Mechanical Systems and Signal Processing 93 (2017) 634–644

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/ymssp

A comparison of two types of neural network for weld quality prediction in small scale resistance spot welding

Xiaodong Wan[a,b], Yuanxun Wang[b,c,*], Dawei Zhao[b,d], YongAn Huang[a]

[a] *State Key Laboratory of Digital Manufacturing Equipment and Technology, Huazhong University of Science and Technology, Wuhan 430074, China*
[b] *Department of Mechanics, Huazhong University of Science and Technology, Wuhan 430074, China*
[c] *Hubei Key Laboratory for Engineering Structural Analysis and Safety Assessment, Luoyu Road 1037, Wuhan 430074, China*
[d] *School of Mechanical Engineering, Linyi University, Linyi 276000, China*

ARTICLE INFO

Article history:
Received 14 September 2016
Received in revised form 1 January 2017
Accepted 20 January 2017

Keywords:
Small scale resistance spot welding
Titanium alloy
Quality monitoring
Electrode voltage
Dynamic resistance
Neural network

ABSTRACT

Our study aims at developing an effective quality monitoring system in small scale resistance spot welding of titanium alloy. The measured electrical signals were interpreted in combination with the nugget development. Features were extracted from the dynamic resistance and electrode voltage curve. A higher welding current generally indicated a lower overall dynamic resistance level. A larger electrode voltage peak and higher change rate of electrode voltage could be detected under a smaller electrode force or higher welding current condition. Variation of the extracted features and weld quality was found more sensitive to the change of welding current than electrode force. Different neural network model were proposed for weld quality prediction. The back propagation neural network was more proper in failure load estimation. The probabilistic neural network model was more appropriate to be applied in quality level classification. A real-time and on-line weld quality monitoring system may be developed by taking advantages of both methods.

1. Introduction

Owing to the superior properties of low density, high specific strength and corrosion resistance, titanium alloy is now widely applied in aerospace, electronic and biomedical industries. The long service life makes equipments fabricated by titanium alloy very promising. Welding of titanium alloy has been drawing more and more attentions due to the increasing demands. It is a crucial task in joining titanium alloy considering the inherent materials properties. Titanium alloy reacts actively with atmosphere gases like the nitrogen and oxygen at high temperature, which may result in the severe embrittlement of weld nugget. Contaminations can be introduced because of the insufficient shielding gas and inappropriate surface pretreatment. Traditional "large scale" resistance spot welding (LSRSW) is generally adopted in the automotive industry [1]. Weld nugget is formed between overlapped sheets by resistance heating in LSRSW. Weldability of pure titanium sheets in LSRSW has been verified by Kahraman et al. [2,3]. An ideal gas isolation could be provided by the electrode force during resistance spot welding of titanium alloy.

The fabrication of miniaturized medical and electronic devices is now in an increasing demand. Sheet metals to be jointed under these conditions are generally thinner than 0.5 mm. The concept of small scale resistance spot welding (SSRSW) is thus put forward. There are many differences between SSRSW and LSRSW, especially in aspects of the magnitude of electrode

---

* Corresponding author.
E-mail address: wangyuanxun@hust.edu.cn (Y. Wang).

http://dx.doi.org/10.1016/j.ymssp.2017.01.028

force and welding current, cooling way, electrical and mechanical control precision [4]. Maintaining a high weld quality in SSRSW is not easy considering the complicated welding mechanism. Electrode sticking, non-repeatable welding and expulsion may occur easily simply by scaling down welding parameters from LSRSW to SSRSW [5].

The sensor based quality monitoring approach is generally adopted in welding and joining processes [6,7]. Different dynamic signals were measured, and various signal processing methods could be used to monitor the weld quality [8,9]. As to the resistance spot welding process, quality monitoring and control in LSRSW can be realized using the dynamic resistance [10–12], electrode displacement [13–15], electrode force [16–20], electrode vibration [21], electrode temperature [22], and sonic emission [23], etc. However, there remains a lack of investigation on quality monitoring in SSRSW despite the great demand.

Tan et al. [4] analyzed the dynamic resistance curve in SSRSW of 0.2-mm thick bare Ni sheets. The curve obtained was supposed useful for weld quality control. Farson et al. [24] found that expulsion occurrence in SSRSW could be detected from the electrode voltage spike, electrode displacement decrease, and magnitude of electrode force fluctuation. Tseng et al. [25] stated that the maximum electrode displacement was an effective signal reflecting nugget formation and growth in SSRSW. Chen et al. [26] proposed a finite element model to simulate the SSRSW process of stainless steel. Nugget size was estimated through the minimum dynamic resistance and maximum electrode displacement.

A reliable weld quality estimation is helpful to promote the application of SSRSW. Our study focuses on the quality monitoring in SSRSW of titanium alloy. The measured electrode voltage and dynamic resistance were adopted as monitoring signatures. The relationship between weld quality and features extracted from the electrical signals was analyzed. Different neural network model were proposed for weld strength estimation and quality level classification.

2. Experimental procedure

TC2 is one of the commonly used titanium alloys. Here, the TC2 titanium alloy with 0.4-mm thickness was selected as the base material. Chemical composition of TC2 is listed in Table 1. Sheet metals were cut into dimensions of 100×30 mm. The specimen size prepared for SSRSW and tensile-shear test is shown in Fig. 1. Mechanical and chemical cleaning were both applied before welding. Ranges of welding parameters are listed in Table 2. Welding parameters were selected randomly and distributed as uniform as possible. Sixty samples were used in the experiment.

The welding machine was produced by Miyahci Unitek Corporation, and worked at high frequency inverter power supply. Welding was conducted under constant welding current mode. Tip diameter of the electrode was set as 3.0 mm. No cooling water was provided during the welding. Quasi-static tensile-shear test was performed by a universal testing machine at constant cross-head speed of 1.0 mm/min. Failure load (F_l) was extracted from the load-displacement curve. The nugget size was measured from failed sample after tensile-shear test.

As to the signal acquisition system, electrode voltage was obtained directly by clamped probes, and a Rogowski coil was applied to measure the welding current. Both signals were acquired at a fixed sampling rate. Signals were then delivered to the digital signal processor, filtrated and noise reduced. The dynamic resistance curve was obtained through dividing

Table 1
Chemical composition of TC2 titanium alloy, wt.%.

Alloying elements			Impurities (not higher than)					
Al	Mn	Ti	Fe	C	N	H	O	Others
3.5–5.0	0.8–2.0	Bal.	0.30	0.10	0.05	0.012	0.15	0.40

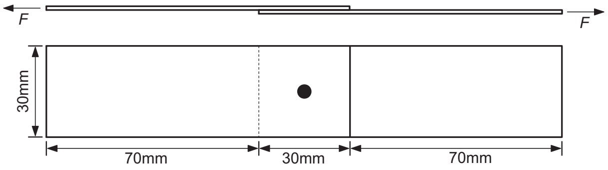

Fig. 1. Specimen dimensions for SSRSW.

Table 2
Ranges of welding parameters.

Welding parameter	Symbol	Unit	Scope
Electrode force	F	N	100–200
Welding current	I	kA	1.2–2.4
Welding time	T	ms	6–12