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Exploring the features of Infrared Thermography for Friction stir welding process – a tool of new era

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ABSTRACT
Friction stir welding (FSW) is a well-known process adopted for joining of different metals and alloys. The process invented by TWI, UK in 1991, is widely used in marine and aerospace industries. Major thrust was given on the effect of tool design and effect of process variables on quality of weld. Thermal analysis of the weldments is very lean in literature. The researchers have used thermocouples for temperature measurement. Infrared thermography is widely used for preventive maintenance in industries. The present paper is different from the view of 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. It was found to have a great potential in adapting the IR Thermography for friction stir welding experiments.
Keywords: Friction stir welding, tool design, thermocouple, IR Thermography.

I. INTRODUCTION

Infrared (IR) thermography is the process of generating visual images that represent variations in IR radiance of surfaces of objects. Similar to the way objects of different materials and colors absorb and reflect electromagnetic radiation in the visible light spectrum (0.4 to 0.7 microns), any object at temperatures greater than absolute zero (-273^{o}C) emits IR energy (radiation) proportional to its existing temperature. The IR radiation spectrum is generally agreed to exist between 2.0 and 15 microns. By using an instrument that contains detectors sensitive to IR electromagnetic radiation, a two-dimensional visual image reflective of the IR radiance from the surface of an object can be generated [1].

Jing Liu et al. [2] worked upon the use of infrared thermography for analysis of fatigue damage in Ti6Al4V-Welded Joints by laser beam welding (LBW) and base metal (BM) specimens during a fatigue test.

The FSW process though was invented and patented by The Welding Institute, UK, 1991 [3]. There are a number of potential applications of the FSW process, particularly in the case of dissimilar material joints and difficult to weld aluminium alloys.

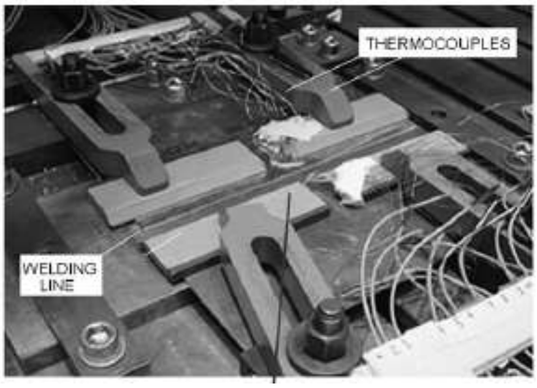

Figure 1: Thermocouples for measuring temperature during welding cycle

As shown in Fig.1, S.T. Amancio-Filho et al. [4] used thermocouples for measuring temperature during welding cycle. The method was robust and giving direct temperature values. But the method adopted needs to insert thermocouple at depth; was found to be very difficult. The limitation was the number of thermocouples to be installed along the line of weld joint on advancing and retreating side. When the tool is near to the thermocouple, it will give the real temperature, while the temperature between two thermocouple positions was not possible to be measured perfectly. The second limitation was about the temperature of the tool. It was very difficult to measure tool temperature while in motion.

V. Soundararajan et al. [5] developed the thermo-mechanical model along with the actual experimental work and concluded that for determining the temperature at the interface of the tool shoulder and workpiece during the friction stir welding process, we have to rely on results of thermal simulation. The workpiece surface temperature right under the tool reaches very close to the solidus temperature as seen from the obtained thermal results.

E. T. Akinlabi et al. [6] imbedded the thermocouples into the backing plate. It enables the user to determine the temperature distribution along the lengths of the workpieces. This concept is not ideal for tool temperature monitoring as the mechanism of heat transfer between the tool and the workpieces may be complex.

So a methodology need to be developed for non-contact type measurements. And IR Thermography is a new technique found to be most suitable for want of the time.

The preliminary work was carried out by Jordan MĘŻYK1 and Szymon KOWIESKI [7] and qualitative results were presented.

II. EXPERIMENTAL WORK

The IR Thermal imager is used in the present study. AA 6082 T6 Al alloy of the size 100x100x6.1 mm^3 was welded in butt joint configuration across the rolling direction. The experiment was conducted on CNC machine. A specially designed jig type fixture was used to clamp the substrate in position. A square pin tool was used to weld the plates.

The welding was carried out using different rotational and translational speeds. The result presented in this paper is for 1000 rpm rotational speed and 48 mm/min traversing speed.

Because IR radiation falls outside that of visible light (the radiation spectrum to which our eyes are sensitive), it is invisible to the naked eye. An IR camera or similar device allows us to escape the visible light spectrum and view an object based on its temperature and its proportional emittance of IR radiation. Fig. 2 shows one of such classifications based on the atmosphere high-transmission windows as well as the type of detector materials that are sensible on each particular band. Four IR spectral bands are of interest for infrared vision applications: (1) the near infrared (NIR, from ~ 0.7 to 1 μm), (2) the short-wave IR (SWIR, from ~1 to 2.5 μm), (3) the mid-wave infrared (MWIR, from ~ 3 to 5 μm), and (4) the long-wave infrared (LWIR, from ~ 7.5 to 14 μm) [8].

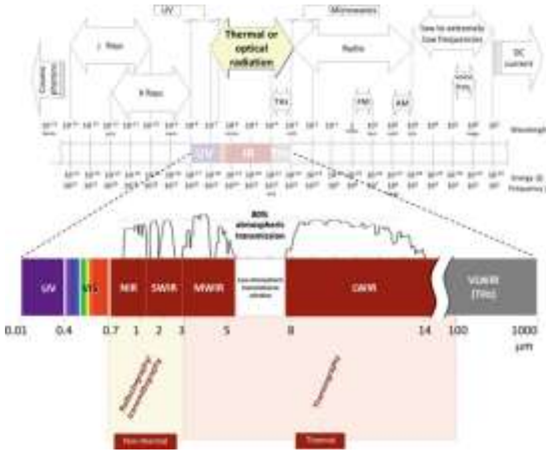

Figure 2: The infrared bands in the electromagnetic spectrum [8]

The instrument used in this experiment was NEC, Japan make infrared thermal imager for capturing the images during actual welding as shown in Fig.3.

Figure 3: Infrared Thermal Imager Used For Thermography (NEC, Japan)

III. RESULT AND DISCUSSION

The Fig. 4 shows IR image along with the actual image of the FS welding in progress. The reading shows maximum temperature at the tool during welding. Fig. 5 displays the thermal variation details at Thermo mechanically affected zone (TMAZ), while Fig. 6 shows temperature bands at heat affected zone (HAZ).

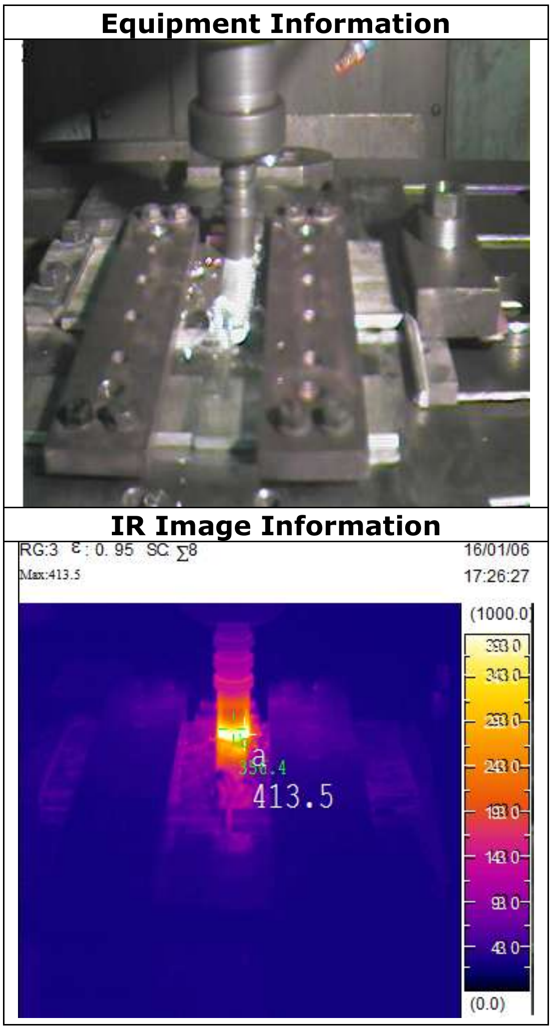

Figure 4: IR image for FSW of AA6082 T6 alloy with spindle speed 1000 rpm and welding speed 48mm/min,

In FSW experiment, a tool rotational speed was 1000 rpm. As said above, it is very difficult to measure the temperature at such a high speed by conventional or contact type measuring device. But it can be measured easily by adopting infrared technology. The IR thermometer (non-contact) can be used for measuring temperature, but it will not show the exact location where the measurement was made. Thus the IR thermal imager will serve this purpose and will help you in deciding and locating the spot of measurement.

From Fig. 5, we observed the temperature at TMAZ; and found that the temperature on advancing side (AS) is higher by 20.1 ºC than at retreating side (RS) [9]. The temperature difference between AS and RS at HAZ is very less (Table 1).

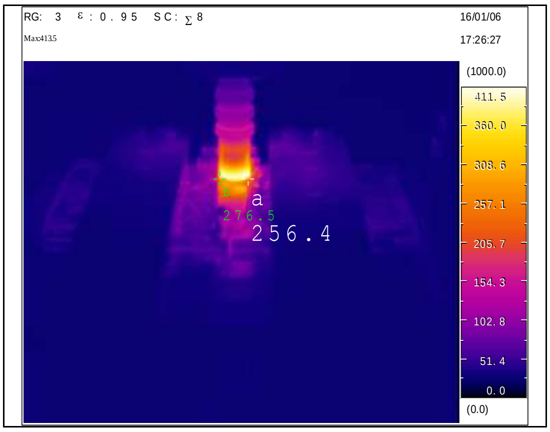

Figure 5: IR image at TMAZ region of FSW

A wide temperature difference was observed between HAZ and TMAZ from Fig. 5 and 6. It shows that HAZ is near the base metal and cool zone while TMAZ is near weld zone or hot zone.

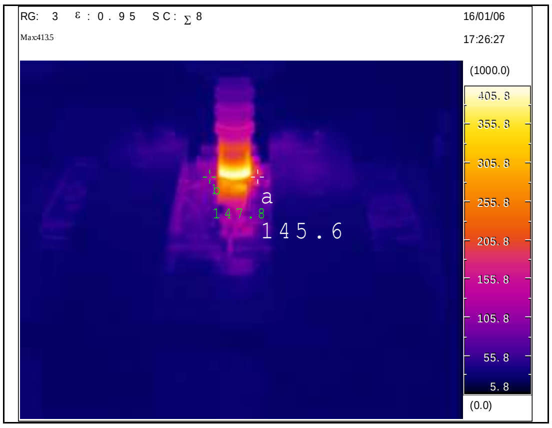

Figure 6: IR image at HAZ region of FSW

Table 1: Temperature distribution zones for FSW weld

Figure No.		Fig. 4 to 6
Process variables		N=1000 rpm f =48mm/min
Max. Temperature. at tool	(º C)	413.5
Temperature at TMAZ (ºC)	AS	276.5
	RS	256.4
ΔT_{TMAZ} Between AS and RS	(º C)	20.1
Temperature at HAZ (º C)	AS	147.8
	RS	145.6
ΔT_{HAZ} Between AS and RS	(º C)	2.2

IV. CONCLUSION

- The maximum temperature at the tool is 413.5 ºC.
- The temperature on advancing side is higher than that at the retreating side.
- Also the temperature difference ΔT at TMAZ is higher than ΔT at HAZ region.
- IR Thermal imager can help and facilitate measurement of temperature of FSW tool while in motion, which otherwise is very difficult task.
- It proves that the Infrared Thermography can be fruitfully utilized for thermal analysis of FSW weld and thus can further be used to predict the quality of weld.

V. FUTURE WORK

The IR Thermography can further be adopted for online monitoring of weld cycle during the length of weld in FSW.

It also can be extended to study the effect of tool design and process variables on weld quality. The work in this direction is in progress.

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