FINITE ELEMENT SIMULATION OF LASER WELDING OF TAILOR WELDED BLANK ON DIFFERENT MATERIAL

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DECLARATION

This declaration is to clarify that all the submitted contents of this project are original in its figure, excluding those, which have been admitted specifically in the references. All contents of this project have been submitted as a part of partial fulfillment of Bachelor of Manufacturing Engineering with Management in Mechanical Engineering. I hereby declare that this is my original work excluded for the references document and summaries that have been acknowledge. It is not submitted to any other organization for any other purpose.

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NOMENCLATURE/SYMBOLS

Notation/Symbol	Definition	Units (SI)
TWB	Tailor Welded Blank	
SS	Stainless Steel	
Al	Aluminium	
FE	Ferrum (Iron)	
Ti	Titanium	
Cu	Copper	
FEM	Finite Element Method	
HAZ	Heat Affected Zone	
Di	Initial Difference of Maximum and Minimum Displacement	mm
Df	Final Difference of Maximum and Minimum Displacement	mm
θ_i	Initial Deformed Bend Angle	^{o}
θ_f	Final Deformed Bend Angle	^{o}
l	Length of blank	mm
K	Springback/ K-Factor	

Abstrak

Industri automotif biasanya menghasilkan bahagian-bahagian produk yang lebih ringan daripada kepingan logam yang dikimpal dengan khusus (TWB) manakala TWB mengandungi sekurang-kurangnya dua bahan kepingan logam yang berbeza supaya mempunyai kelebihan terutamnya mengurangkan berat. Lazimnya, TWB digabungkan dengan mengguna kimpalan berasaskan laser untuk menghasilkan manik yang kecil, penyelewengan yang rendah serta tegasan dan terikan lebih. Banyak kajian hanya memberikan maklumat tentang keupayaan kimpalan dan rupa kecacatan TWB. Walaubagaimanapun, keupayaan pembentukan kepingan logam selepas dikimpalkan seperti ramalan pegas pengembali yang tepat masih sulit. Melalui kajian ini, analisis kaedah unsur terhingga (FEA) dijalankan bagi kimpalam laser dengan menggunakan analisis pindahan haba yang tidak linear dalam ANSYS pakej. Projek ini bertumpukan kepada simulasi kimpalan laser dan juga kesan pegas pengembali pada TWB. Kadar suhu daripada kimpalan laser didapati boleh dijejaskan oleh tenaga laser. Keputusan kadar suhu kimpalan yang tepat bergantung kepada jenis bahan didapati melalui simulasi konduksi kimpalan laser dalam projek ini. Tambahan pula, kesan pegah pengembali TWB dapat diukurkan melalui pembengkok bujuran yang berbentuk V. Perubahan bentuk mengikuti keplastikan bahan dan pegah pengmbali TWB telah diperolehi dengan sepenuhnya serta dikajikan melalui analisis struktur statik dalam ANSYS pakej.

Kata kunci: kimpalan berasakan laser, kaedah unsur terhingga, kepingan logam dikimpal dengan sempurna, pegah pengembali

Abstract

Automotive companies now prefer forming the parts from tailor-welded blanks (TWB) for lighter weight parts. The TWB consists of more than two sheets with different material mainly due to advantages in reducing weight. TWB is typically welded using laser since it produces a narrow weld bead, lower distortion, residual stress and strain. Many studies have presented a wide range of information about the weldability and failure patterns of TWB. However, accurate prediction of formability of blank after welding such as springback remains elusive. In this study, a three-dimensional finite element analysis (FEA) was carried out to perform the laser welding using non-linear heat transfer analysis with ANSYS workbench package. This project focuses on the laser welding simulation and the springback effect observed on the TWB. It found that the affected temperature range of laser welding is depends on the laser power. The appropriate welding temperature range based on the material properties resulted with conduction mode laser power is simulated in this paper. Furthermore, springback effect of blank was measured through longitudinal V-bending process. The plasticity deformation and springback of the blank was fully obtained and studied through static structural analysis used in ANSYS workbench.

Keywords: laser welding, finite element, tailor welded blank, springback

1.0 Introduction

The automotive industry faces two major challenges nowadays which are emissions reduction and improvement of safety standards [1]. Reducing vehicle weight by using lighter or thinner materials is a useful way to reduce fuel consumption. Thus, tailored-welded blank offers these advantages in reducing vehicle weight. A tailor-welded blank (TWB) is a composed blank by at least two different base metals sheet [2]. Typically, the different base metals have difference in thickness, coatings, material properties are tailored to specific requirements as greater strength. Both different blank sheets joint up by abundant type of welding method. For instance, the TWB could comprised of steel for the blank which has a higher strength of material properties and other lower weight and strength for the other portion of the welded blank. However, the problem is the procedure and the method used suitable for these combinations.

One of the common welding methods for TWB is laser welding. Laser welding is a high-power density welding process having a focus diameter of 0.2 to 1.0mm, resulting in a narrow weld bead [3]. Hence it results in lower distortion, residual stress and strain compared to the conventional welding [4].In manufacturing automotive parts, the welded blank will undergoes metal forming operation such as deep drawing, stamping, bending or other metal forming processes. Bending is a frequently encountered process for sheet metal forming. Generally, quality of bend workpiece depends on a geometrical defect namely as springback. Springback is a phenomenon where the metal strip tends unbends itself after a forming operation such as bending process. One of the methods to study the springback is using V-bending. In this case, quality of the laser welded blank is critical for a successful bending operation and this may affect springback pattern.

It is very costly and time consuming to study the laser welding and bending operation. Thus, the performance of the tailor welded blank and formed part is studied utilizing the finite element method to reduce unnecessary trial and error during the sheet metal forming operation in industry. In addition, the process is quite complex and challenging. However, there is still many challenges remain in FE analysis of laser welding techniques as the laser welding comprise with many interrelated mechanisms and metallurgical processes. Thus, accurate and reliable FE modelling of laser welding is still a very difficult task as the behaviour of laser welding joints is influenced by various factors and their combinations. Thus, this paper will study on the FE simulation of springback on TWB by V-bending process to fill the deficiency of Danyi's experimental result [5]. As a conclusion, present research aims to investigate the simulation of entire V-bending and springback compensation in TWB.

2.0 Related Works

In recent development trend, tailor welded blank (TWB) become important in automotive component manufacture. In typical production, the joining welding process of the blanks is usually done by laser welding because it produces a very narrow and precise weld seam and small heat affected zone (HAZ) [6]. Despite the laser welding is common method used to weld up two distinct material, there is a wide range of research activity has been undertaken in laser welding structure. From a past research America Welding Society explains how the weld zone is form through the laser beam [7]. The difference between conduction and the keyhole/penetration laser welding as in Figure 1 [8]. They found that the penetration laser welding only occurs when the laser source intensity is higher than 10000000 W/cm². In this work, a conduction laser welding was studied due to the laser radiation would not penetrate the welded blank and HAZ is neglected. HAZ is a zone created by transient thermal welding of TWB which has different mechanical properties from the both base materials [2]. They are between the interface of the deposited weld metal and extending into the base metal far enough that any phase change occurs.

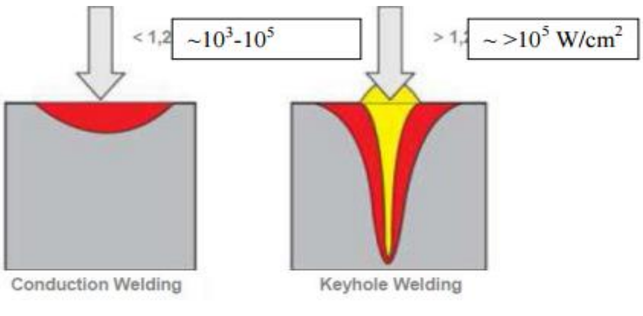


Figure 1: Comparison of conduction mode and keyhole mode welding

According to laser welding mechanisms, joining of two distinct material with laser welding is possible without melting of material. They proved that TWB of high-alloy stainless steel cannot be welded to low-alloy ferrite steel without the addition of a filler material [9]. With this concern, joining of the aluminium-steel blank without a filler material in a butt joint configuration by assuming that laser parameters should choose temperatures at the weld area remained below vaporization temperature of zinc but above melting point of aluminium [10]. A 3D model was developed to simulate the laser welding process and predict the final distortion of the butt joint blank [11]. Similarly, FE model was developed to simulate the laser welding process of butt joints to predict the temperature distribution and weld bead geometry [12]. They concluded that the 3D conical Gaussian heat distribution model obtain better results than Goldak's heat source model in laser welding. Microstructure and mechanical properties change in laser welding of Ti6Al4V with a multi physics prediction model was analysed [13].

A numerical model for stamping and compared strain distribution of a single blank with TWB was developed in [14]. They found that the presence of weld leads to irregularity in the strain scheme of TBW. However, more accurate description of material mechanical characteristics in the heat affected zones (HAZ) should be studied to allow further improvement. In the HAZ, martensite microstructure of material grew from the single blank area toward the melted zone. HAZ should be neglected in [2] as there is only little effect on springback. Previous studies on TWBs mainly focused on the microstructure, mechanical properties, wrinkling behaviour, FLD, drawing ratio and formability of these materials quite rare and only few studies reported on the springback compensation of TWBs. Springback should not be neglected because many researchers had study about the springback of blank but not on the TWB. FEM analysis had been used to conduct the creep test and investigate to the springbacks on uniform thickness aluminium plate [15]. Higher friction coefficient leads to higher springback and thicker blank will exhibit less spring back due to higher stiffness of blank [16]. The result may not satisfy when it is a TWB so in recent year, experiment of V bending on TWB conducted with different thickness found that springback of the thinner sheets is bigger when the bending radius is the same [5]. Nevertheless, there is some lack of prediction skill of FE simulation in this experiment result to analyse the springback effect in V bending of TWB.

3.0 Methodology

For the solution, a thermo-elasto-plastic analysis associated with metallurgical transformation was performed using finite element method. Basically, the solution will be generated in two steps. First the finite element simulation of laser welding of TWB is performed through the thermal transient analysis with metallurgical transformation. Second step is static structural analysis used to study springback effect through the deformation of TWB in V-bending. Therefore, this section is separated into two sub-sections which are thermal transient analysis and static structural analysis. As shown in the flow chart of Figure 2 the following steps were taken prior to the static structural analysis.

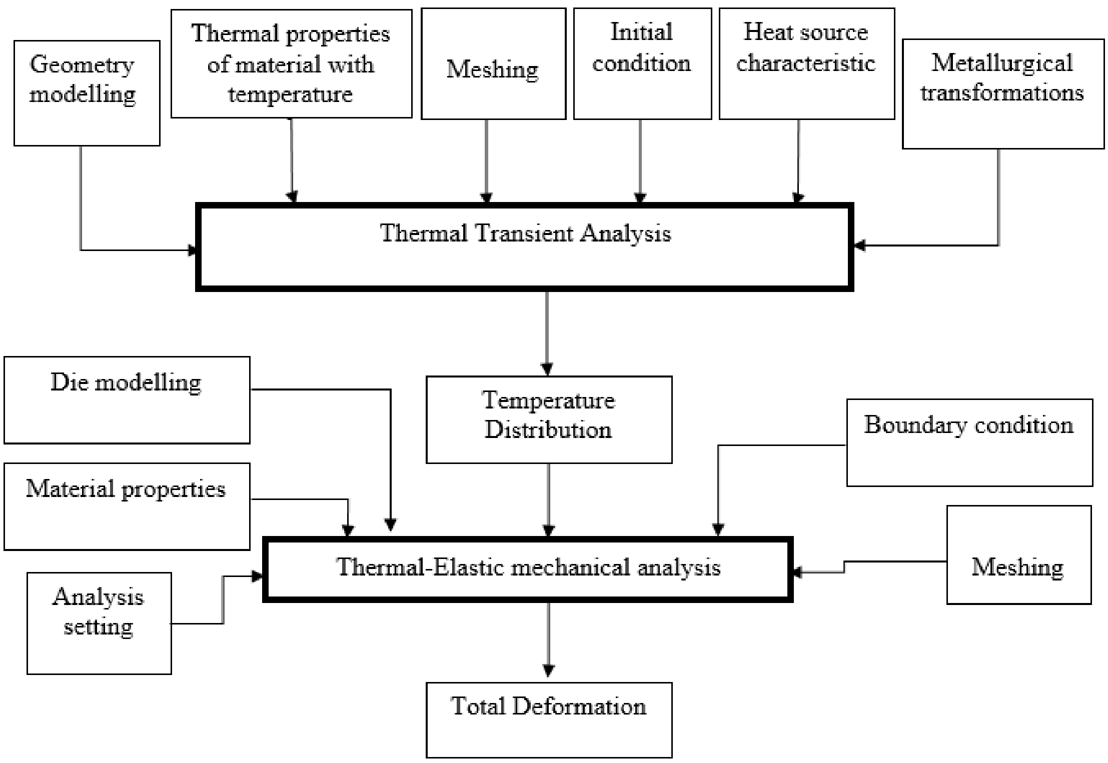


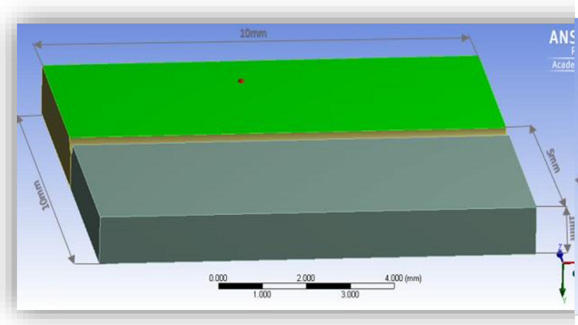
Figure 2: Flow chart of laser welding simulation procedure

3.1 Thermal Transient Analysis

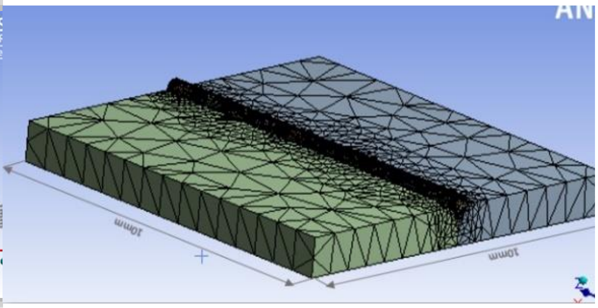
A few of three-dimensional finite element model was developed to simulate the laser welding process for the butt joint of two different blank using the commercial ANSYS workbench. Besides, simulation of laser welding also developed to the model of these set combination of blank with different thickness.

3.1.1 Geometry Modelling

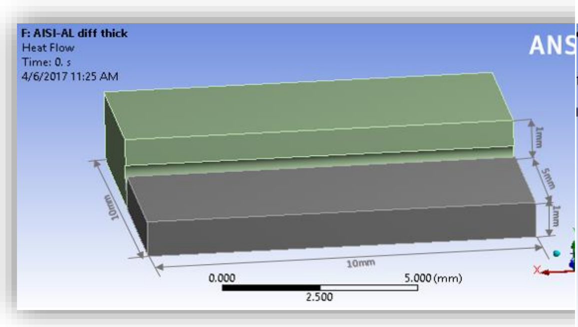
A 3D solid geometry of tailor welded blank was modelled by using Solid Work and converted into compatible IGES file then import to ANSYS Workbench. Each of the single thin blank having a length x width x height rectangular size of 10mm x 5mm x 1mm combined to form a 10mm x 10mm x 1mm TWB as shown in Figure 3 (a) and (b). Figure 3(c) and (d) shows the thinner blank having a size of 10mm x 5mm x 1mm and the thicker or cheaper blank is 10mm x 5mm x 2mm.



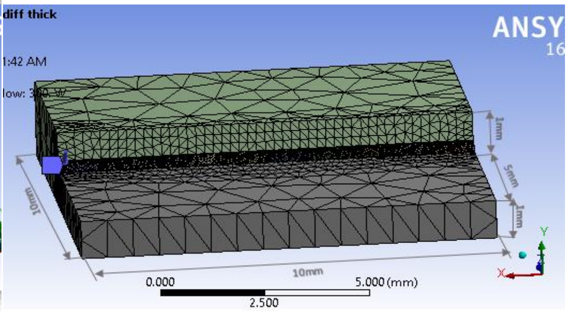
(a) Geometry model of TWB without mesh



(b) Geometry model of TWB with mesh



(c) Geometry model of TWB without mesh



(d) Geometry model of TWB with mesh

Figure 3: Measurement configuration of TWB for same thickness combination in (a)and (b), and different thickness combination in (c) and (d).

3.1.2 Material Properties

As the temperature dependent material was used, the material properties of each of the blank inserted to the engineering data in ANSYS workbench. Content and thermal properties value of aluminium alloy 6016 T6, AISI 304 stainless steel, Titanium alloy Ti-6-4 and pure copper Cu is tabulated in Table 1 and Table 2.

Table 1: Atomic content of different blank in wt% [17], [18]

Al 6016-T6	**Al**	**Cr**	**Cu**	**Fe**	**Mg**	**Mn**	**Si**	**Ti**	**Zn**	**Other**
	95.8-98.6	0.04-0.35	0.15-0.4	Max 0.7	0.8-.1.2	Max 0.15	0.4-0.8	Max 0.15	Max 0.25	Max 0.15
AISI 304 SS	**Fe**	**Cr**	**C**	**Mn**	**Ni**	**P**	**S**	**Si**		
	66.345-74	18-20	Max 0.08	Max 2	8-10.5	Max 0.045	Max 0.03	Max 1		
Ti – 6Al-4V	**Ti**	**Al**	**V**	**Fe**	**O**					
	90	6	4	Max 0.25	Max 0.2					
Pure Cu	**Cu**									
	100									

Table 2: Material properties of different blank [18]

	Thermal Conductivity (W/mK)	**Specific Heat Capacity (J/kgK)**	**Density (g/cm^3)**	**Tensile Strength (MPa)**	**Yield Strength (MPa)**	**Young Modulus (GPa)**
Al 6016-T6	167	896	2.71	310	276	71
AISI 304 SS	16.2	500	8.00	505	215	193
Ti -6Al-4V	6.7	526	4.43	950	880	96
Pure Cu	388	385	8.89	210	33.3	110

3.1.3 Meshing

In order to get a simulation result with higher accuracy, refinement meshing level of 3 was generated along the intermediate weldment area is far most finer than the blank area as seen in the Figure 3 (b) and (d). Therefore, the overall mesh size of blank contains 70918 of nodes and 34721 of elements in same thickness whereas 37733 elements and 67913 nodes in different thickness.

3.1.4 Initial Condition

The initial condition was applied in the temperature of the environment which is 30℃. Laser heat is transferred to the metal by conduction and convection. Heat loss by free convection follows Newton's law, where the coefficient of convection was assumed to vary with temperature and orientation of boundary. So, an optimal coefficient of convection with 0.15 $W/mm^2 \, ^{o}C$ is applied to the weldment area.

3.1.5 Heat Source Characteristic

In order to simulate the heat distribution and flow in the welding direction, the laser beam is modelled as a three-dimensional moving heat source, so ten steps in laser moving heat source specified with 300W laser power. In the laser welding of TWB, cooling and solidification of TWB is fast in at most 2 seconds. So, the ending time for one step is set to be one second.

3.1.6 Solver Output

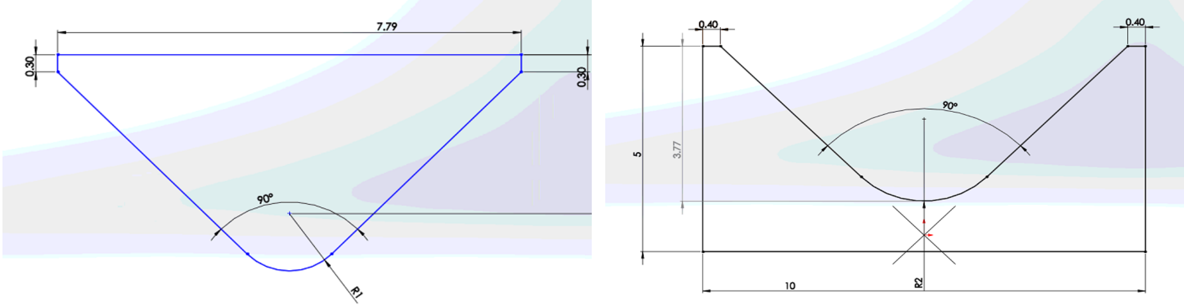
The temperature distribution on the tailor welded blank is simulated and obtained as in a smooth contour result. Maximum and minimum temperature probe displayed to annotate the crucial area on the blank during laser welding process.

3.2 Static Structural Analysis

For determination of the metal combination and thickness influence on springback phenomenon, the simulations have been done under the following conditions.

3.2.1 Die Modelling

Bend radius of lower die must be equal to the summation of 1mm bend radius of upper die and 1mm thickness of TWB [19]. In this case, bend angle of 45° is simulated as measurement of bending die set shown in Figure 4.



(a) (b)

Figure 4: Measurement of (a) upper die and (b) lower die

3.2.2 Material Properties

Non-linear material properties of TWB inserted as in the section 3.1.2. In addition, die set were made up of the common Tool Steel UNS T30102. General material properties of tool steel tabulated in Table 3.

Table 3: Material properties of tool steel [18]

Density (g/cm³)	Tensile Strength (MPa)	Yield Strength (MPa)	Young Modulus (GPa)
7.86	460	250	203

3.2.3 Boundary Condition

Boundary condition is crucial in order to prevent any abrupt changes in geometry in order to achieve convergence while solving elements. Therefore, a frictional contact with only 0.19 coefficient between the die and blank is applied with 0.1 normal stiffness matrix to prevent nonlinear buckling occurrences in which the structure either collapse or snap through another structure.

3.2.4 Meshing

In static non-linear analysis, mesh element control plays a very important role in mesh convergence of solver output. Other than the refinement, body sizing with only 0.5mm of the elements size is used to obtain the most accurate result in bending. Tetrahedral element type is used for the TWB. For the same thickness blank, tetrahedral mesh has of 31811 nodes and 16642 elements with less degrees of freedom are solved in this static structural analysis. For different thickness blank, 67913 nodes and 37733 elements is generated.

3.2.5 Analysis Setting

The third crucial consideration in non-linear analysis is the number of time step subjected. Ten steps are inserted with one second end time. Besides, the large deflection is experienced in this load applied situation. Load applied through the tabular displacement setting of the die. Maximum 4.5mm as the height of die valley was input. Stabilization also must be applied with a constant energy factor to reduce the damping force.

3.2.6 Solver Output

Total and directional elastic deformation of TWB is generated. Springback behaviour is observed through the deformation graph and data. Deformation data was export to an excel file to calculate the bend angle θ_f.

3.3 Springback Analysis

In V-bending simulation, the dies are generally assumed to be rigid bodies that do not deform. However, the deformed blank is three-dimensional and can expected to return its original shape after undergoing bending due to the elastic recovery issue on non-linear metal blank. After the die released, the residual stress will cause the TWB to spring back slightly. According to the minimum and maximum displacement region of TWB as shown in Figure 5Figure 5: Deformation of TWB , difference between the minimum and maximum point, D was calculated against time. The difference should be increase during bending process until completely bent and slightly decrease in distance as the springback effect occur. Springback factor was then calculated by using the formulae (1) and (2), mapping with trigonometry method in Figure 6. Springback factor indicate the amount of springback through ratio of initial angle to final angle without consider the material factor.

$$\frac{\sin 90^\circ}{l} = \frac{\sin \theta_i}{D_i} = \frac{\sin \theta_f}{D_f} \tag{1}$$

$$K = \frac{\theta_i}{\theta_f} \tag{2}$$

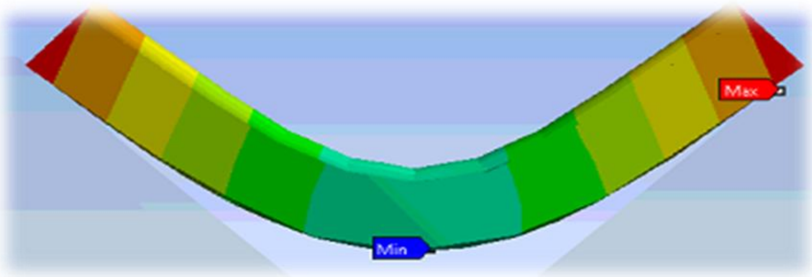


Figure 5: Deformation of TWB

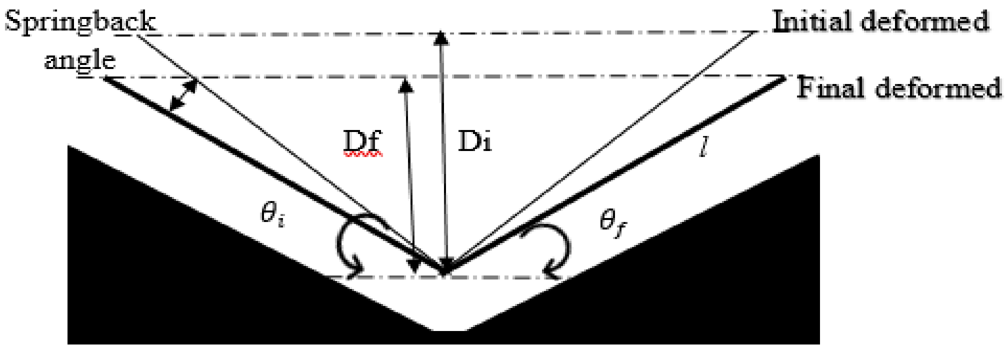


Figure 6: Section line of TWB before and after bending

4.0 Results and Discussion

Temperature result from laser welding simulation of three sets dissimilar material combination with same thickness and different thickness are discussed. Meanwhile, validation of the laser model and convergence test was carried out to ensure optimal laser welding model is developed. Furthermore, bending deformation of each TWB with the plotted graph and data along the time step helped in getting springback angle which then discussed by comparison.

4.1 Effect of Conduction Mode Laser Welding

Along the 10mm of TWB, it was separated into ten patches in longitudinal way to show the moving heat source of laser. Using the geometry, mesh and heat source distribution model described above and the geometrical parameters of the conduction mode weld pool were observed by FE analysis as in Figure 7 viewed from the side with new section plane. Obviously that this model forms a narrow weld bead with a less than 500W of laser power does not create a penetration keyhole and heat affected zone is just only small area that occur at the weld bead. This is because the power density of laser is insufficient enough to penetrate the blank and forming keyhole. Thus, the keyhole mode is not considered in current project and the HAZ is neglected in order to further study the springback effect.

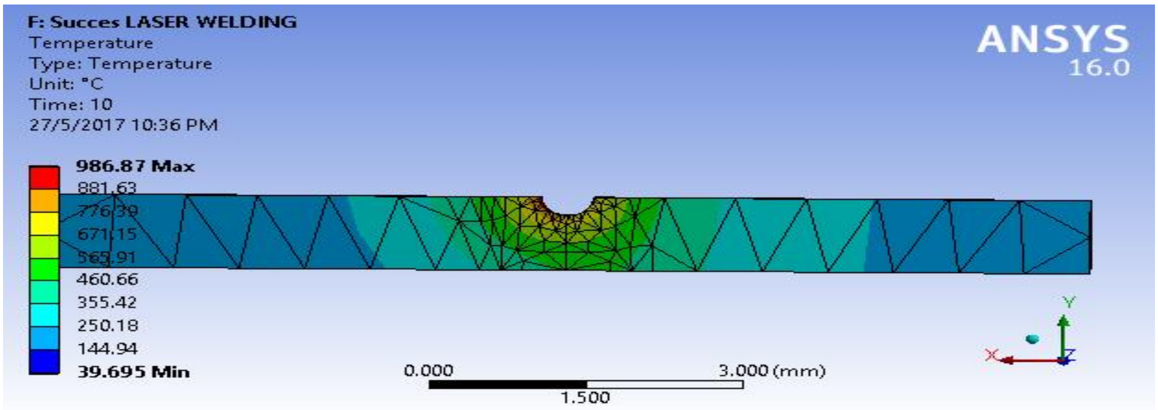
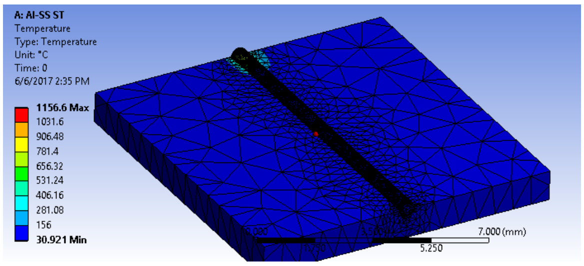


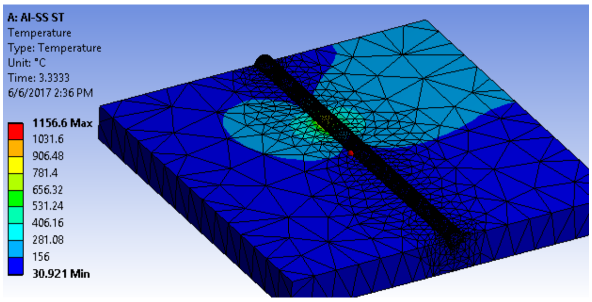
Figure 7: Section view of different material combination TWB with same thickness

4.2 Relationship of Material Properties to Temperature Distribution Region

First in the Al-SS combination, know that the AA 6016-T6 (known as Al after this) having a low melting point, 652º C compared to the AISI-403 (known as SS after this) which is 1450º C, therefore laser power that able to produce a heat temperature is slightly lower than the melting point of Al, which in turn to melt the SS by thermal conduction. From the observation of temperature distribution in Figure 8, the weld bead is formed by slightly melt the Al portion which is the right side in the intermediate area. Narrow and less depth portion of melted Al having the phase transformation together with the SS as it turns to heated up thermally by conduction mode. Thus, the intermediate weld zone is the highest temperature region which would not melt both Al and SS but in the welding range [20]. Due to the microstructure and phase transformation in the intermediate weld region, dual phase diagram must be considered in this modal in order to ensure the optimal input power and welding temperature range to prevent the single material melted during welding. Moreover, Al having a higher thermal conductivity compared to SS. Therefore, Al have higher cooling rate than SS. This statement can be observed through the simulation of laser welding in Figure 8. It shows clearly the large temperature gradients at the area near to the laser beam and the cooling of the TWB away from the heat source. Since Al heat and cold faster than SS as the laser moving heat source applied and leaved respectively, Figure 8 shows the cooling phase region (low temperature region with blue contour colour) in Al is larger than SS blank. Red colour contour region showing the area having the maximum temperature during laser welding as it covered in appropriate temperature range for Al-SS combination. Second in the Ti-Al combination, Ti-6-4 (known as Ti) on the left side of blank in Figure 9(a) has even higher 1660ºC melting point. The same theory is used to describe the temperature profile in Figure 9. The third combination which involved copper (Cu) and SS, Cu in the right side of the blank of Figure 9(b) has the higher thermal conductivity and lower melting point.



(a)



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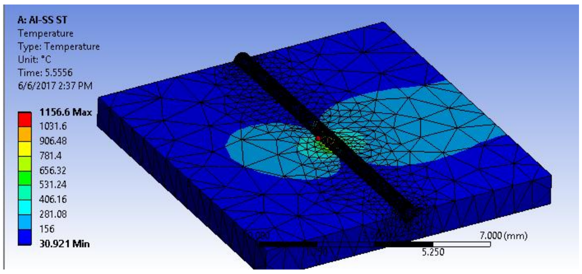
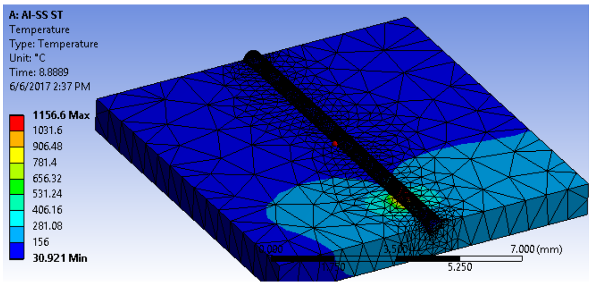
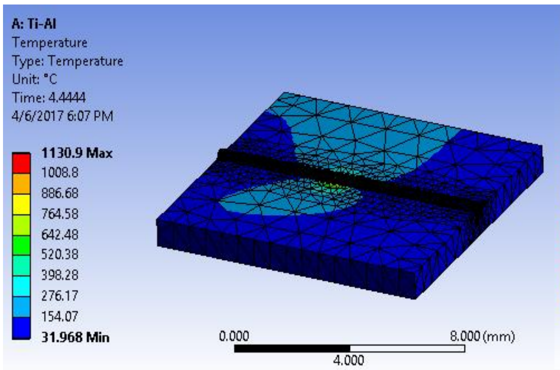


(c)

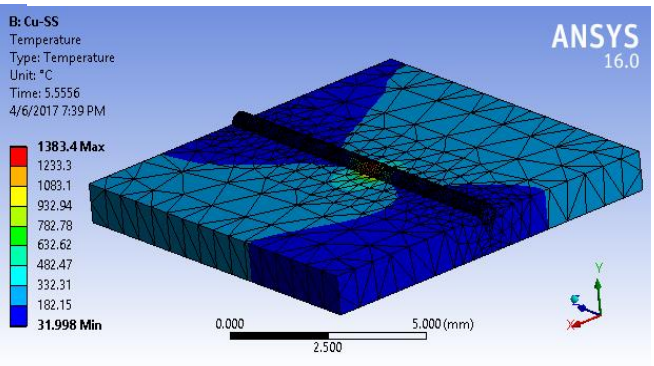


(d)

Figure 8: Temperature distribution of Al-SS TWB at four different time steps, (a)0s, (b)3.3s, (c)5.6s and (d)8.9s



(a) Ti-Al combination

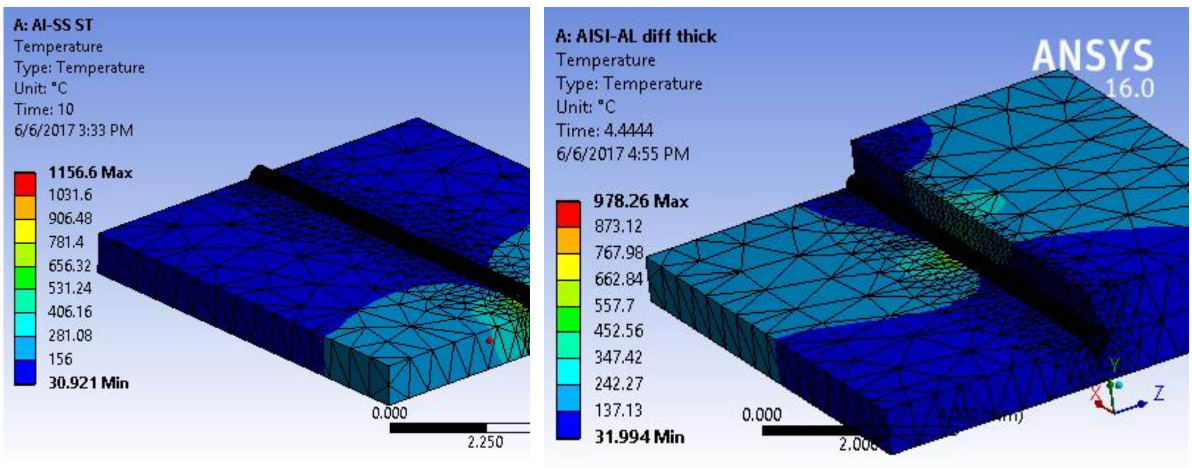


(b) SS-Cu combination

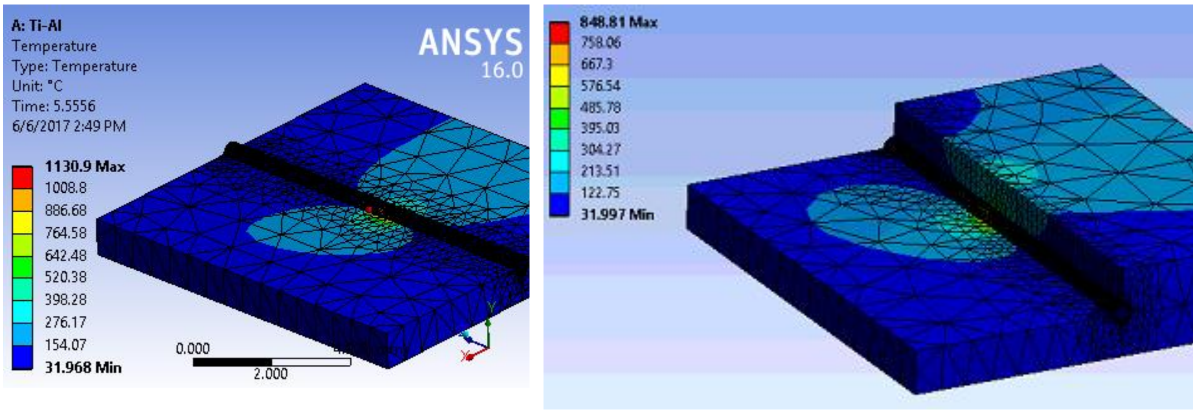
Figure 9: Temperature distribution of TWB.

4.3 Relationship of Material Properties and Thickness to Temperature Distribution Region

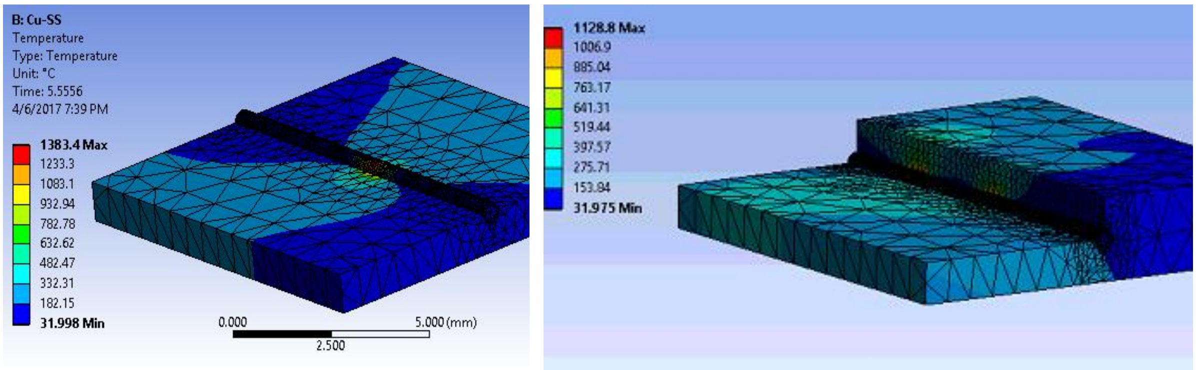
As in the Figure 10, result of temperature profile on the dissimilar material and thickness TWB is actually same as the uniform thickness TWB. The only difference is the welded portion of TWB in different thickness much larger than the same thickness TWB. As compared to the Figure 7, penetration level is higher in different thickness by observing the contour colour of the blank through side view in Figure 11. Moreover, temperature distribution is almost the same along the weld line in both same and different thickness TWB with the same input setting. However, maximum temperature of the welded zone would be smaller in TWB of different thickness. This is because a lower maximum temperature reached while the thicker blank able to conduct heat in faster rate. More heat conduction occurs to melt the thinner blank as compared to the heat directly come from laser used to slightly melt the thicker blank especially Al. Usually the laser heat having a higher rate and temperature than the conduction heat transfer. Therefore, heat conduction involved more in the different material combination and thickness leads to a smaller maximum temperature reached.



(a) Al-SS TWB



(b) Ti-Al TWB



(c) Cu-SS TWB

Figure 10: Comparison of temperature distribution in TWB with same and different thickness

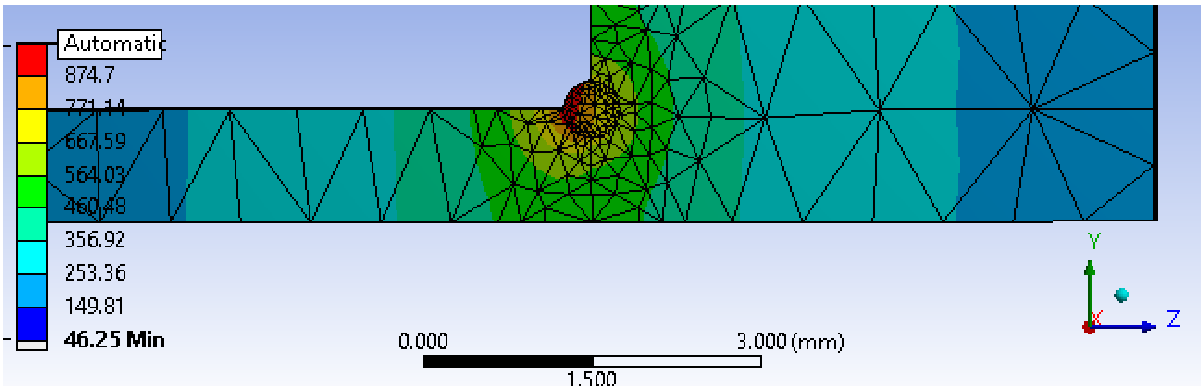


Figure 11: Section view of different material combination and thickness

4.4 Convergence Factor

Another important aspect of laser welding modelling is the mesh density, especially along the weld line and the HAZ. A number of convergence tests were conducted in order to select the appropriate number of elements specifically in the area close to the weld line. More specifically geometries with different refinement level which different obtained total number of mesh elements were tested. The result is plotted in graph as shown in Figure 12. It was decided to use refinement level of 3 and above since this mesh required reasonable convergence and solution time with no significant loss of accuracy as in the graph obtained.

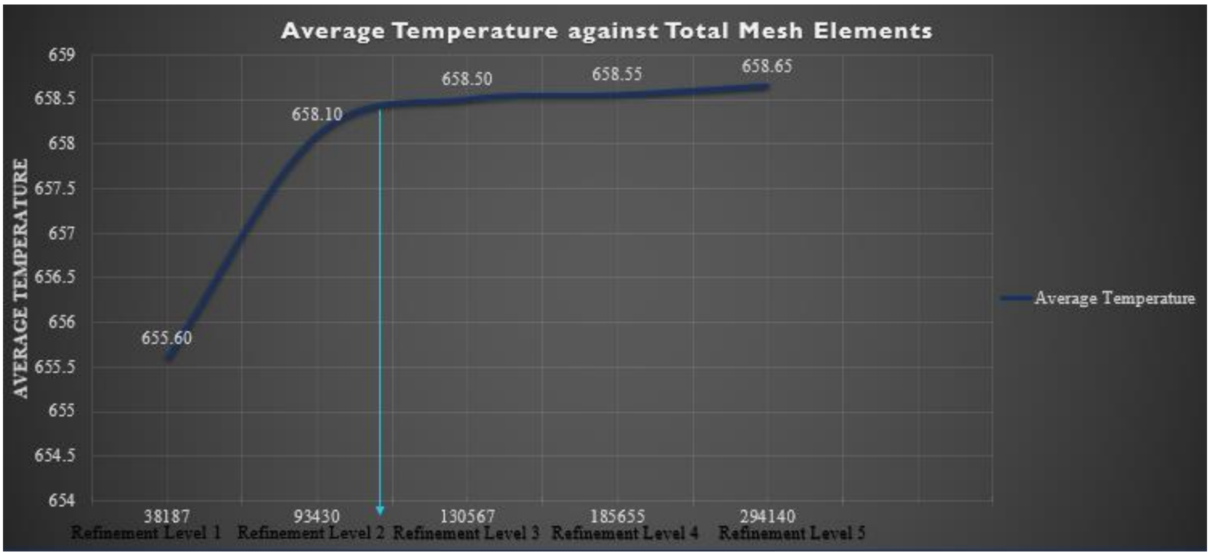
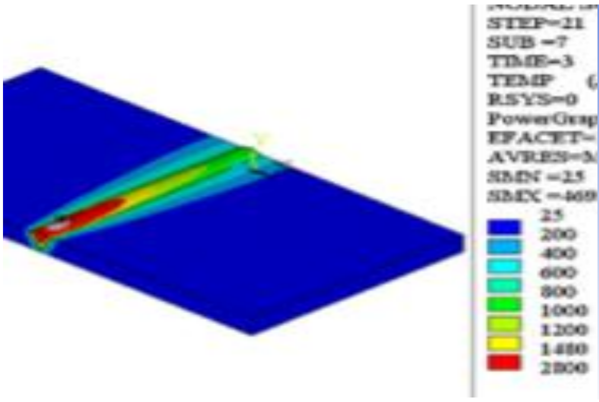


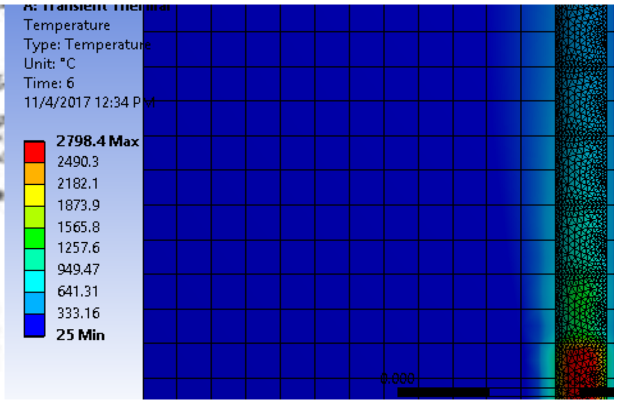
Figure 12: Convergence test

4.5 Validation of Model

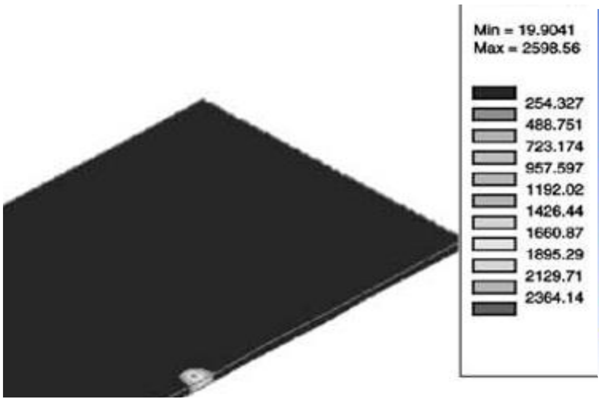
For validation of simulation model, a comparison with previous work [21] was done. In the study, numerical and experimental laser welding in thermally induced residual was conducted ASTM A36 carbon steel blank with same thickness of 6mm. The result getting in temperature distribution is almost same in the range as obtained from the reference study as in Figure 13. The comparison of temperature profile in one second on both previous and current method used to simulate the laser welding model clearly shown in Figure 14. Previous work shows the increment of temperature in one second is just slightly higher than current method. This smaller deviation caused by emissivity of material. Lack of emissivity input in current method effect the temperature on heated surface as the ability of heat absorbed is different. Furthermore, AH36 steel TWB with different thickness is used to validate the current method in welding of different thickness TWB by comparing the maximum temperature result within 15seconds of duration. Maximum temperature was compared in longer duration because the previous work does not show the increment value within one second as in Figure 15. From the graph, the previous work shows the slightly higher maximum temperature result compared to the current work. The reason can be the implementation of heat flux in previous simulation. Heat flux is not considered in current method which is the amount of heat transferred from hot to cold material but only involved with the heat flow and convection. It means the heat flow from the hot to cold parts through a convection coefficient. Note that radiation was used in this study, instead of convection coefficient because the keyhole penetration laser welding was performed in the referenced study due to the higher thickness of blank was used to weld. Besides that, there was no tailor welded blank with dissimilar materials performing laser welding by finite element method yet.



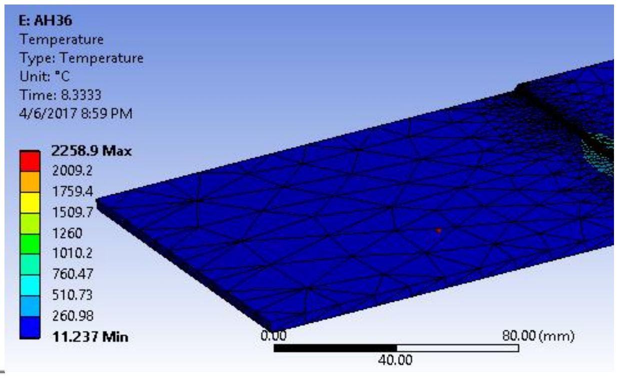
(a) Previous model for same thickness TWB



(b) Current model for same thickness TWB



(c) Previous laser model for different thickness TWB



(d) Current laser model for different thickness TWB

Figure 13: Comparison of same work in previous and current method

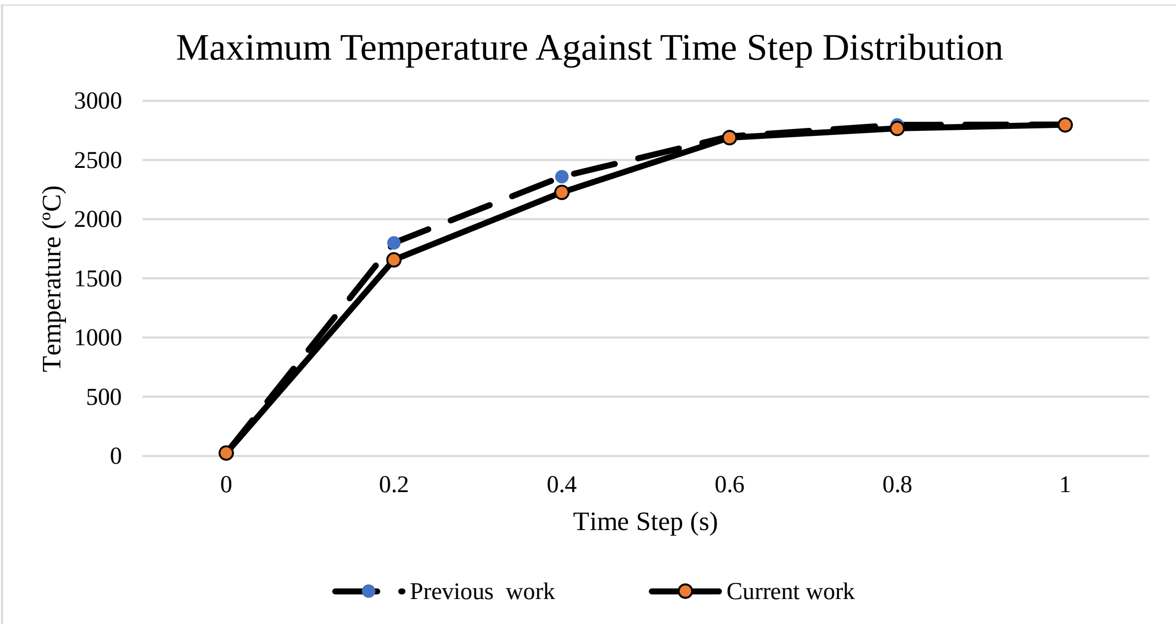


Figure 14: Graph of temperature distribution comparison within 1s time step

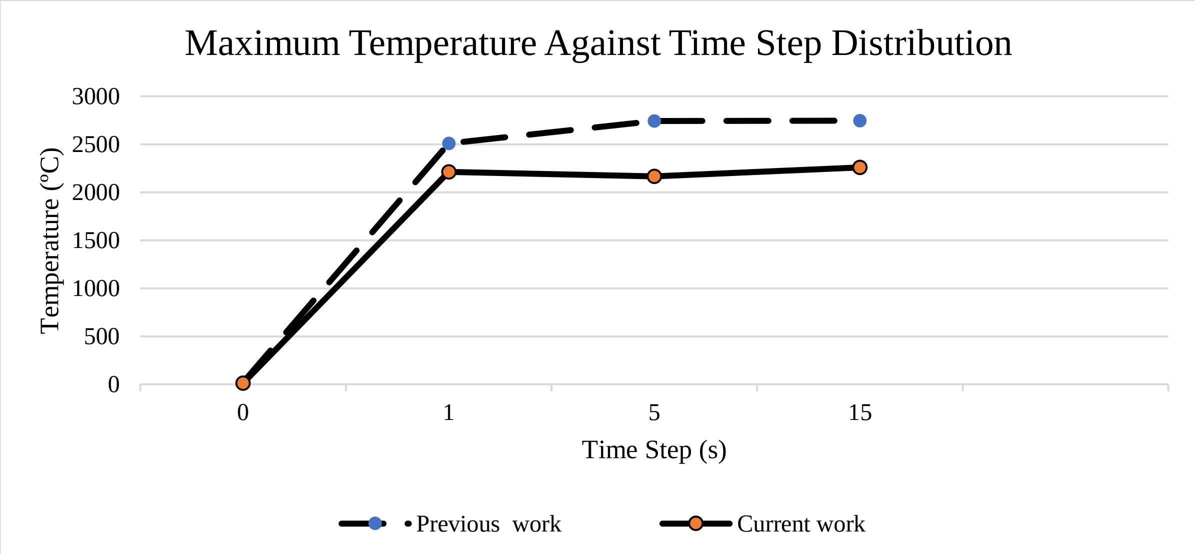
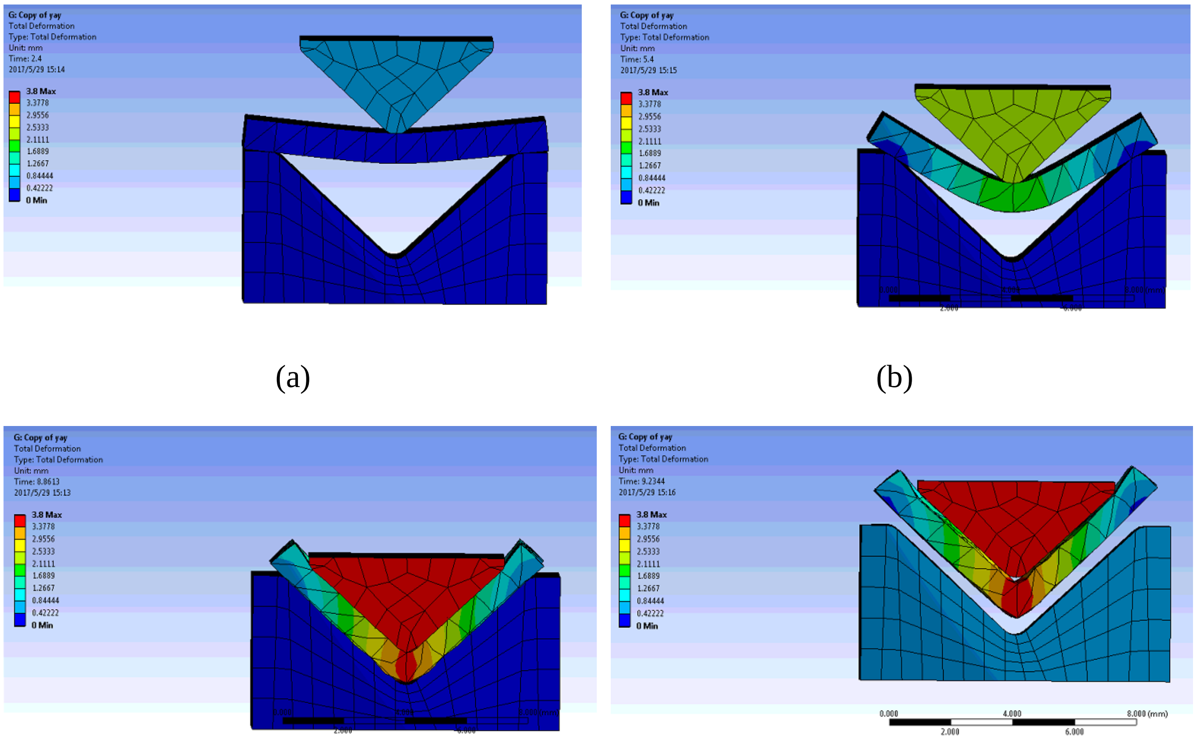


Figure 15: Graph of maximum temperature comparison within 15s of time step

4.6 Correlation of Material Combination and Thickness with Springback Behaviour

Tailored weld blank with different material combination and thickness were undergone structural static analysis for further springback study. Figure 16 shows the changes of the welded blank shape during longitudinal V-bending. It is observed that at the blank distorted more at the side of the laser entry which is also the intermediate weld line. However, at the end of the bending process in Figure 16(d), the die set shifted away from the blank to ease the measurement of springback. Springback is one of the most important problems that should be taken into consideration during TWB forming process. The springback factor on the TWB is difficult to judge through the material as the combination of different material may result in different K-factor as each of the material factor is distinct. Influence of springback in TWB for different material combination is compared as in Table 4. By assuming $\theta_i = 45^{\circ}$ which the TWB was fully bent, bend angle of final deformation calculated through equation (1) and the springback factor, K illustrated by using equation (2). In this case, the thinning of material is not neglected as the initial distance, Di is distinct for every set of combination. The difference basically affected by the material properties of metal. Initial deformed distance in different thickness material combination must be smaller than the same thickness as the distance affected by the thicker region of blank. The thicker and harder the blank, perfectly bending is difficult to be achieved. From the Table 4, springback factor is all larger than one which means springback behaviour occur in every sheet combinations. Combination of Al-SS TWB has the least springback effect whereas the Ti-Al combination having the highest springback effect. As in a single material blank, the springback with a higher tensile strength such as Ti in this case, the greater the springback effect as the thickness of blank is thin as well [22]. Conversely, the springback effect may reduce as the thickness of cheaper blank is increase [23]. This is due to the stiffness of blank increase after combination with a higher ductility material and also thicker blank. Therefore, the springback factor normally decreased with a different thickness TWB. Therefore, springback effect would change by the factor of different thickness and also the relative position of material in TWB when dissimilar metal is combined. Different thickness of the blank which having non-uniform material properties having a high impact in springback behaviour. For an example, a higher tensile strength material arranged in the thicker region may having a different springback to the lower tensile strength arranged as thicker blank. Even in the same thickness combined blank, K-factor is different for the same and dissimilar material TWB. For instance, the springback factor for only stainless-steel blank is 2.0 where the K-factor for only aluminium is 1.5 [24]. However, the Al-SS combined TWB having a spingback factor of only 1.08. This is mainly because the microstructure and phase changes in harder TWB after combine the material, in turn to change the stress-strain value of TWB and stiffness.



(a) (b) (c) (d)

Figure 16: Cross-sectional deformed shape of TWB at various times, (a)2.4s, (b)5.4s, (c)8.9s and (d)9.2s.

Table 4: Result of deformation in TWB

	Same Thickness				Different Thickness			
TWB	Di	Df	θ_f	K	Di	Df	θ_f	K
Al-SS	3.74	3.52	41.7º	1.08	3.35	3.28	43.8º	1.03
Ti-Al	3.91	3.62	40.8º	1.10	3.91	3.86	44.3º	1.02
Cu-SS	3.92	3.70	41.8º	1.08	3.59	3.56	44.5º	1.01

5.0 Conclusion

A three-dimensional finite element model has been developed to simulate the laser welding process and predict the springback of a butt-joint tailor welded blank by longitudinal V-bending process. The finite element calculations were performed using the ANSYS workbench FE code, which takes into account thermal and also the static structural analysis. Unlike the other three-dimensional analyses, the current work takes into account phase transformation to perform V-bending. It was using the temperature dependent material properties and the dual phase diagram with consider a moving heat source model in simulation of laser welding. A previous researcher's work on laser welding was conducted in order to validate the finite element model. Good agreement between the previous finite element method and current model result was obtained. In contrast, temperature distribution of TWB with dissimilar material properties which having the same and different thickness does not much affected during laser welding but the springback effect can be huge different. Springback of TWB was obtained in approximately 1.08 degree for Al-SS laser welded blank,1.10 for Ti-Al, and 1.08 for Cu-SS TWB in same thickness. Approximately reduction of 0.05 to 0.10 differences in springback factor when a different thickness TWB was examined. Thus, springback effect affected by the material properties of welded blank and also the different thickness of TWB.

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