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Study on the nugget growth in single-phase AC resistance spot welding based on the calculation of dynamic resistance

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ABSTRACT

The process of nugget growth is invisible and difficult to test nondestructively in the process of resistance spot welding. In this study, the change of welding current and electrode voltage in the secondary circuit was monitored in real-time. Accordingly, the variation of the dynamic resistance was obtained across electrodes and the dynamic resistance in welding process was analyzed to characterize the nugget growth. The results show that the whole process of nugget growth is composed of initial stage, growing stage and stable stage according to the curve of dynamic resistance. The curve variations of three stages indicate the characteristic of nugget growth. Different types of nugget growth show diverse curves of dynamic resistance, which is a useful means to estimate the nugget growth and nugget quality. But only the forming process of adequate nugget is composed of three stages (initial stage, growing stage and stable stage) completely. The welding parameters such as welding current, electrode force, etc affect the process of nugget growth. Larger welding current and larger electrode force improve the rate of nugget growth.

1. Introduction

The resistance spot welding (RSW) process is widely used in manufacturing, especially automotive industry. This welding process is very complicated as it involves interactions of electrical, thermal and mechanical phenomena. The nugget formed in the workpiece plays a crucial role in joining structure. As the nugget of spot welding is enclosed in joining structure, the process of nugget growth is invisible and difficult to test. Researchers have investigated the possibility to analyze the mechanism of nugget growth and estimate the weld quality by various methods.

Destructive test is the most common method for spot weld quality, which is widely used in macrostructure or microstructure observation and mechanical characteristics testing. But destructive test has low efficiency and results in the invalidation of spot weld. So, researchers toward quality evaluation and nugget growth of spot welds tend to develop nondestructive test technology. At present, spot weld quality test based on on-line technology has been proposed, which could provide basis for technological development of nondestructive test. The measurement of various dynamic signals in RSW process is necessary in order to realize that. Ling et al. (2010) took the input electrical impedance of the welding system as quality monitoring signature for characterizing resistance spot welding, which provided a method for the weld quality classified non-destructively and automatically. Podrzaj et al. (2005) introduced audible sound signals detected in RSW to estimate spot weld strength. The method made it possible to develop the system to test the spot weld quality nondestructively. Certainly, the welding parameters such as welding current, electrode force and current duration brought a direct impact to weld quality, which was proved by Danial et al. (2014). So, the welding current, voltage and other parameters in welding were detected by an on-line method to monitor the welding process. Li (2012) developed a high speed data acquisition and spot welding signal processing system for on-line monitoring and controlling the quality of RSW. The welding current and voltage were two important signals source in this system. Similar on-line system was developed by Mei et al. (2009) for electrode invalidation monitoring during spot welding of zinc-coated steel, which was valuable for industrial production. Wang et al. (2009) took electrode displacement as an ideal monitoring parameter. Accordingly, a quality monitoring system was developed to

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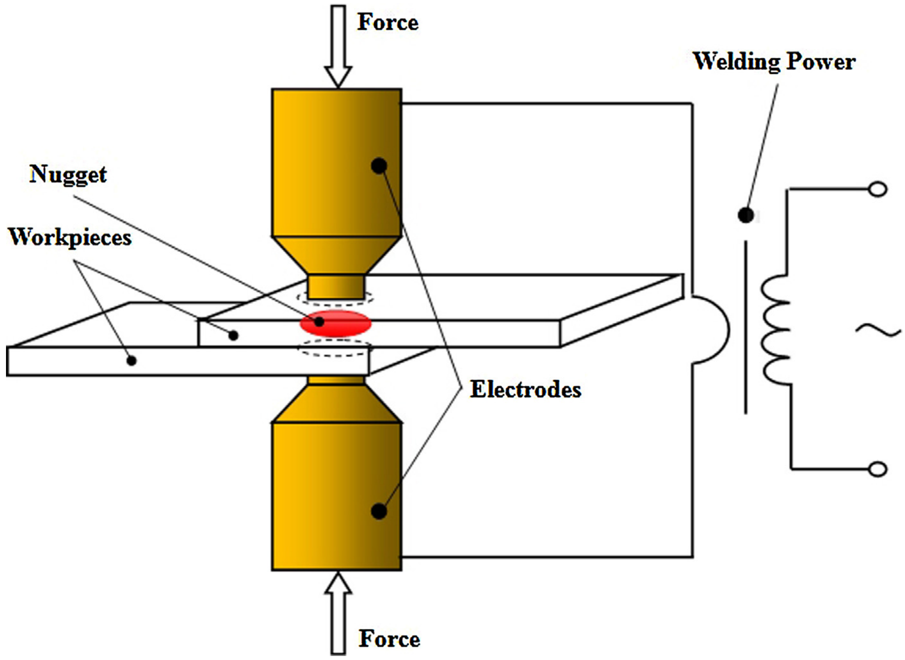

Fig. 1. Schematic diagram of nugget formation.

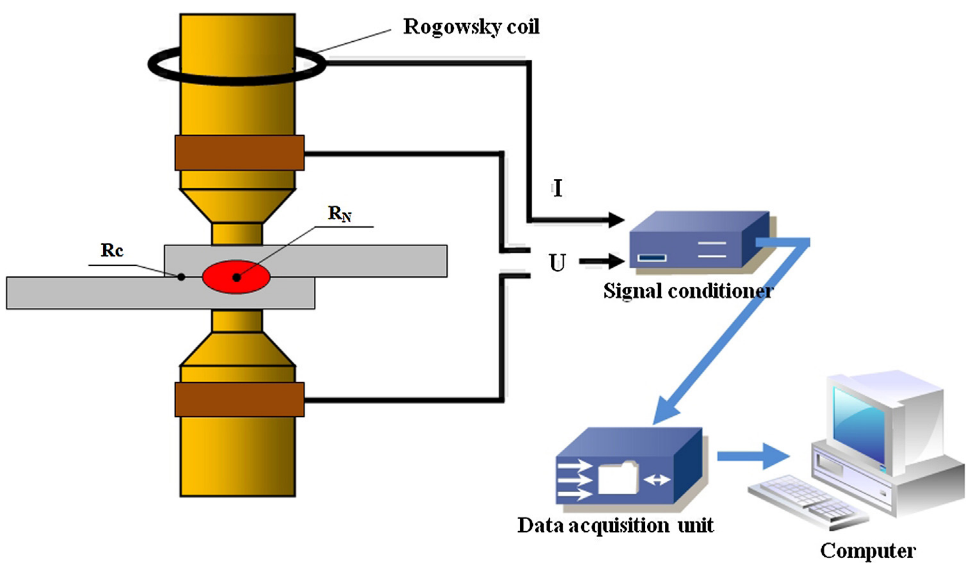

Fig. 2. Schematic diagram showing the detection of dynamic resistance by the secondary circuit and monitor system.

reflect the nugget formation of spot weld directly, which results demonstrated the validity and effectiveness of the methodology.

Mathematical model is seemed as an effective means to predict welding quality and optimize welding process design. According to the basic welding parameters, a model of artificial neural network was proposed to predict the tensile shear load bearing capacity of spot weld by Óscar et al. (2009). Statistical models also were developed to demonstrate various fundamental relationships between welding parameters and quality characteristics by Han et al. (2011). More effective means were numerical simulation. Hessamoddin and Iradj (2012) developed a Finite Element Method program to simulate the process of nugget growth and predict nugget size. The coupling of the electrical field, thermal field and mechanical field during resistance spot welding was considered by Ma and Murakawa (2010). The quality features of nugget were accurately estimated by the simulation. Feulvarch et al. (2004) proposed a general finite element formulation of the electrothermal contact. The results of the finite element analysis presented a correct correlation with experiments in terms of HAZ size as well as nugget shape.

Dynamic resistance signals are considered to be closely related to the nugget formation of the spot weld, which is used to estimate the weld quality. But the dynamic resistance fluctuation is affected by the contact surface condition at sheet/sheet and electrode/sheet. Wei and Wu (2012) thought the contact surface condition was uncertainty in welding, which increased the difficulty of direct measurement to dynamic resistance in nugget development. Cho and Rhee (2000) monitored the process variables in the primary circuit of the welding machine and the primary dynamic resistance was obtained. Furthermore, a monitoring system was proposed to estimate the weld quality using the primary dynamic resistance. Zhou and Cai (2013) provided an integrated real-time control