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RESEARCH ON THE SURFACE COATINGS INFLUENCE ON FORMATION MECHANISM OF THE RESISTANCE WELDS

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ABSTRACT
The goal of the work is the research of formation mechanism of the spot resistance welds in the case of copper wires with nickel and tin coatings. The existing approaches for investigation of the formation mechanisms of welds of wires with and without coatings are analysed. A new approach for modeling of welding joint formation is offered. The analog model of the heat input during resistance welding of wires with coating is described.
Keywords: resistance welding, coating, formation mechanism, modeling

1. INTRODUCTION

Nickel-plated and tin-coated wires are widely used in the electric engineering. Resistance welding is one of the basic methods for joining wires during the manufacture of semiconductor and vacuum devices, integrated circuits, and radio components.

Despite its wide use, the understanding of the process is very limited. This is due to the fact that hypotheses suggesting the impact of one or another physical phenomenon on the material joining mechanism were put forward on the grounds of interpretation of the post-weld microstructure analysis and detailed mechanical testing [1-4]. There is a range of computational methods allowing performing the assessment of impact of individual factors on the joining mechanism and calculating the welding modes with the specified degree of accuracy. However, there is no unified theory explaining the formation of weld joints with pressure. Multiple interpretations for microstructural evolution of welds occur because researches have been performed without direct confirming evidence of the actual phases occurring during welding. For this reason, real time X-ray diffraction methods were presented as means for the direct observation of phase transformations during welding [5]. Anyway, such a pattern is characterised by some limiting factors. First is a large size of the samples currently used for these experiments. Second is the speed and resolution of the X-ray detectors.

On the other hand, modern requirements of the quality of weld joints are high. That is why it is necessary to create the process model for electrical resistance welding taking into account both the welding mode parameters and physical mechanical properties of wire and coating materials in order to perform predictive modelling of resultant weld joints. The aim of this work is to study the mechanism of resistance spot welding of crossed copper wires by carrying out the analog modelling.

2. WELD FORMATION MECHANISM FOR WIRES WITH AND WITHOUT COATINGS

During the modelling and study of weld formation mechanism for wires with coatings the properties of the coatings must be taken into account. Coating material significantly influences the welding process, especially during the welding of multifilament wires. In general, the welding properties of wires with coatings are determined by physical mechanical properties of coating and basic material as well as their thickness. Copper wires without coating have the worst welding properties due to their specific physical and mechanical properties [6,7].

It is known, that process of metal joining formation in a solid phase for any methods of pressure welding should be considered in four basic stages. For the case of crossed fine nickel wire, it is proposed [1] that welding process includes the following stages:

(1) cold-wire collapse;
(2) surface melting;
(3) molten-phase squeeze out, and
(4) solid-state bonding.

It is believed that sufficient surface melting and subsequent squeezing out of the molten phase is needed to produce fresh metal surfaces for strong solid-state bonding. The basic stages for wires with coating are as follows:

(1) formation of physical contact, i.e. approachment of atoms of connected materials due to plastic deformation in the length where the physical interaction due to Van der Waals forces or chemical bonding may occur;

(2) activation of contact surfaces (formation of active centres). At this stage of welding the heterogeneous materials, the formation of active centres on the surface of harder material occurs. Existence and duration of this stage are conditioned by characteristics of plastic deformation. During the welding of homogeneous metals the first and second stages occur simultaneously since activation of the contact surfaces begins at the moment of approachment of surfaces;

(3) volumetric interaction. This stage starts from the moment of formation of active centres on the welded surfaces. At this stage, the development of interaction of connected metals occurs in both a plane of contact and volume of contact zone.

We can assume that coating significantly influence the weld formation mechanism.

The fragmentary models of electrical resistance welding process are known. Thus, in [8] the empirical model describing the electrical contact resistance per unit area for steel/steel and steel/copper contacts as a function of contact pressure, temperature, and material properties was offered. An analytical model was developed [9] to relate the electrode displacement to the change of clamping force in welding for the welding head of a small-scale resistance spot welding machine. The welding head was simplified by two one-degree-of-freedom systems being composed of spring, damper, and mass. The model parameters were defined, by the applying the experimental data.

It could be assumed that application of traditional procedures such as experimental method, statistical approach, and fragmentary logic analysis for study of resistance welding process may take the significant time and does not describe all aspects of process. Other existing real time methods are quite expensive.

That’s why for research of formation mechanism of the spot resistance welds we have decided to use the method of the analog (non-discrete) modelling, which was proposed by R. B. Rudzit [10] and was successfully used by authors and other researchers [11-14]. The main advantage of this method is that the application of system analysis by logical functions allows describing the causal and effect relationships between large numbers of parameters of the welding technological process. Analog modelling is especially efficient in development of new welding technological processes and in optimization of known processes [10-14].

3. ANALOG MODEL OF THE HEAT INPUT DURING THE RESISTANCE WELDING OF WIRES WITH COATING

The quality of electrical resistance welding process of copper wires with coating mainly depends on the amount of heat discharging *Q* during the resistance welding of wires with coating. We decided to start the analog modelling of resistance welding of wires with coating from analog modelling of the

heat input during the resistance welding. The structural logical analysis scheme of Q characteristic is shown in Figure 1.
The logical analysis is performed until the stage, where the function's arguments are variable parameters we are interested in.

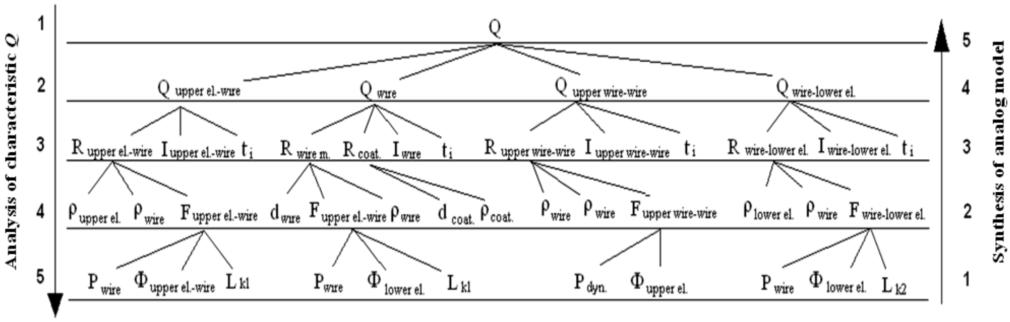

Figure 1. Structural logical analysis scheme of Q characteristic.

In the first stage of logical analysis, the Q characteristic may be displayed as a function:

$$Q = f\,|\,Q_{upper.el.\text{-}wire} / + / Q_{wire1} /+/ Q_{upper\ wire\text{-}wire} /+/ Q_{wire2} / + / Q_{wire\text{-}lower\ el.}|, \qquad (1)$$

where $Q_{upper\ el.\ wire}$ – the amount of heat discharged during the impulse of welding current in the resistance of upper electrode wire contact; Q_{wire1} – the amount of heat discharged by impulse of welding current in the contact while passing through resistance of the first wire; $Q_{upper\ wire\text{-}wire}$ – the amount of heat discharged during the impulse of welding current in the resistance of upper wire-wire contact; Q_{wire2} – the amount of heat discharged by impulse of welding current in the contact while passing through resistance of the second wire; $Q_{wire\text{-}lower\ el.}$ – the amount of heat discharged during the impulse of welding current in the resistance of wire-lower electrode contact.
After conducting a system analysis, the fusion process must be carried out via consecutive substitution of parameters-arguments from previous stages of analysis by parameters-arguments from the following stage determining those of previous stages [10].
As a result of all substitutions, the analog formula of Q characteristic is defined. Its record in logical relations represents the analog model of the amount of heat discharged during the electrical resistance welding of wire with coating:

$$\begin{aligned} Q = f(&\Big|^{1}_{5}\Big|^{1}_{4}\Big|^{1}_{3}\Big|^{1}_{2}\Big|^{1}_{1} P_{wire} /+/ \underset{P_{wire0}}{\exists}\, \Phi_{upper\ el.} /+/ L_{K_1} \Big|_{1} /+/ \rho_{upper\ el.} /+/ \rho_{wire} \Big|_{2} /\cdot/ J_{upper\ el.\text{–}wire} /\cdot/ t_i \Big|_{3} \Big|_{4} /+/ \\ /+/ &\Big|^{2}_{4}\Big|^{2}_{3}\Big|^{2}_{2}\Big|^{2}_{1} P_{wire} /+/ \underset{P_{wire0}}{\exists}\, \Phi_{upper\ el.} /+/ L_{K_1} \Big|_{1} /+/ d_{wire} /\cdot/ \rho_{wire} \Big|_{2} /+/ b_{coat} /\cdot/ \rho_{coat} \Big|^{3}_{2} /\cdot/ J_{wire} /\cdot/ t_i \Big|_{3} \Big|_{4} /+/ \\ /+/ &\Big|^{3}_{4}\Big|^{3}_{4}\Big|^{4}_{2}\Big|^{3}_{1} P_{dyn} /+/ \Phi_{upper\ el.} \Big|_{1} /+/ \rho_{wire} /+/ \rho_{wire} \Big|_{2} /\cdot/ J_{upper\ wire\text{–}wire} /\cdot/ t_i \Big|_{3} \Big|_{4} /+/ \Big|^{4}_{4}\Big|^{4}_{3}\Big|^{5}_{2}\Big|^{4}_{1} P_{wire} /+/ \\ /+/ &\Phi_{lower\ el.} /+/ L_{K_2} \Big|_{1} /+/ \rho_{wire} /+/ \rho_{lower\ el.} \Big|_{2} /\cdot/ J_{wire\text{–}lower\ el.} /\cdot/ t_i \Big|_{3} \Big|_{4} \Big|_{5}). \end{aligned} \qquad (2)$$

where P_{wire} – static pressure on the wire; $\Phi_{upper\ el.}$, $\Phi_{lower\ el.}$ – shape parameters of upper and lower electrodes; Lk_1, Lk_2 – the length of contact surface between upper and lower electrodes and wire; $I_{upper\ el.\text{-}wire}$, I_{wire}, $I_{upper\ wire\text{-}wire}$, $I_{lower\ el.\text{-}wire}$ – the current passing through resistance of upper electrode - wire contact, wire, resistance of wire - wire contact, resistance of wire - lower electrode contact; t_i – welding current impulse time; $P_{dyn.}$ – dynamic pressure. In expression (2) we can find, that (4-1) function is $Q_{upper\ el.\text{-}wire}$; (4-2) function is Q_{wire}; (4-3) function is $Q_{upper\ wire\text{-}wire}$ and (4-4) function is $Q_{lower\ el.\text{-}wire}$.

Item-by-item examination of various combinations of variable parameters as well as analysis of possible solutions for managing the characteristics $Q_{upper\ el.\text{-}wire}$, Q_{wire}, $Q_{upper\ wire\text{-}wire}$, $Q_{lower\ el.\text{-}wire}$ allows finding the optimal solution for regulation and projecting the amount of heat *Q*.

Thus, as a result of investigation the analog model is obtained, which describes the cause-and-effect relations between welding process parameters and physical mechanical properties of wire and coating materials as well as the thickness of coating.

4. CONCLUSION

The existing approaches for investigation of the resistance welding are offered. The formation mechanisms of welds in the cases of wires with and without coatings are analysed. A new approach for modeling of welding joint formation is offered. The analog model of the heat input during resistance welding of wires with coating is described. The obtained analog model includes the cause-and-effect relations between welding process parameters and physical mechanical properties of wire and coating materials as well as the thickness of coating.

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