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Thermal analysis of TIG welded Ti-6Al-4V plates using ANSYS

Prashant Sagar*, **Deepak Kumar Gope and Somnath Chattopadhyaya**
Department of Mechanical Engineering, IIT (ISM) Dhanbad 826004 India
*corresponding author- prashantsgr92@gmail.com

Abstract. The exceptional properties of Titanium push it for research activities. A perfect and efficient welding of Titanium in similar and dissimilar manner is also a difficult task for manufacturing companies. Although there are so many ways for welding of Titanium but the most reliable method is Tungsten Inert Gas Welding (TIG). This study is based on the TIG welding and main focus is on temperature distribution. The aim of the study presented in this paper is to determine the temperature distribution profile by using effective and reliable method of simulation. Simulation was performed for Titanium-G5 alloy (Ti-6Al-4V), the most commonly used alloy of titanium. The used analysis was "transient analysis". The concept of "Moving heat source" and "element birth & death model" technique is used to simulate welding Process. An experiment was also carried out on Titanium-G5 alloy (Ti-6Al-4V) for validation of ANSYS results. In this experiment a noncontact thermal image camera was used for temperature measurement. After the experiment and simulation it was found that temperature varies inversely with welding speed.

1. Introduction

Titanium has some specific properties due to which Titanium (Ti) has its special place in manufacturing industry. Now a days in aerospace industry, medical surgery and marine engineering mostly used structural material is Ti. Ti is light in weight, highly corrosion resistive and can sustain high temperature and have good specific strength, these properties made Ti more useful in industrial engineering. The machining and welding of Ti is difficult process in comparison to other materials due to high friction coefficient and wear resistance [1]. Finite elemental method and computational methods are more popular because they can give approximate result prior to actual experiment [2]. Thus in terms of saving time and money for analysis simulation is a very good approach. For Ti-6Al-4V TIG welding is most suitable welding technique [3][4]. The process parameters in TIG welding are welding current, welding voltage, shielding gas flow and most important parameter is welding speed, with variation in welding speed it can affect heat affected zone, depth of penetration and weld microstructure [5][6][7].
In a journal *GaoyangMi et al* studied that there is a very good impact of temperature distribution on microstructure and phase transformation [8]. Laser welding is also very good technique for welding of titanium alloys for similar and dissimilar joining but the optimum thickness for perfect joining is 3 mm so need arises for joining of more thickness material and for that TIG is convenient [9][10][11].
During welding process residual stresses is generated which is unwanted and inevitable, so for reducing these stresses a new technique known as LENS (Laser Engineered Net Shaping) is also used [12]. The heat input and formed weld pool in TIG welding depends on formation of welding arc and with the help of ANSYS study of arc formation can be done for relevant research [13].

2. Simulation

For simulation the properties of Ti-6Al-4V such as density 4.43 g/cc, thermal conductivity 6.7 w/m-k, specific heat 0.5263 J/g-c. The size of the plate was 100*50*4 mm^3. Simulation of Ti-6Al-4V was done by ANSYS 18.1; The concept of moving heat source and birth and death model was used for the simulation [14], in ANSYS birth and death model can be understand by "element death" effect, actually the ANSYS program does not remove "killed" elements instead ANSYS deactivates them by multiplying their conductivity or stiffness. The values of loads are zero for deactivated element out of the load vector however; these deactivated elements still appear in element-load lists. Similarly damping, mass, specific heat and other such effects are supposed to be zero for deactivated elements. In the load summation of the model the effect of mass and energy is deactivated. As soon as that element is killed Element's strain energy is also set to zero. For the same condition when elements are "born" they works like simply reactivated and not actually added to the model; the elements that are born in later stages of analysis are also considered for analysis. In easy method birth and death model means one time load is applied on one node and for next load the previous load should be deleted, this process create a moving heat source loading. The heat source can be assumed moving horizontally. The engineering data was selected for Ti-6Al-4V.

Meshing is one of most important part of simulation. It directly affects the results of simulation. Sometimes results may deviate a little due to meshing. For better results meshing should be dense near to the welding line and rare away from the center line as shown in figure 1. A simple meshing can be seen in figure 2.

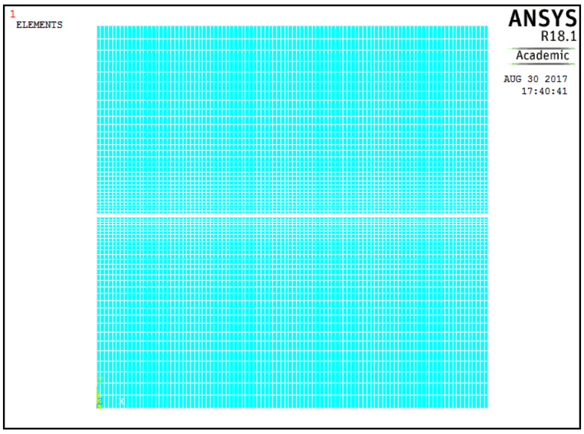

Figure 1. Size controlled meshing on two plates.

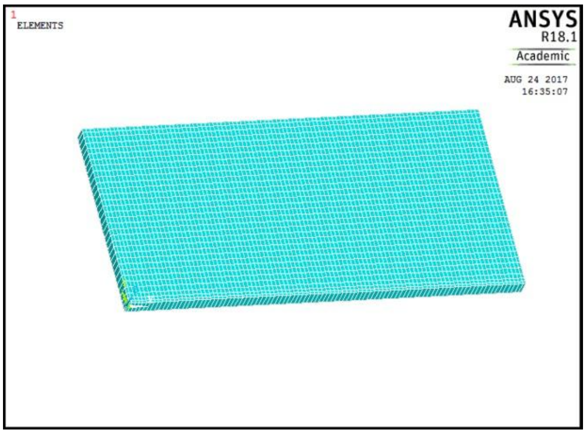

Figure 2.Simple meshing on single plate.

3. Experimental procedure

In this experiment two Ti-6Al-4V plates were used and the size of the plates is 100*50*4 mm^3. The chemical composition of Ti-6Al-4V is shown in table 1.

Table 1. percentage of chemical composition in Ti-6Al-4V

Element	Al	C	Fe	O	V	Ti
Weight %	5.9	0.10	0.20	0.2	4.2	Bal.

A modified TIG welding machine was used for welding at 60 ampere and 80 voltage. In this modification a PUG cutter is used to clamp the TIG torch to control the speed and arc length. Initially two Ti-6Al-4V plates were tagged and after that welding was performed on three specimens. In first specimen welding speed was 3 mm/sec in second specimen welding speed was set to 4.5 mm/sec and in third specimen welding speed was kept 6 mm/sec. The shielding gas used for the TIG welding was 99.9% argon gas.

During the welding process a thermal imaging camera was used for temperature measurement at different welding speeds. After welding process the thermal images were collected form the thermal imaging camera and compared with the temperature profiles by ANSYS.

4. Results and discussion

In this welding experiment the voltage and current were set at 80 volt and 60 ampere respectively. For simulation the input parameter is heat flow that is to be applied in “define loads” option and this heat flow can be calculated by equation (1)

$$Q(\text{KJ/mm}) = \frac{60 \times \text{Volt} \times \text{Current}}{1000 \times \text{Travel speed in mm/min}} \quad (1)$$

Simulation was done for three different welding speeds. In first experiment the welding speed was 3 mm/sec on this welding speed the heat input according to equation (1) is 1600 J/mm, let us suppose the melting efficiency during welding is 85% so accordingly for 3 mm/sec the heat input is 1360 J/mm and the temperature distribution profile was found like figure 3.

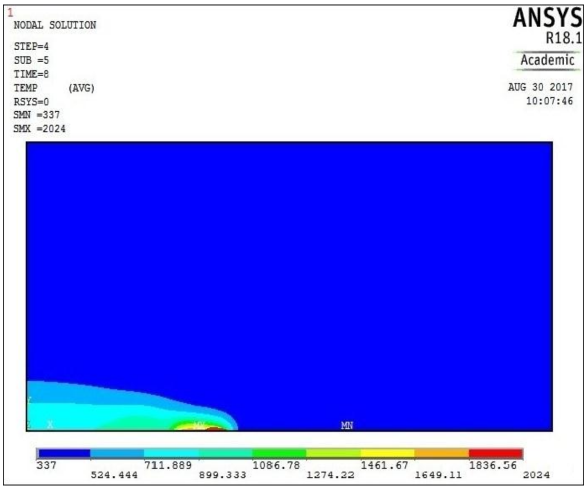

Figure 3. Temperature profile by ANSYS APDL on 3 mm/sec welding speed.

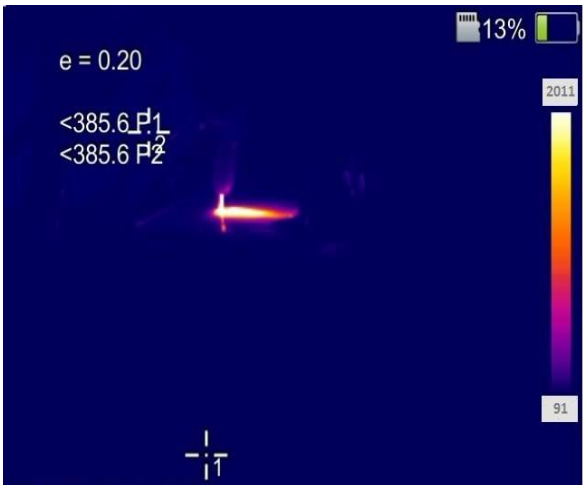

Figure 4. Temperature measurement by thermal camera on 3 mm/sec welding speed.

After getting temperature profile by ANSYS figure 3, it was compared with thermal image obtained by thermal imaging camera figure 4. After analysis it is found that on 3 mm/sec speed according to ANSYS result the maximum temperature of plate went up to 2024ºc and by thermal imaging camera the maximum temperature of plate was found to be 2011ºc and this comparison shows that both are very close values as the difference of maximum temperature values is 13ºc only and this difference is due to following reasons:

1. Distance between welded plate and thermal imaging camera
2. Air present in atmosphere
3. Shielding gas for welding
4. Finite element model is not correctly calibrated

The minimum temperature of plate on 3 mm/sec speed according to ANSYS was found 337ºc and by thermal imaging camera the minimum temperature was 91ºc and this major difference 246ºc is due to environmental temperature.

For 4.5 mm/sec welding speed keeping voltage and current constant, the heat input for simulation was 1066.66 J/mm and with 85% efficiency it becomes 906.66 J/mm. For simulation 4 steps were used , 5 sub steps were used for a time of 8 sec and the result for maximum temperature was 1726ºc and minimum temperature was 326ºc and the temperature profile on this speed is shown in figure 5.

For same welding speed the temperature measurement by thermal imaging camera can be seen in figure 6. the maximum temperature comes to be 1699 ºc and minimum temperature was 86 ºc and the difference of maximum and minimum temperatures by ANSYS and thermal imaging camera was found to be 27ºc and 240ºc, the reason for temperature difference is same as that of welding for 3 mm/sec as described above.

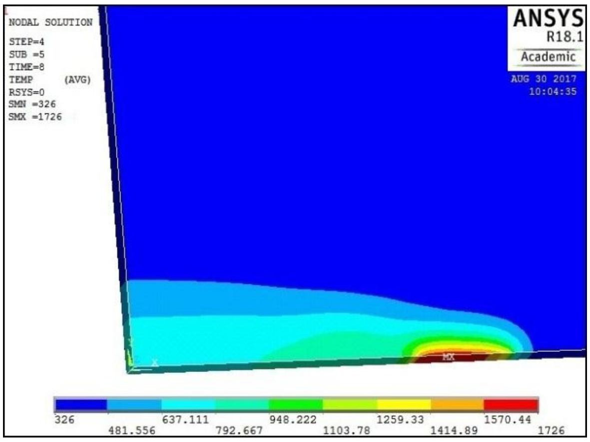

Figure 5. Temperature profile by ANSYS APDL on 4.5 mm/sec welding speed.

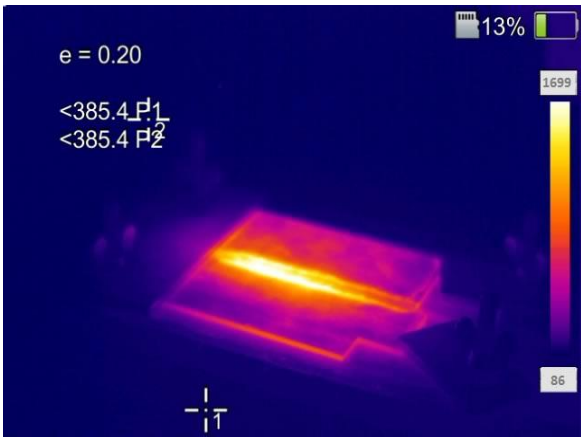

Figure 6. Temperature measurement by thermal camera on 4.5 mm/sec welding speed.

For welding speed of 6 mm/sec keeping voltage and current constant at the values of 80 volt and 60 ampere the heat input value for simulation was 800 J/mm and with 85% melting efficiency it becomes 680 J/mm. At this welding speed the simulation was done with 4 steps, 5 sub steps and for 8 sec time the results found and the temperature profile is shown in figure 7.
According to temperature profile by ANSYS the maximum temperature was 1245ºc and minimum temperature was 320ºc. At this welding speed the maximum temperature and minimum temperature found were 1212ºc and 63ºc by thermal imaging camera as shown in figure 8.

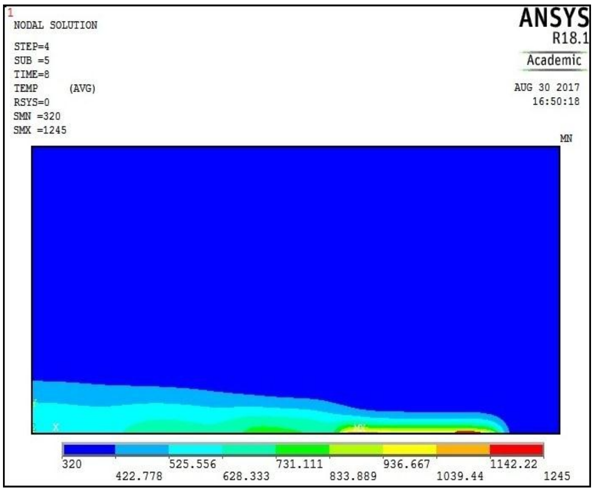

Figure 7. Temperature profile by ANSYS APDL on 6 mm/sec welding speed

Figure 8. Temperature measurement by thermal camera on 6 mm/sec welding speed

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Table 2. Table for maximum temperature measured by ANSYS and thermal camera

Sr no.	Welding speed (mm/sec)	Max temp by ANSYS (a)	Max temp by thermal camera (b)	Difference (a-b)
1	3	2024	2011	13
2	4.5	1726	1699	27
3	6	1245	1212	33

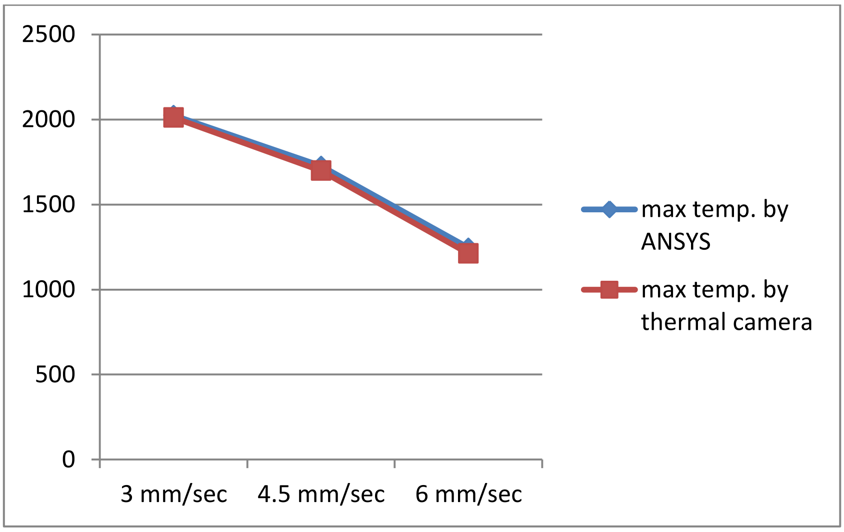

Figure 9. Graph according to table 2.

With the study of graph it can be said that the simulation results of weld joint for Ti-6Al-4V by ANSYS APDL is near to actual experiment analysis results and that is validation of simulation.

5. Conclusion

After TIG welding on Ti-6Al-4V on different welding speeds following points can be concluded:

1. The ANSYS model developed in present study was in upright agreement with experimental results.
2. With the study of ANSYS temperature profile it was found that the heat affected zone is more at low speed welding (3 mm/sec) specimen and very less at high speed (6 mm/sec) because of high heat concentration at low speed.
3. With the study of graph it can be concluded that with the increment in welding speed the temperature decreases.

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