser sealing machines can be modelled at ease, with high accuracy, by ANSYS software.

References

- [1] V. Ye, X. Luo, Y. Zhang, Application of Laser Edge Banding in Production of Panel-type Furniture, China Wood-Based Panels (2017).
- [2] B.S. Yilbas, A.F.M Arif, B.J.A. Aleem, Laser bending of AISI 304 steel sheets: Thermal stress analysis, Optics & Laser Technology. 44(2) (2012) 303 - 309.
- [3] X. Tian, G. Peng, M. Yan M, Process prediction of selective laser sintering based on heat transfer analysis for polyamide composite powders, International Journal of Heat & Mass Transfer. 120 (2018).
- [4] A. F. M. Arif, A.S. Al-Omari, B.S. Yilbas. Thermal stress analysis of spiral laser-welded tube, Journal of Materials Processing Tech. 211(4) (2011) 675 - 687.
- [5] E. Jie. Laser Seal Technology, Furniture. (2010).
- [6] J. Wang, L.I Zi-Liang, Q.I. Dong-Jie, Thermal Analysis of ABS Material Based on the Birth and Death Element Method of ANSYS, Synthetic Materials Aging & Application. (2017).
- [7] Y. Li, D. Gu. Parametric analysis of thermal behavior during selective laser melting additive manufacturing of aluminum alloy powder, Materials & Design. 63(2) (2014) 856-867.
- [8] A. Hussein, L. Hao, C. Yan C, Finite element simulation of the temperature and stress fields in single layers built without-support in selective laser melting, Materials & Design, 52 (24) (2013) 638 - 647.
- [9] K. Dai, L. Shaw, Finite element analysis of the effect of volume shrinkage during laser densification, Acta Materialia. 53(18) (2005) 4743 - 4754.
- [10] L. Dong, A. Makradi, S. Ahzi, Three-dimensional transient finite element analysis of the selective laser sintering process, Journal of Materials Processing Tech. 209 (2) (2009) 700 - 706.