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Studies on Distortion of Dissimilar Thin Sheet Weld Joints Using Laser Beam Welding

K. Kalaiselvan, A. Elango

Abstract**—**To achieve reliable welds with minimum distortion for the fabrication of components in aerospace industry laser beam welding is attempted. Laser welding can provide a significant benefit for the welding of Titanium and Aluminium thin sheet alloys of its precision and rapid processing capability. For laser welding, pulse shape, energy, duration, repetition rate and peak power are the most important parameters that influence directly the quality of welds. In this experimental work for joining 1mm thick TI6AL4V and AA2024 alloy and JK600 Nd:YAG pulsed laser units used. The distortions at different welding power and speed of titanium and aluminium thin sheet alloys are investigated. Test results reveal that increase in welding speed increases distortion in weldment.

Keywords**—**Laser Beam Welding, Titanium, Aluminium alloy sheets and distortion.

I. Introduction

WELD distortion is defined as the change in shape of weld parts during metal joining. It is caused by the non-uniform expansion and contraction of weldment and adjacent base metal during heating and cooling cycle of the welding process. The extent of welding distortion is depend on various factors such as geometry of the joint, type of weld preparation, width, rate of heat input during welding process, volume of weld deposition, alignment of structural elements in the weldments and the sequence in which welds are made [1]-[3]. Different types of distortion are produced in fusion welding such as transverse, longitudinal, angular, rotational, longitudinal bending and buckling. These are all given in Fig. 1.

Distortions of welded structures lead typically to uncertainty in design and manufacture and to high rectification costs. These drawbacks are especially evident in thin plates [4]-[7]. For a given material, the magnitude of distortion depends primarily on the specific thermal energy input of weld metals.

The heat input rate, weld penetration and fusion zone shape are the main factors for contraction deformation and distortion. The peak temperature at a given location is the primary driver for the distortion process. In order to predict the initial shape more accurately, gravity and support conditions should be considered. It is well known that titanium and aluminum alloys are used extensively due to their attractive combination of high specific strength and excellent corrosion resistance. Hence considerable interest is shown in welding of Ti/Al dissimilar joints in the world [8]-[13]. Most researchers dedicate to the theoretical formula, computing model and discuss the effects of welding parameters and material properties on welding residual stresses and distortions [14]-[16].

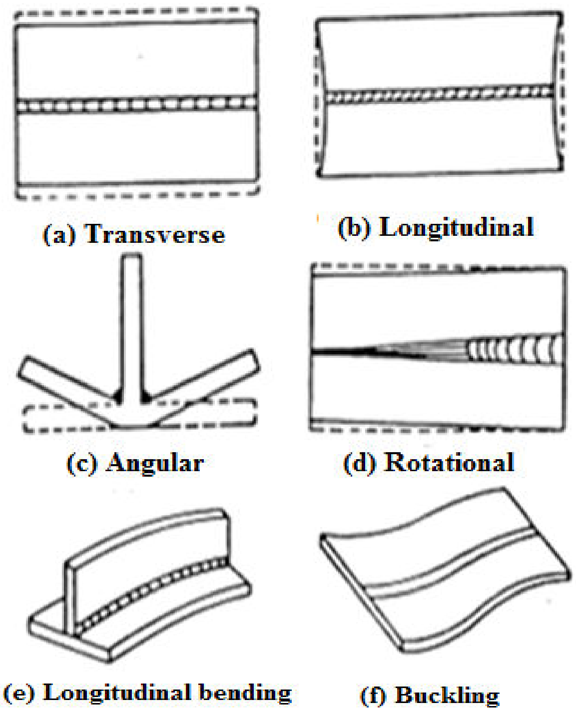

Fig. 1 Types of distortion in fusion welding (a) Transverse (b) Longitudinal (c) Angular (d) Rotational (e) Longitudinal bending and (f) buckling

Welding is the most important pulsed laser application describes a series of overlapping spot welds to form a fusion zone. The formation and the quality of welds are the results of a combination of various pulsed laser processing parameters, such as the travel speed, the average laser power, the pulse energy, the pulse duration, the average peak power density and the spot area [17], [18]. This gives control of the thermal input with a precision and also permits a wide range of experimental conditions to be applied.

In the present investigation a new approach is adopted to obtain information of distortions with various parameters. The characteristics of distortions at different welding power and speed of TI6AL4V and AA2024 thin sheet alloys are studied. The research results provide some information for predicting and controlling welding distortion.

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II. Experimental Setup

A. Laser Welding System

Titanium and Aluminium thin sheet alloys are welded using the JK600 Nd:YAG pulsed mode laser welding system as shown in Fig. 2. It is including laser head, Argon gas, online monitoring system and working table with clamping system.

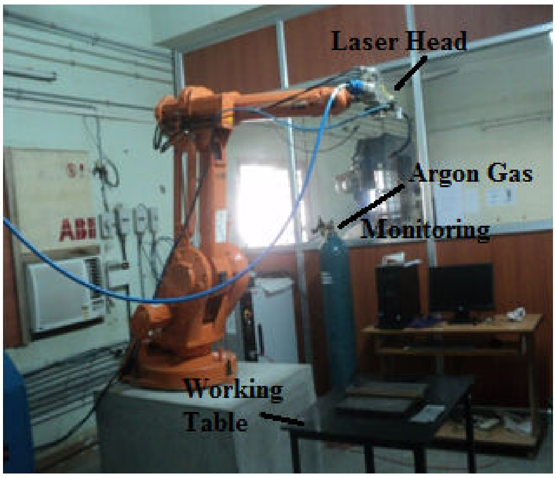

Fig. 2 Schematic diagram of pulsed Nd:YAG Laser welding system

The laser welding system supplied by M/S GSI Group is shown in Fig. 3. It consists a pulsed laser industrial with average power 600W, maximum frequency 1000Hz, pulse with range 0.2 – 2.0ms, fibre diameter 600µm.

Fig. 3 JK laser GSI Group Nd:YAG pulsed mode

In pulsed laser applications a small molten pool is formed by each laser pulse and within a few milliseconds it solidifies. When the peak power is low or the spot size is increased, a shallow and smooth weldment is seen. On the other hand, when the peak power is increased or the spot size is reduced, a much deeper weld pool is observed.

The gap between the joint interfaces has been varied from titanium to aluminium alloy. Gap distance 0.1mm is maintained. The specimens are positioned on the clamping system, constraining a well defined region as shown Fig. 4. During welding time the robot moves automatically with laser head near by the specimen of distance 200mm height. Mostly argon and neon gases are used for shielding gas purpose. But here the laser unit consist argon gas only. The gas is supplied by the gas cylinder through separate hose and connected to the laser head.

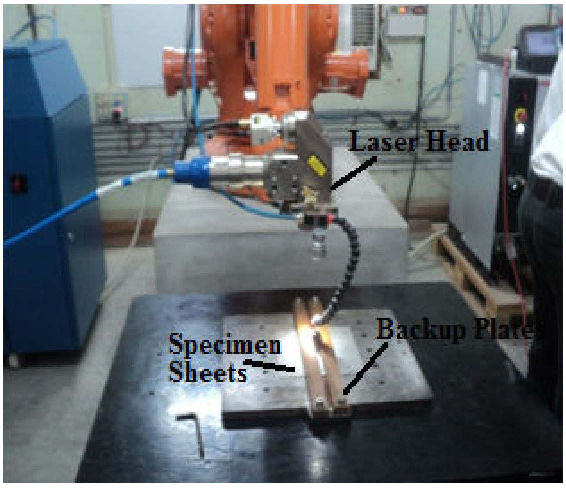

Fig. 4 Clamping system for Ti/Al weld

B. Experimental Details

Titanium alloy TI6ALVA and Aluminium alloy AA2024 with 150mm length, 75mm width and 1mm thickness of sheets are used for butt joint which is the most common alloy combination in aerospace and automotive industries.

TABLE I
TI6AL4VA Titanium Alloy Chemical Composition

Component	Wt. %
Al	5.5 – 6.75
V	3.5 – 4.5
H	0.015
Ti	Balance

TABLE II
AA2024 Aluminium Alloy Chemical Composition

Component	Wt. %
Si	0.500 -1.200
Cu	3.800 - 5.000
Zn	0.063
Fe	0.700
Mg	0.200- 0.800
Ti	0.010
V	0.001
Pb	0.028
Mn	0.300- 1.200
Al	Balance

The chemical composition of Ti and Al sheets used for the laser welding are shown in Tables I and II respectively. Also actual material is shown in Fig. 5. Left side is indicating titanium sheet and right side sheet is aluminium sheet. Both sheets are equally cutting with correct dimensions by using shearing machine. These sheet materials are purchased from sheet metal suppliers. Aluminium has high thermal conductivity [19]. Actually melting temperature of Aluminium alloy is 650˚C and higher specific energy per volume is required to effectively melt the metal due to its high reflectivity [20].

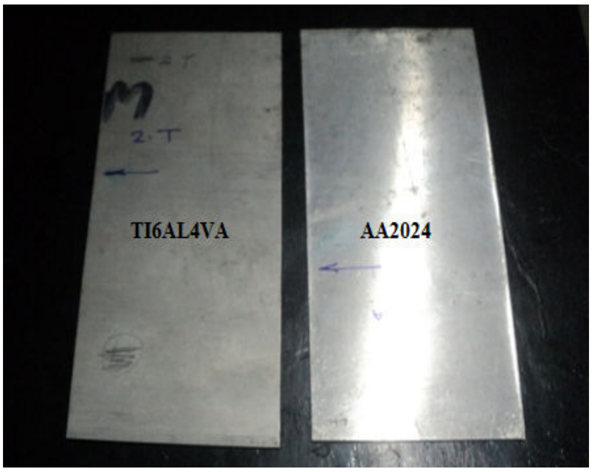

Fig. 5 Actual materials of Titanium and Aluminium

Differences both in terms of heat conductivity and reflectivity between titanium and aluminium an offset of the laser beam towards the titanium has been suggested [21]. In this study an offset of 0.3mm has been considered as shown in Fig. 6 and gap to allow 0.10mm.

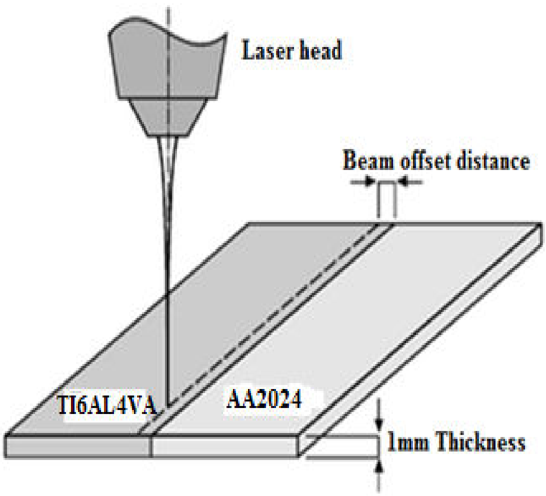

Fig. 6 Off set distance to the joint interface

The laser head is focused perpendicular to the direction of titanium sheet. The head is moving from one end of titanium to the other end with various speeds. The sheets are perfectly clamped so in welding process no variations occur. A system integrated camera is employed for primary fit up when setting the welding path of the laser head. The robot which moves the laser head provides accuracy for excellent pose and a repeatability of the process.

Welding is performed with focused beam and the focus position is kept as constant aiming to conduct a first explorative study on the subject. Preliminary trials are conducted to find an adequate power level to be used in proper range of welding speed for deep penetrative beads. It has been pointed out that hybrid laser welding of titanium to aluminium is only possible for certain levels of thermal input per unit length and power to speed ratio. In order to the base metals during dissimilar welding for this experimental plan speed ranging between 200mm/min, 210mm/min, 220mm/min 230mm/min and 240mm/min. The thermal input varies from 24.8J, 25.1J, 24.3J, 24.9J and 25.2J. The resulting welding conditions of the plan are listed in Table III.

TABLE III
WELDING CONDITIONS FOR PULSED 600W ND: YAG LASER

Sl.No	Rate Hz	Width ms	Height %	Energy J	Speed mm/min	Focus mm	Gas flow rate l/min
1	20	8.5	32	24.8	200	200	10
2	20	8.5	32	25.1	210	200	10
3	20	8.5	32	24.3	220	200	10
4	20	8.5	32	24.9	230	200	10
5	20	8.5	32	25.2	240	200	10

III. RESULT AND DISCUSSION

By using JK600 Nd:YAG Pulsed laser welding unit TI6AL4VA and Aluminium Alloy AA2024 dissimilar sheet metals are welded by using various parameters such as Rate 20Hz, Width 8.5ms, Height 32%, Different energy, J (24.8, 25.1, 24.3, 24.9 and 25.2), Various speed, mm/min (200, 210, 220, 230 and 240), Focus 200mm, Gas flow rate 10 lit/min. After welding the top sides of specimens are shown in Fig. 7.

Fig. 7 Top side of the specimen

Fig. 8 Back side of the specimen

Comparing to top side of the weldment, back side visual appearance is different. Fig. 8 shows back side of the welded specimens.

Titanium and Aluminium sheets are welded by using different speed ranges such as 200mm/min, 210mm/min, 220mm/min 230mm/min and 240mm/min. After welding starts, the temperature of weld metal is increased; causing expansion of volume, but this behavior is hindered by the base metal. So the transverse shrinkage distortion is generated and the displacements slowly increase.

The moving of laser head, metal after welding starts to cool, which cause transverse and longitudinal shrinkage of weld metal and the increase of displacements. The maximum distortions founded at room temperature as shown in Fig. 9.

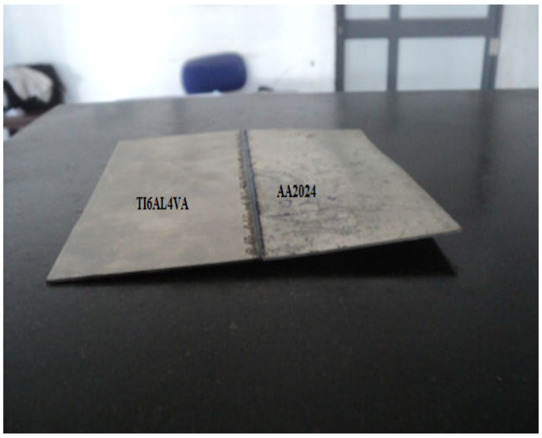

Fig. 9 Maximum distortion at room temperature

This indicates that the transverse shrinkage and downward longitudinal bending are the main factors inducing distortion in the welding process. The thickness of sheet metal is 1.0mm so after completion of welding distortion is occurred. This distortion is depending upon the speed ranges. Fig. 10 shows distortion at the speed range of 200mm/min. This distortion is measured by using vernier height gauge. Before that this instrument is calibrated using slip gauges to identify the percentage of error. After that the welded metal is placed on the surface block.

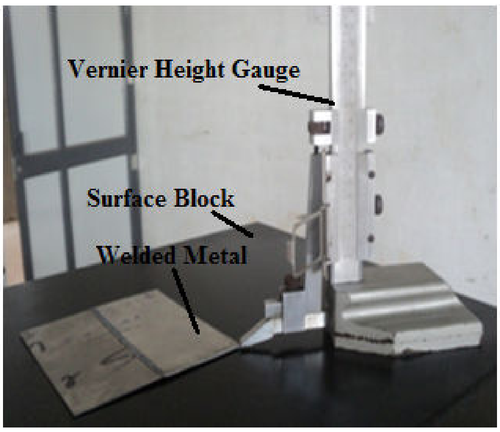

Fig. 10 Measurement at speed 200mm/min

To adjust the vernier height gauge using main scale and vernier scale, distortion height variation is measured. Distortion at 210mm/min is shown in Fig. 11.

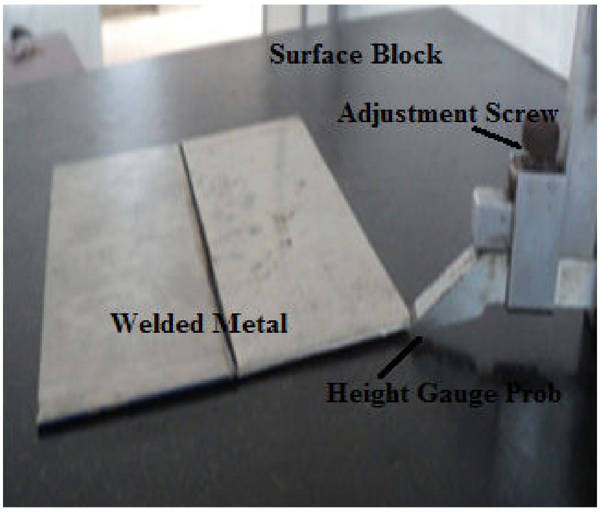

Fig. 11 Measurement of speed 210mm/min

Comparing to speed at 200mm/min, the distortion is changing at 210mm/min. The height variation also increased. While increasing the welding speed the upward longitudinal bending is obviously strengthened, the distortion is counterbalanced and the displacements are reduced. Fig. 12 shows distortion height changes at the speed range of 220mm/min. Comparing to speed at 210mm/min, the height is increased.

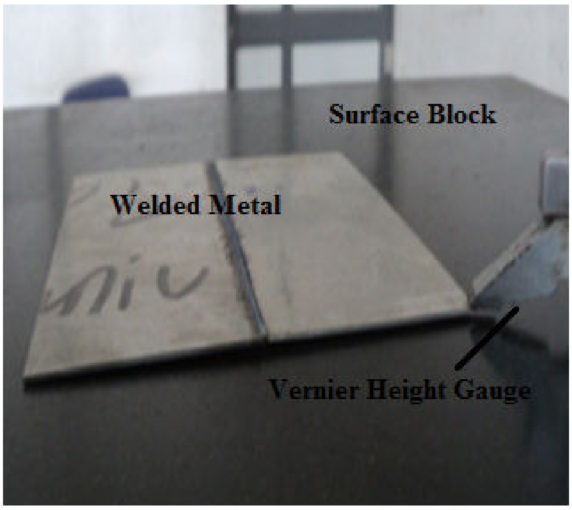

Fig. 12 Measurement at speed 220mm/min

The expansion coefficient of aluminum alloy is higher than that of titanium alloy. The displacement of AA2024 alloys rapidly increases and decreases. But the distortion tendency keeps in short duration and then rapidly rises again until reaching the maximum value. For TI6AL4VA alloy distortion slowly increase until it reaches the maximum value after some time. Fig. 13 shows distortion at the speed range of

230mm/min. By using vernier height gauge the distortion height is increased comparing to 220mm/min.

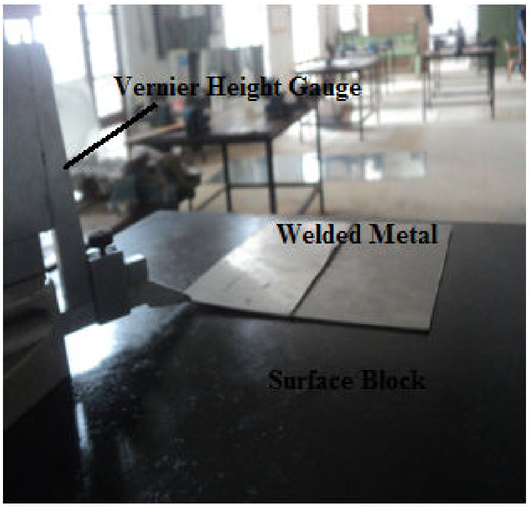

Fig. 13 Measurement at speed 230mm/min

The physical properties of two alloys are different, the thermal expansion coefficient of aluminum alloy is much higher and the displacement of AA2024 alloy is higher than that of TI6AL4VA alloy. Fig. 14 shows distortion height at the speed range of 240mm/min. Comparing speed at 200mm/min, more different is occurred.

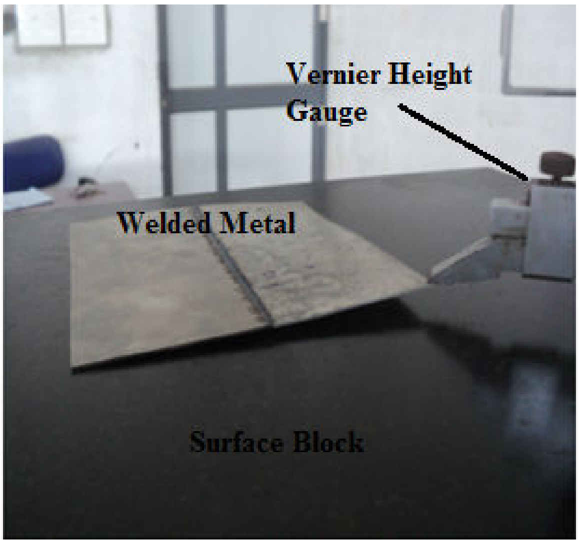

Fig. 14 Measurement at speed 240mm/min

Displacements of AA2024 alloy rapidly decreases after welding. The downward distortion is observed. While aluminium alloy completely melts, excess penetration bead is formed. The center of weld moves down. Although the partial dropping tendency is counterbalanced by upward distortion, the position of weld center is the primary factor affecting the distortion. The height variation of distortion using vernier height gauge at different welding speed is listed in Table IV.

TABLE IV
HEIGHT VARIATION USING DIFFERENT SPEED

Speed (mm/min)	Distortion height (mm)
200	2.00
210	2.17
220	2.30
230	2.82
240	3.18

For aluminium alloy the total tendency of distortion is found upward. As welding progresses, the distortion is increasing.

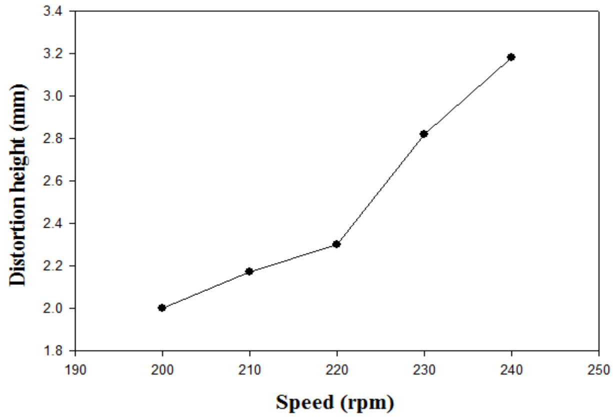

Fig. 15 Effect of distortion on welding speed

Speed ranges at 200mm/min, 210mm/min, 220mm/min, 230mm/min and 240mm/min increases the distortion changes. The effect of distortion on speed is shown in Fig. 15. In this graph shows the lowest speed distortion height is reduced and higher speed increases distortion height. Generally the distortion of these two alloys varies due to their difference in linear thermal expansion properties. However in welding of these two dissimilar alloys, the distortion gradually increases as increase in welding speed.

IV. CONCLUSION

The following conclusions are arrived at from the above investigation:

1. The transverse shrinkage and downward longitudinal bending are the main factors inducing distortion in the welding process.
2. The distortion of aluminum alloy is found higher than that of titanium alloy.
3. The thermal expansion coefficient of aluminum alloy is higher than titanium and hence AA2024 alloy is higher than that of TI6AL4VA alloy.
4. The position of weld center is the primary factor affecting the distortion.

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