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## **MONITORING MATERIAL JOINING PROCESSES WITH USE OF ADVANCED VISION METHODS**

### **Key words**

Friction stir welding, quality inspection, optical inspection, thermal imaging.

### **Abstract**

The article presents a method and a system for monitoring the processes of joining the materials with use of advanced vision techniques. The method and system are intended for use with the FSW joining method or similar techniques. The monitoring method consists in using a dual vision system comprised of a visible light camera and an infrared camera. The images recorded by both vision tracts are used to monitor the parameters of the process and to identify possible non-conformities of the weld. The developed system allows the monitoring of the process during the production of the joint with non-destructive, contactless techniques. The construction of the system allows its portability and adaptability for different types of FSW machines. Typical applications of the system include the monitoring of welding processes in the production line as well as laboratory testing for the development of the welding techniques.

### **Introduction**

The article presents the authors' method for monitoring the Friction Stir Weld (FSW) process. The FSW method [1, 2, 3] is a modern and still not very popular

method of joining two materials by “stirring” them after previous plasticisation with use of a proper tool. The rotary movement of the tool and its pressure against the welded surface generate friction and local heating of the materials that causes plasticisation. Next, the tool is moved linearly along the path of the expected weld, while the tool’s pin stirs the materials and the tool’s shoulder compresses the material in the produced weld. The important feature of the process is that the heated materials do not transform into liquid state and remain in the solid state. The method allows joining materials that are hard to arc weld or simply unweldable, including welding of different types of materials together.

### 1. Research problem and research method

There are few critical parameters to the welding process, which are spindle speed  $v_n$ , welding speed  $v_z$ , tilt angle  $\alpha$ , and the plunge force  $F_p$ . A poor choice of the parameters may result in producing faulty or just non-conformant welds. Non-conformant welds are not necessarily bad welds, but being merely mechanically strong it does not fulfil the requirements of the standard [4].

Typical non-conformances include excessive burrs, discontinuities, cracks, or an uneven edge of the weld. The following images present some examples of non-conformances (Fig. 1).

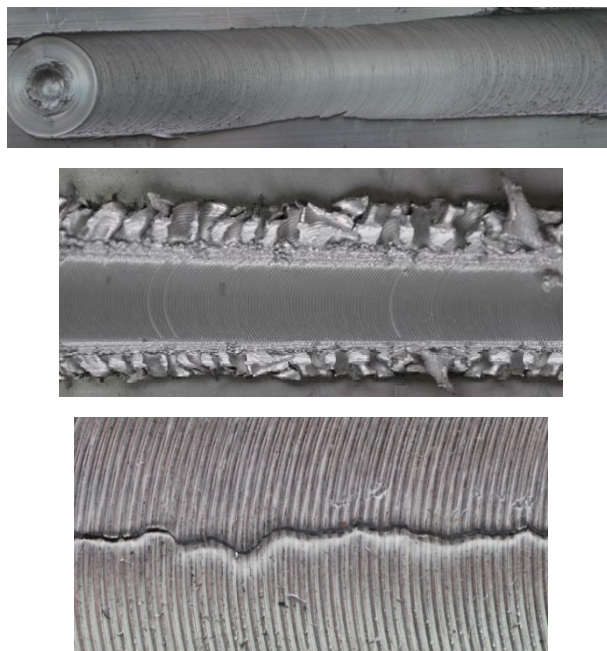


Fig. 1. Sample non-conformances in FSW process: (top to bottom) uneven edge of the weld, excessive burr on the edges, crack as an effect of overheating

In case of FSW welding, the quick and continuous inspection of the process should allow the elimination of produced faults in an automated manner already in the welding stand and allow the elimination of faulty elements. The authors of the article propose the method for monitoring the FSW process with use of a hybrid vision method, which is the recording of the image of the weld with use of thermovision camera and visible light camera (Fig. 2).

The surface of the welded material is observed by a matrix infrared camera to assess the temperature field behind the tool and with a line-scan camera that observes the surface of the material to observe the geometry of the weld.

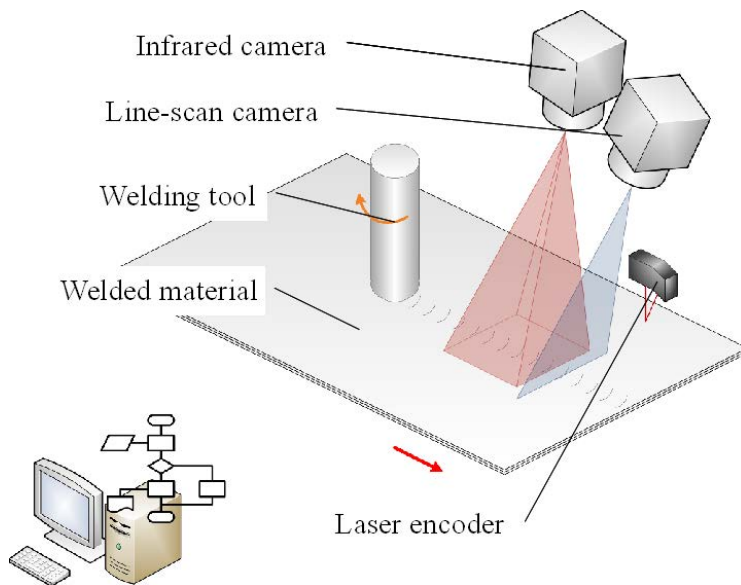


Fig. 2. The principle of the hybrid monitoring method for FSW process

The article presents selected results of introductory research performed with the use of only infrared imaging. The research on the monitoring of the FSW process of different types of materials was performed on a research stand built on the conventional vertical mill FYF32JU2. The stand was equipped with a process monitoring system based on the thermal imaging camera Flir SC5200 [5, 6], with a cooled InSb sensor for short wave IR that is for 2.5–5.1  $\mu\text{m}$ . The measurement range is divided into three sub-ranges: 5–300°C, 25–600°C and 300–1500°C. The camera was controlled by the manufacturer's software "Altair". A photograph of the stand is presented in Figure 3.



Fig. 3. The view of the research stand for monitoring the FSW process with installed thermal imaging camera

## 2. Results

Several recordings of the process were made for different rotary and linear speeds of the tool. That allowed production of both correct and faulty welds that included non-conformances, such as excessive burrs, discontinuities, or an uneven edge of the weld. The recorded thermal sequences allow identification of the faults and non-conformances of the weld during the welding process. The application of thermal imaging camera also allows the detection of sub-surface faults.

A sample image from the camera recorded during correct process of FSW welding is presented in Figure 4, and Figure 5 presents a sample profile of the temperature during along the measurement line.

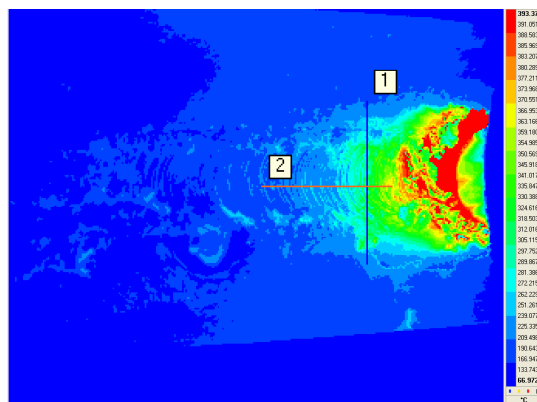


Fig. 4. The results of the measurement of the temperature with use of the camera: the thermogram from the FSW welding process

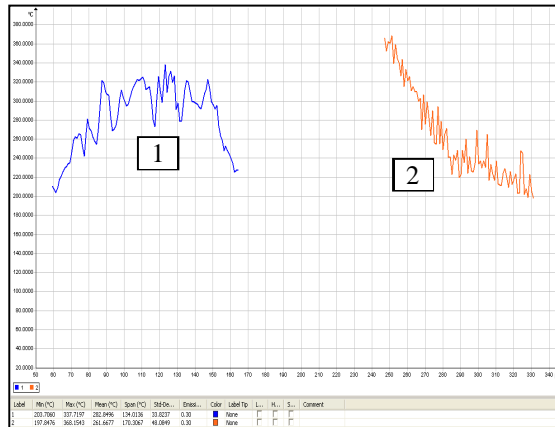


Fig. 5. The results of the measurement of the temperature with use of the camera: the profiles of the measured temperature along the measurement lines (see Fig. 4)

One of the characteristic phenomena in case of FSW welding is the appearance of excessive burr on both sides of the weld. There are also situations when part of the burr (a shaving) is pushed out behind the tool and stays on the surface of the weld causing disturbances during the measurement with the camera. Such disturbances are clearly visible on the thermograms and on the temperature profiles in the form of a local momentary decrease or increase of the temperature. The image from the camera and profile with the disturbance are presented in Figures 6 and 7.

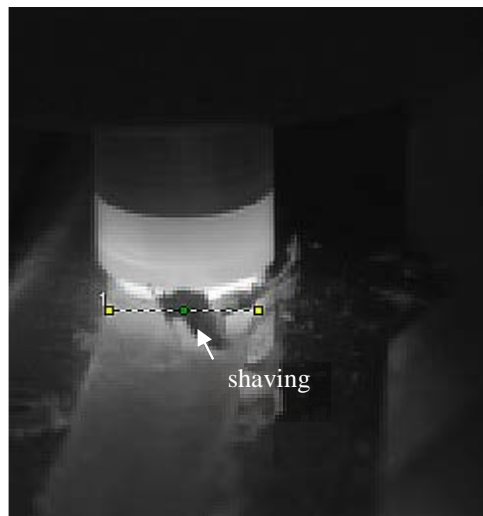


Fig. 6. Thermogram with recorded disturbance in form of a shaving

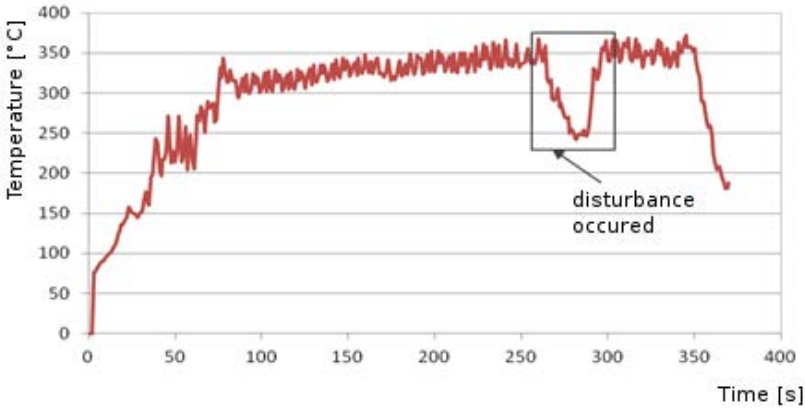


Fig. 7. The profile of the temperature with a marked result of the disturbance in form of a shaving

The recorded temperature profile (Fig. 7) has a clear “pit” that shows the presence of foreign material in the range of the observation of the surface of the weld.

The applied system intended for monitoring the FSW processes, built on the basis of the thermal imaging camera also allows the detection of sub-surface faults, such as empty spaces under the layer of the metal, cracks or the thermal results of tool’s pin fracture, which are visible on the infrared camera but visible to the human eye. The view of the weld after the process, the thermogram of the surface recorded during process, and the temperature profiles along lines 1 and 2 are presented in figures 8 and 9.

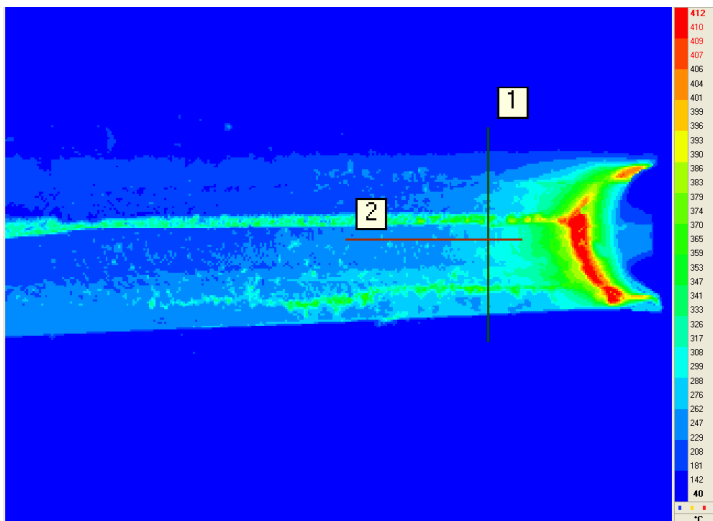


Fig. 8. Detection of sub-surface faults: thermal image of the surface during the process (see Fig. 9)



Fig. 9. Detection of sub-surface faults: temperature profiles along the lines 1 and 2 (see Fig. 8); marked is a temperature peak that shows the sub-surface cavity

Another example of sub-surface fault detection is shown below. The surface of the weld (Fig. 10) is unequal, but the weld itself seems continuous. Visual observation does not show excessive non-conformities.



Fig. 10. The view of the weld surface

The observation of the weld using thermal imaging camera (Fig. 11) shows that there exists some irregularity in the structure of the weld.

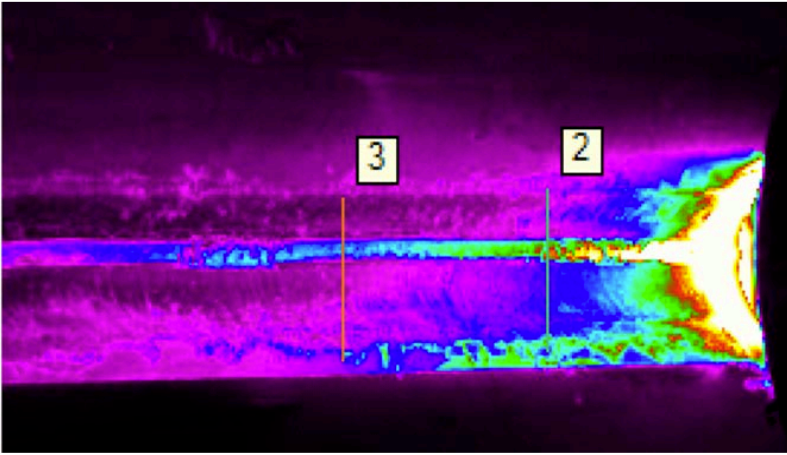


Fig. 11. Thermal image of the surface during the process (see Fig. 10)

The irregularity shows as a line of increased temperature along the path of the tool. The analysis of the temperature profiles along lines 2 and 3 indicates obvious variations of temperature.

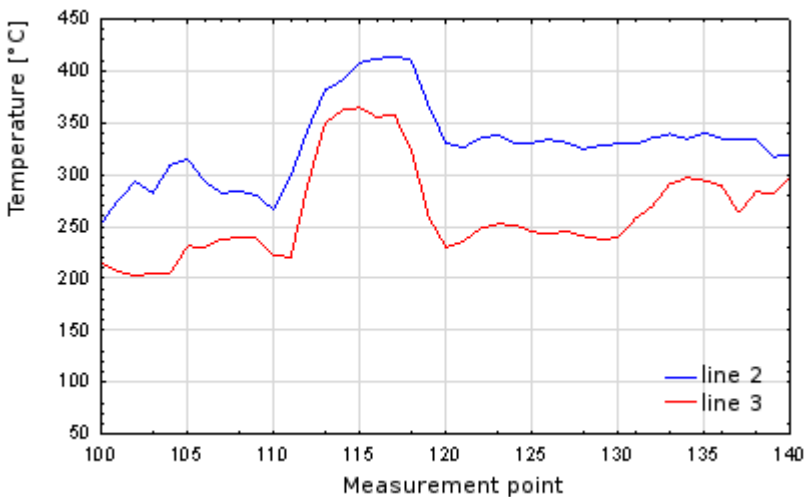


Fig. 12. Temperature profiles along the lines 2 and 3 (see fig. 11)

The assessment of the weld should be unequivocal – the weld is faulty.



## Conclusion

The presented monitoring method for the friction stir welding process consists in the utilisation of information contained in the images of the weld recorded in infrared band and visible light band. The proposed hybrid inspection system, thanks to its modular and flexible structure, may be adapted to all kinds of FSW types and FSW machinery. A crucial element of the system is a database with a pattern catalogue as well as non-compliances catalogue.

The method is intended for FSW processes, but its general principle of using two light wavelengths allows its application for other uses, such as arc-welding process monitoring, the assembly of components at high temperatures, and the testing of products at high temperatures.

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## **Monitorowanie procesów łączenia materiałów z wykorzystaniem zaawansowanych metod wizyjnych**

### **Słowa kluczowe**

Zgrzewanie tarciove z mieszaniem materiału FSW, kontrola jakości, optyczna inspekcja, analiza termograficzna.

### **Streszczenie**

W artykule zaprezentowano metodę oraz system do monitorowania procesów wytwarzania połączeń materiałowych z użyciem zaawansowanych technik wizyjnych. Metoda oraz system przeznaczone są do wykorzystania z technologią zgrzewania tarciovego z mieszaniem materiałów (FSW – ang. *Friction Stir Welding*) lub podobną. Metoda monitorowania polega na wykorzystaniu dualnego systemu wizyjnego składającego się z kamery światła widzialnego oraz kamery termowizyjnej. Obrazy rejestrowane w obu torach optycznych wykorzystywane są do monitorowania parametrów procesu oraz do identyfikacji potencjalnych niezgodności powstałej spoiny materiałowej. Opracowany system pozwala na monitorowanie procesu łączenia on-line z wykorzystaniem nieniszczącej, bezkontaktowej techniki pomiarowej. Konstrukcja systemu umożliwia jego montaż i adaptację do różnych typów maszyn do zgrzewania tarciovego. Typowe zastosowania dla prezentowanego rozwiązania obejmują monitorowanie procesów zgrzewania na liniach produkcyjnych oraz badania laboratoryjne, których celem jest rozwój technologii zgrzewania tarciovego.