Application of Infrared Thermography in Bobbin Friction Stir Welding – Exploring a New Dimension

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DOI : 10.22486/iwj.v52i3.184310

ABSTRACT

Friction stir welding (FSW) is a known process widely used for different metals, metal alloys and composites. The process is widely used in marine, automobile, railway and aerospace industries. The weld quality depends on tool design. Frictional heat is the main factor governing weld quality. Measurement of this developed heat or temperature during FSW is very difficult. Such measurements and thermal analysis of the weldments is very lean in literature. Researchers have used thermocouples for direct temperature measurement. Infrared (IR) thermography, a technique widely used for preventive maintenance in industries, will be an upcoming technology one can use fruitfully in metal joining. Quality of the weld joint is dependent on the generation of frictional heat during the welding. Measurement of the heat or temperature during welding is a big issue. Again the measurement of temperature of tool in running condition is another issue to be thought of. The present paper will be a flashlight in applying a new concept of IR Thermal imaging for testing and thermal analysis. The technique was adopted by the author to know its utility for FS Welding. The IR Thermography was carried out using IR imager. It was found to have a great potential in adapting the IR Thermography for friction stir welding experiments. The experiment was carried out using fixed gap bobbin tool for welding AA6082 T6 Al alloy in butt configuration. Characterization of the welded samples showed better results of the experiment with zero defect.

Keywords: IR Thermography; BFSW; thermocouple; bobbin tool design; convex-convex tool.

1.0 INTRODUCTION

The Welding Institute (TWI), UK in 1991 [1], developed the joining process using frictional heat generated through external agency called as tool. The process uses a harder tool to develop heat through its rotation and friction. The material is plasticized due to heat and displaced continuously from front to rear position of the tool along the weld line. Quality of the weld joint is dependent on the frictional heat developed during the welding. How to measure this heat or temperature variations during welding, is a big issue. Again the tool is rotated at high speed and measurement of its temperature in running condition is another issue to be thought of.

Infrared Thermography (IRT) is an upcoming and fruitful technique one can adopt for different applications like machining process, material joining, defect detection and material degradation or condition monitoring [2].

Yi et al. [3] did the experiments to find out heat input during FSW. The experiment was bead on welding of Al alloys. They used copper as a backing plate as it has higher thermal conductivity. The temperatures were measured using K-type

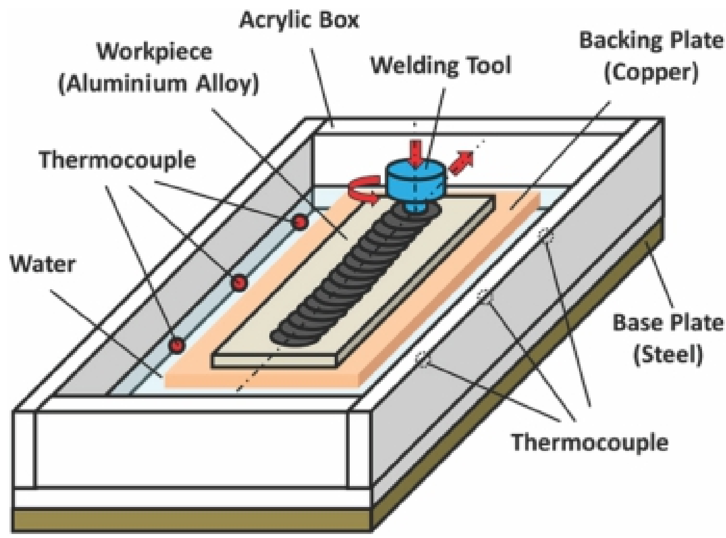


Fig. 1 : Schematic illustration of the apparatus used for the heat input measurement

thermocouple dipped in the water circulated around the copper backing plate in an acrylic tank (**Fig. 1**). The limitation in this type of setup is the loss of heat transferred from tool-workpiece interface (junction) to Al plate to copper plate to water. There is vast difference between the actual frictional heat and that measured through thermocouples dipped into water.

Interfacial friction and plastic deformation of material are the means of heat generation in FSW process [4]. This heat generated out of friction is difficult to be measured easily, because the coefficient of friction is temperature dependent [5].

1.1 Principles of Infrared Thermography

In 1800, Sir F.W. Herchel discovered the existence of infrared IR radiations lying in the visible and microwave electro-magnetic spectrum (**Fig. 2**). Heat or temperature (thermal radiation) being the basic source of IR radiation; every object (including ice cubes) emits IR radiation, having temperature greater than absolute zero i.e. 0 K [6] [7] .

The IR bands of electromagnetic spectrum as shown in **Fig. 2** exist between 2.0 to 15 microns [7] .

Akinlabi et al. [8] suggested that IR Thermography can be a suitable tool for temperature measurement in FSW experiments. He explained through simulation and assumption.

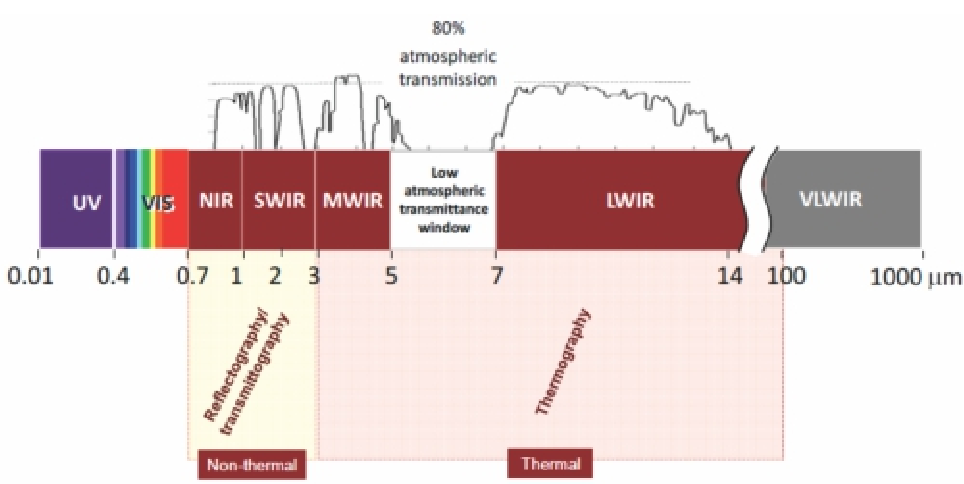


Fig. 2 : The infrared bands in the electromagnetic spectrum

Rubtsov et al. [9] studied the passive IR inspection during FSW process. They concluded that for detecting internal defects, during welding process infrared inspection can help you. Proper thermal detectors and data processing technique will be required to obtain reliable results.

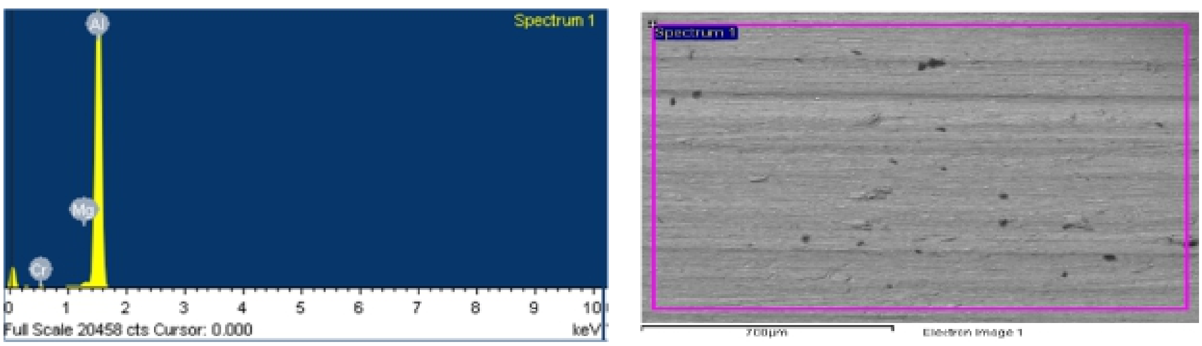
Kryukov et al. [10] used IR Thermography as a NDT tool for measuring defects in FS Welded samples. They confirmed that the technique is very much suitable as a non-destructive testing method [11].

2.0 EXPERIMENTAL WORK

Online thermal imaging is very lean in literature and has a wide scope to explore actual experimental investigations. The author has carried out the experiments and actual thermography data is presented in this paper.

The FS welding of AA 6082 T6 Al alloys (**Fig. 3**) was done on MORI SEIKI Vertical Machining Center (Model NV5000AI) in industry. The rigidity of machine is very important to get quality welds. The 6mm sheet was cut to size of 100mm x 150mm and machined properly to get butt joint configuration with zero gap. Chemical compositions of wok material are as per **Table 1**.

A fixed gap bobbin tool (**Fig. 4**) was specially designed and fabricated for the experiment and used for butt welding of Al sheets across rolling direction.



(a) (b)

Fig. 3 : Analysis of AA 6082 T6 Alloy (a) EDS Curve for AA 6082 T6 Alloy (b) Image for Base metal

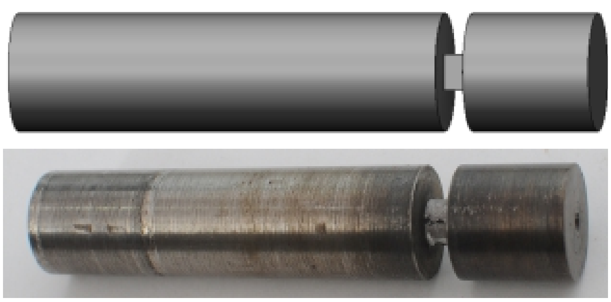


Fig. 4 : Fixed gap bobbin tool having square pin, convex - convex shoulder BT2

Fig. 5 : Infrared Thermal Imager Used For Thermography (NEC, Japan)

Table 1 : Chemical compositions of AA 6082 T6 Alloy

Element	Si	Fe	Cu	Mn	Mg	Cr	Al
Weight %	0.88	0.45	0.04	0.43	1.05	0.11	97.03

The thermal images were captured using Infrared thermography camera (NEC, Japan) (**Fig. 5**). The camera was kept 400mm from the object at 60^0 angle with respect to the surface.

3.0 RESULTS AND DISCUSSION

An attempt was made by Cobo et al. [12] correlate IR images with visible CCD images and a comparative study was done using GTAW process. IR thermography was proved to be the better option as compare to CCD visible camera because the image quality of later is not giving correct results.

From the initial experimentation done, it can be said that the use of IR Thermography to measure temperature of welds during the process of FSW is a very promising method that could replace the use of more commonly used methods such as thermocouples. The use of IR Thermography also has the advantage of measuring temperatures of the weld without the need to drill holes and embedding foreign material into the sample which could affect the weld process and lead to inaccuracies.

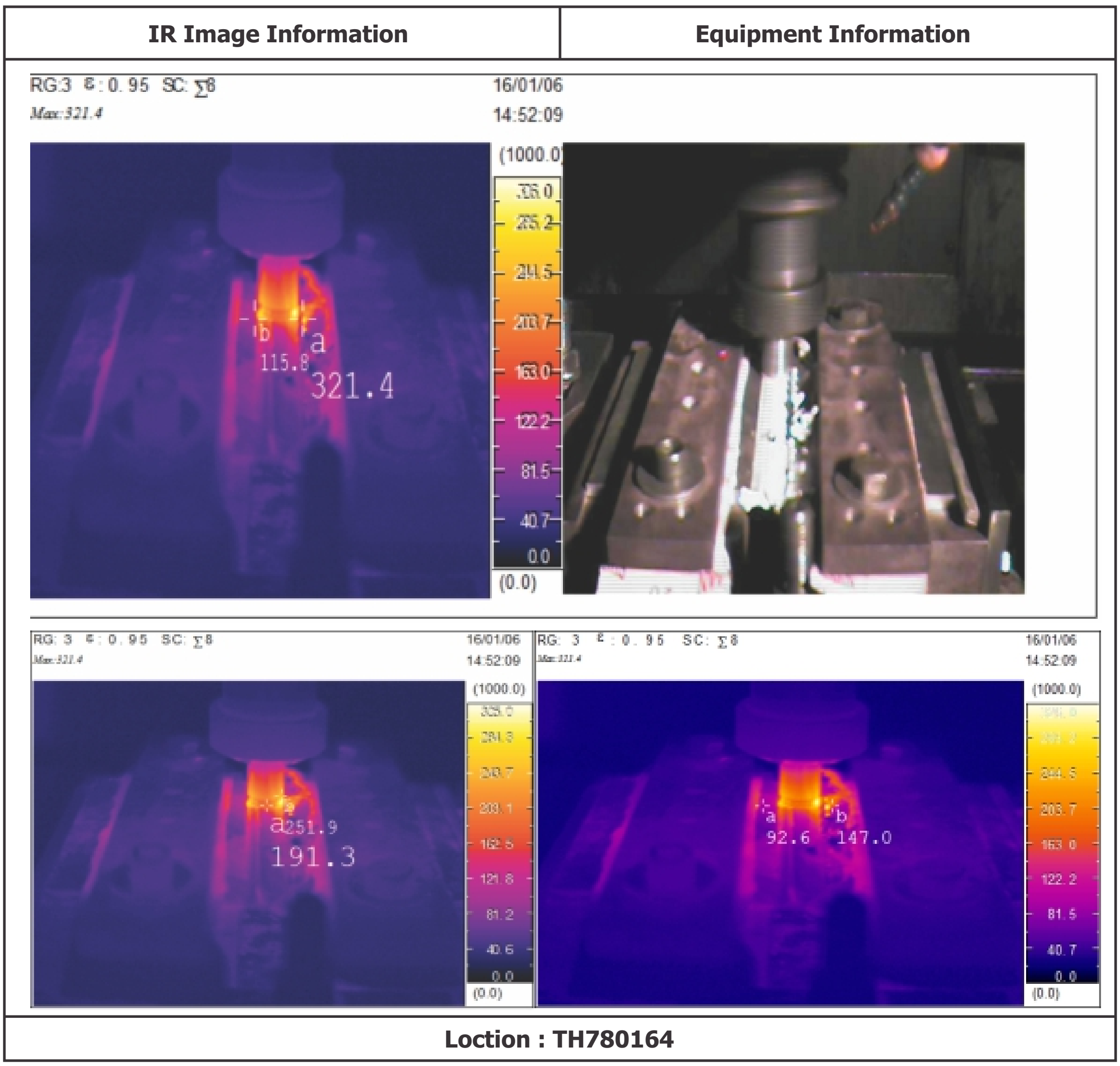


Fig. 6 : IR image for welding AA6082 T6 alloy with spindle speed 1000 rpm and welding speed 24mm/min, using BT2 tool (LHS= Advancing side, RHS=Retreating side)

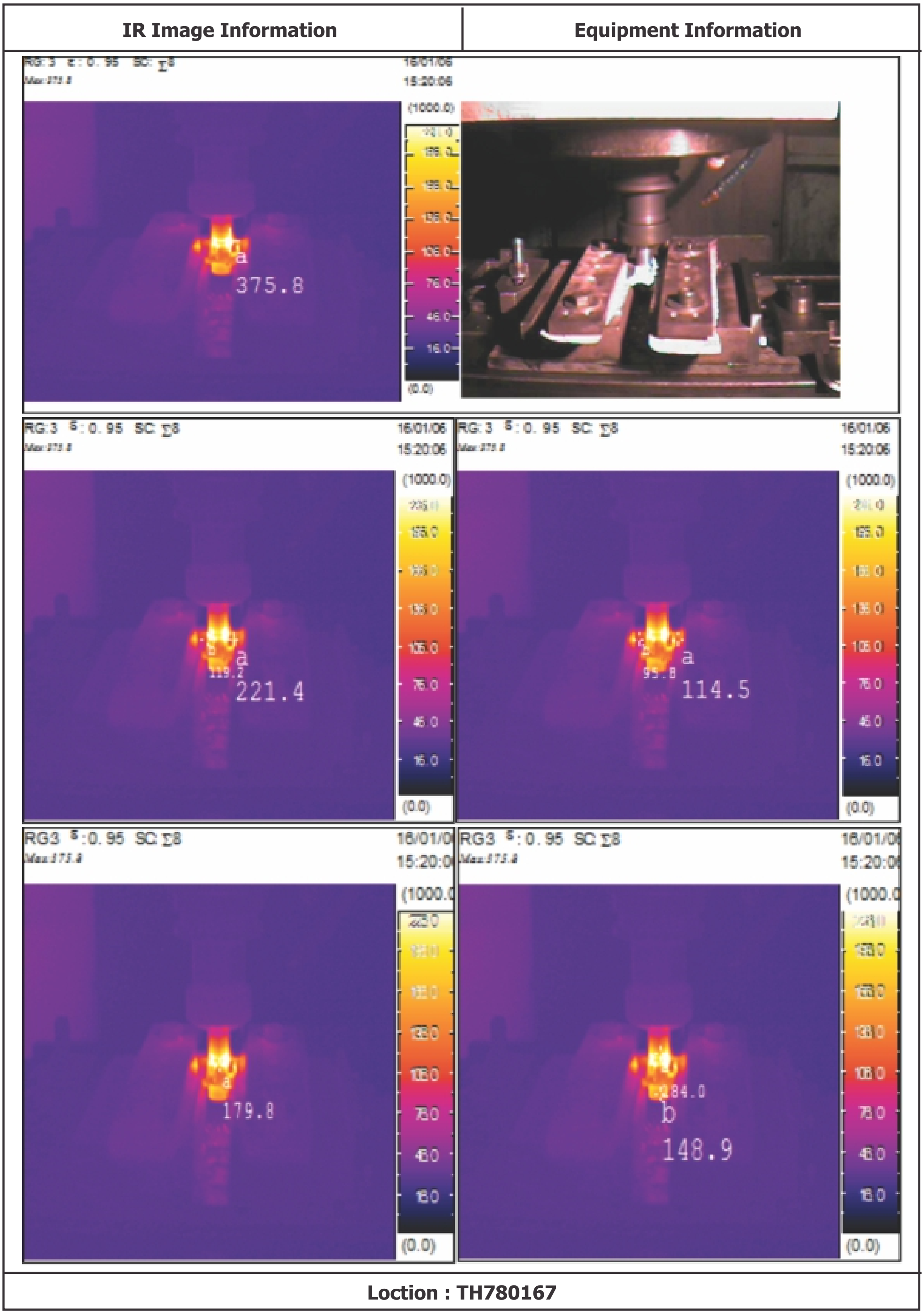


Fig. 7 : IR image for welding of AA6082 T6 alloy with spindle speed 800 rpm and traversing speed 24 mm/min, using BT2 (LHS= Advancing side, RHS=Retreating side)

Table 2 : Temperature distribution zones for BFSW and CFSW weld

Fig. No	Tool No.	Process Variables	Max. temp. at tool (°C)	TMAZ (°C)		ΔT_{TMAZ} Between AS and RS	HAZ (°C)		ΔT_{HAZ} Between AS and RS
				AS	RS	(°C)	AS	RS	(°C)
Fig. 6	BT 2	N = 1000 rpm f = 24mm/min	397.2	115.8	321.4	205.6	92.6	147.0	54.4
Fig. 7	BT 2	N = 800 rpm f = 24mm/min	375.8	119.2	221.4	102.2	95.8	148.9	53.1

The temperature on the advancing side (AS) is different than the retreating side (RS) during FS Welding. This temperature difference between the AS and the RS decreases with the increasing of the rotation speed in case of conventional FSW (CFSW) measured by thermocouple. An experiment was done by Golubev et al. [13] on 2mm 6082 Al alloy sheet. Thermal analysis and/or temperature measurements for bobbin friction stir welding (BFSW) are rarely available in published literature.

In the present experiment from the IR thermography results (**Fig. 6 - 7**), it is observed that with BFSW tool, temperatures either in HAZ or TMAZ are having higher values at retreating side than advancing side. The temperature zones in TMAZ are always on higher side than HAZ. Which means as tool distance increases temperature gradient is reduced.

With same bobbin tool it is found that there is little impact of process variables on temperature on advancing side, while a great difference is observed on retreating side. The temperature difference ΔT (between AS and RS) (**Table 2**) varies with spindle speed in TMAZ region, but in HAZ region ΔT is nearly same. It shows that spindle speed has direct impact on temperature generation and hence the quality of weld. For different tool design the values of temperatures are different in both HAZ and TMAZ regions. It means for getting finer microstructures and temperature distribution design of a tool is very important.

4.0 CONCLUSIONS

Infrared Thermography is a new dimension explored in this research work. Very few researchers have tried to use this excellent device and there is a wide scope to explore it in a complete sense.

With the help of IR Thermal imager we can measure tool temperature easily during welding, which is difficult by other conventional methods, as tool is rotating.

Temperatures at different zones like TMAZ, HAZ were measured and found that temperature on advancing side is lesser than at retreating side of weld line in BFSW. Tool rotational speed also has direct impact on heat generated in TMAZ while it has less impact on HAZ.

The tool design plays a vital role in deciding the temperature distribution as well as the grain structure.

The process parameters also has an equal impact on quality of weld. Very fine grains are found in welds made by convex shoulder, square pin, and fixed gap bobbin tool. A defect free joint was observed, an excellent microstructure ever found.

It is possible to develop the co-relation between process parameters and weld quality through prediction of heat requirement.

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