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Method of tracking of HAZ properties based on sequence of infrared images

Abstract

Arc welding is commonly applied in industry. Assessment of the quality of welded joints is one of crucial tasks especially in automated applications. In the paper preliminary research devoted to the evaluation of Heat Affected Zone (HAZ) properties using method of tracking of defined Region of Interest (ROI) on infrared images continuously acquired during welding process. The proposed method can be useful to detection of welding instabilities as well as welded joint defects.

Keywords: infrared imagining, welding monitoring, image processing.

1. Introduction

During the welding, different instabilities can occur and could have significant influence on properties of welded joint and quality of the whole product. In the case of arc welding, instabilities of the welding speed, welding current and electric arc voltage lead to changes of the linear energy introduced into the joint, and as a consequence, this influences of the welded joint as well as Heat Affected Zone (HAZ) properties. HAZ is an area adjacent to welded join where properties of the material are worse than in the base material. Thus, the key issue is to reduce the width of the HAZ and control its properties.

Detection of welded joint including HAZ properties could be performed in different ways. The most often classical off-line methods based on NDE techniques are applied. Also on-line monitoring based on measurements and analysis of signals of current, voltage, sound etc. can be used [5]. There are also methods based on temperature measurement using infrared devices [4] including infrared cameras [1, 6].

In this article a method of evaluation of HAZ properties based on tracking of temperature profiles during the welding is proposed.

2. Method of tracking of HAZ properties

A more accurate approach to observing and controlling HAZ properties could be the application of infrared thermography [2, 3].

Welding is a dynamic process were welded parts or welding torch are moving during the joint creation thus monitoring of HAZ properties also should be performed in dynamic way through tracking in space as well in time of selected area of welded parts.

Let's consider configuration of welding setup presented in Fig. 4, where welding torch as well as infrared camera are stationary and the welded parts located on trolley are moving with speed *v* relative to a camera. Using an IR camera it is possible to observe in continuous way a transient thermal phenomena during welding and after welded joint creation.

If IR camera Field of View (FOV) will be set in a way presented in Fig. 1 where welding parts are moving across the FOV we can acquire infrared images of heat distribution directly after welded joint creation. Let's assume that it is possible to define Region of Interest (ROI#1) of dimensions *w*x*h* placed on the top of acquired infrared image at the beginning of welding process t_1. Having information about dimensions of FOV, instantaneous welding speed *v* and frame rate *fr* it is possible to calculate shift of the welded parts *dL* between successively recorded images. Knowing of welded parts shift it is possible to shift the defined ROI#1 assuring continuous observation of the same area from image to image. Tracking of weld and HAZ area within the defined ROI boundaries make it possible to analyze changes in temperature distribution and detect HAZ properties, defects in the welded joint as well as welding instabilities. In this article assumed that a profile describing temperature distribution across the joint and the HAZ area can be created and tracked. The profile is calculated by averaging the temperature values along height *h* of the defined ROI#1.

Due to movement of welded parts it is necessary to successively define the next ROIs to track the next sections of the welded parts.

Tracking of defined ROIs should be make as long as parts are moving. After making of whole weld an acquisition of infrared images should be continued to obtain proper cooling profile.

Proposed approach can be implemented in on-line as well as off-line mode. In this article a second way was considered.

Application of above described approach due to necessity of definition of *n* ROIs requires generation of *n* sets of data. Each data set consists *m* temperature profiles ordered in domain of acquisition time. Such data representation allow us to present it in different form and perform a different kind of analysis.

On the basis of the profile series, it is possible to identify temperature profiles across the weld and HAZ as well as cooling profiles (Fig. 2) as a functions time-temperature *T*(*t*) showing the cooling phenomena in the HAZ. Using this function, one can estimate some parameters describing the HAZ's properties.

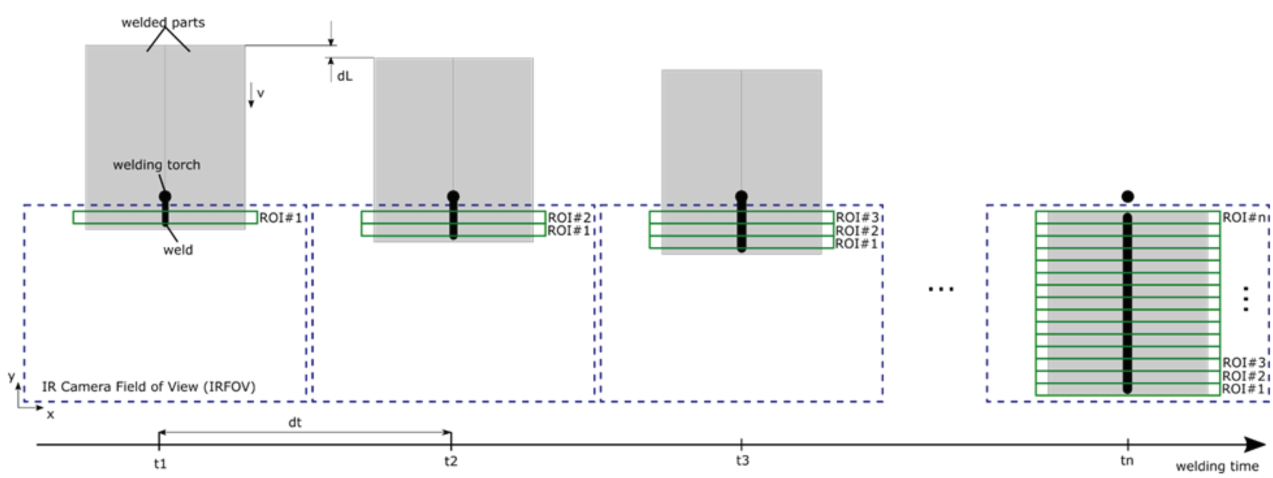

Fig. 1. Idea of tracking of weld and HAZ properties using infrared camera

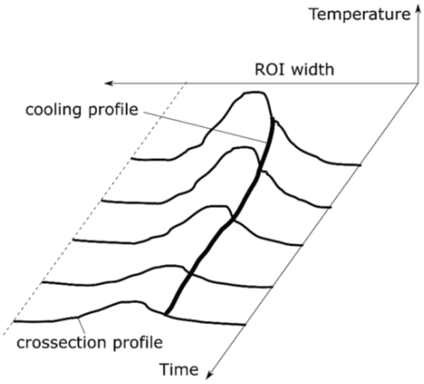

Fig. 2. Possibility of analysis of data set created on the basis of single ROI tracked during welding

During the research a relative cooling time $t_c = t_{max} - t_{1/2}$ was considered as a diagnostic parameter and used to assess welding process. Cooling time describes time from moment corresponding to the maximum profile temperature to time when temperature dropped a half (Fig. 3). The proposed parameter allows to consider the temperatures relatively and partially reduce problem of emissivity variation during the welding.

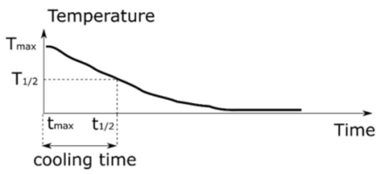

Fig. 3. Idea of assessing of the cooling profile

3. Acquisition of infrared images

In order to verify proposed method of tracking HAZ properties, series of experiments were carried out.

The experiments were performed using laboratory stand (Fig. 4) equipped with welding machine (WM) Castolin TotalArc 5000, wire feeder (WF), table with trolley for rectilinear welding. Infrared images of the welded specimens were gathered using an uncooled infrared camera Infrarec VarioCam connected to FireWire frame grabber (FG) installed in the computer (PC). The IR camera had a resolution of 320×240px, lens of focal length *f*=25mm (FOV 32°×25°) and was able to acquire images with a frame rate of 50 fps. Optical axis of the camera was perpendicular to plane of welding table. Distance (*d*) between camera and surface of welded specimen was 600 mm. In order to protect the camera against very intensive infrared radiation as well as splatters a 1mm thin polyethylene protective shield was used. The shield transmission properties was considered in the camera setup. The laboratory stand was additionally equipped with sensors for measurement of voltage (V), current (A), trolley speed (*v*) and gas flow (*G*). Sensors connected through the signals conditioning module (SC) to multichannel data acquisition card (ADC) installed in the computer (PC). All components of welding monitoring systems were controlled by originally developed software working in the LabVIEW environment.

During the welding, plates made of steel S235JR (EN 10027-1) with dimensions 300 mm × 150 mm × 5 mm were joined. The edges of the plates were chamfered at the angle of $\alpha = 60°$ and the offset between them was b = 1.0 mm. For welding purposes a solid electrode wire with a diameter of 0.2 mm (Castolin CastoMag 45255) and a shield gas M21 (82% Ar + 18% CO_2) were used. Nominal welding parameters are presented in Tab. 1.

During the experiments different conditions of welding process were simulated.

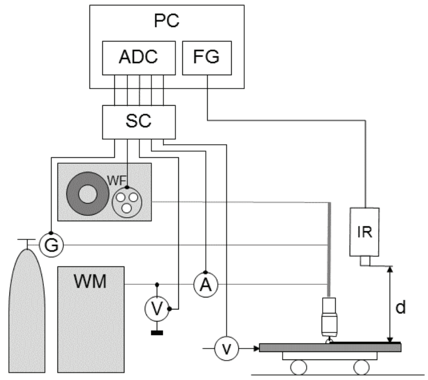

Fig. 4. Experimental setup

Tab. 1. Nominal welding parameters

Welding current, A	Arc voltage, V	Welding speed, cm/min	Wire feeding rate, m/min	Shield gas flow, l/min	Wire tip outlet, mm
240	25	32	7.4	15	15

4. The results of experimental research

Sequences of infrared images gathered during the experiments were processed according to the method described in section 2. In Fig. 5 two infrared images acquired at the beginning and at the end of tracking of welded joint and HAZ by defined ROI are presented.

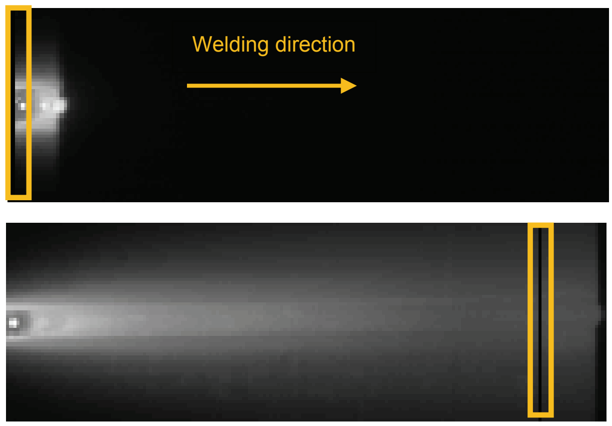

Fig. 5. Welded parts before tracking and at the end of tracking by ROI

During the tracking of the area of welded parts a series of temperature profiles were determined and shown as a temperature map in Fig. 6. Using such map it is possible to clearly describe geometrical properties of HAZ. The plots show irregularities following for instance from uneven cooling process of the weld as well as HAZ. Asymmetric temperature distribution is also confirmed by two temperature profiles (Fig. 7) taken at the beginning and at the end of tracking of area defined by one of the ROIs. As one can see in Fig. 7 the temperature profiles allow to indicate weld region as well as left and right HAZ. It is important for indication of points or areas for estimation of cooling function in HAZ. In Figs 8 and 9 series of cooling profiles determined for left HAZ for 20 pixel are presented.

Cooling profiles were determined for two welding conditions. Fig. 8 shows series of cooling profiles for welding without faults. In Fig. 9 profiles for welding with instability caused by oil contaminations are presented. A cooling profiles during tracking of area with detected instability are indicated in the plot.

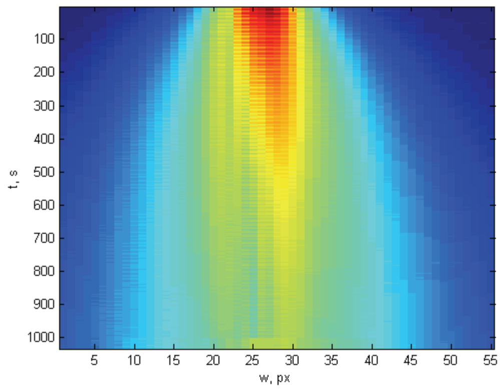

Fig.6. Map o temperatures after tracking of weld and HAZ

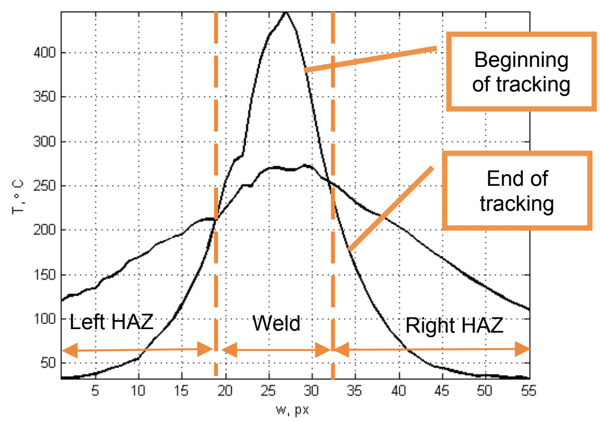

Fig. 7. Profiles of weld and HAZ at the beginning and at the end of tracking

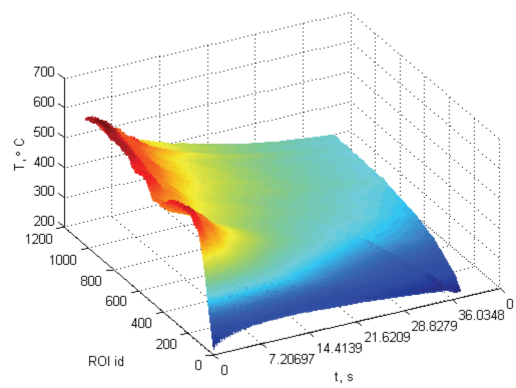

Fig. 8. Cooling characteristics for series of tracked ROIs in selected point of HAZ for welding process without instabilities

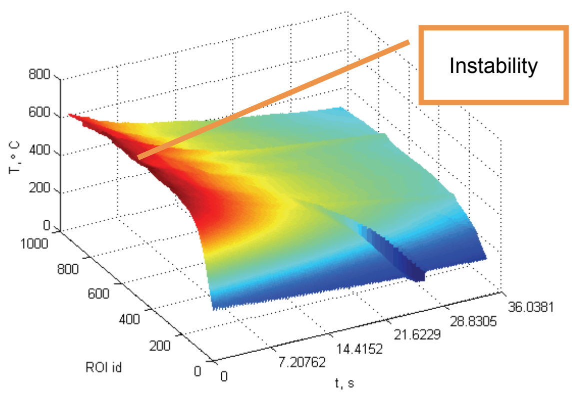

Fig. 9. Cooling characteristics for series of tracked ROIs in selected point of left HAZ for welding process with instability caused by oil contamination

5. Conclusions

The article presents the method of tracking of temperature distribution in selected areas of welded parts during or directly after welding. Preliminary research concerned sequences of infrared images acquired during arc welding confirms potential of the proposed approach to detection of welding instabilities as well as irregularities in temperature distribution during cooling of tracked area.

Data sets generated during the application of the method allow to look at welded parts from different points of view. First of all it is possible to observe, analyze and compare temperature profiles in different cross sections of welded parts as well in different temperatures during cooling process. Secondly it is possible to observe and analyze cooling process in tracked areas. It can be done in different ways. One of possibility is shown in the article however some approaches coming from active thermography also can be applied in the further research. The advantage of the method is possibility of identification of HAZ properties and weld defects (e.g.. cracks) based on analysis of cooling process after making a weld. Metallic surface of the weld and joined parts has good ability to reflect part of heat radiation generated during an arc burning. In this way instabilities of arcing could be revealed. Unfortunately low emissivity of weld and joined parts can be source of interferences affecting the results of tracked areas analysis and finally wrong diagnoses. Additional problem connected with application of the method is huge amount of data generating during tracking of small areas of welded parts. Taking into consideration some disadvantages it is necessary continue development of the method and further research on area of data analysis as well as assessment of influence of low emissivity in the tracked areas. It will be aim of further author's works.

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