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Generalized dynamic transition resistance in spot welding of aluminized 22MnB5

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ABSTRACT

The purpose of this work is to provide generalized information on the transition resistance properties in spot welding of the aluminium–silicon-coated 22MnB5 steel sheet for varying mechanical and electrical contact loads. As the transition resistance is a prominent influence factor on the magnitude of heat release in the process, it is crucial to have in-depth information on it at hand in order to optimize the mechanical properties of the weld by choosing appropriate process parameters. Based on resistance measurements, a numerical simulation method was employed in order to determine the specific transition resistance as a function of temperature and contact pressure. A mathematical formulation of the results is provided. At the sheet–sheet contact, the specific transition resistance was up to ten times higher than at the electrode–sheet contact. Additionally, it was shown that the local contact temperature is the largest influence factor on the specific transition resistance.

1. Introduction

Resistance spot welding (RSW) is perhaps the most important welding process for thin sheet metals, especially in the automotive industry. Its most distinctive feature is that the required process heat is generated in the faying parts themselves by means of resistance heating. Other welding processes usually use dedicated heat sources such as arcs. Therefore, the amount of process heat released at the weld is strongly dependent on the electrical characteristics—namely, the resistance—of the parts being welded. At the weld, two different forms of electric resistance come into effect, one being the bulk resistance, and the other being the transition resistance at the contact interfaces between the electrodes and sheets as well as between the sheets.

The fundamental cause for the presence of the transition resistance is the roughness of the contacting surfaces and their contamination with oxides and residues of oil, which yield an imperfect contact [1,2]. Hence, by the time the current is initiated, only a small portion of the contact area is immediately conductive to electric current. As a consequence, the microscopic conductive paths will quickly heat up by Joule heating due to the locally high current density [1]. Furthermore, the elevated temperature will soften the materials at the contact points, which increases the true contact area resulting in a decreased contact resistance. Simultaneously the bulk resistance of the contact materials will increase with temperature. Mechanical compression of the surface asperities accordingly results in an increase of the true contact area as well, decreasing the transition resistance [3]. Those effects are locally superimposed over each other and strongly coupled, making it impossible to separate bulk resistance from transition resistance using in situ measurements [4–7]. In the RSW process, huge changes in the transition resistance are generally observed [6,8,9]. The quantity will therefore be referenced to as the dynamic transition resistance (DTR). In this context, it is important to distinguish between the absolute DTR and the specific DTR: while results on the absolute DTR with units of $[R_i] = \Omega$ can only be compared to results obtained under similar conditions, the specific DTR with units of $[r_i] = \Omega m^2$, provides more general information. The specific DTR is a function of contact temperature and pressure and is defined as

$$r_i(p,T) = \frac{U_c}{I} \cdot A_c \tag{1}$$

with A_c being the conducting contact area, U_c the contact voltage and I the current.

In the literature, several approaches to analytically describe the specific transition resistance have been published [4,10–13], which usually require data on surface parameters that are hard to measure. Therefore, the models are of great theoretical value but only little practical relevance. Richard et al. [4] first published an empirical model in order to describe the specific transition resistance based on measured data.

Several authors used dedicated, heated press apparatuses in order to obtain transition resistance data [4–6,9,10]. Richard et al. [4] and Galler et al. [7] introduced numerical simulation to inversely calculate the transition resistance.

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While the fundamentals of material physics clearly show a steady increase of the bulk resistance with increasing temperature for most metals, the DTR is usually assumed to have a decreasing tendency towards zero with increasing temperature [5,14] and pressure [4]. However, the work of Galler et al. [7] reported the specific DTR to have a local maximum at about 400 °C surface temperature on uncoated sheets. Rogeon et al. [6] also determined the DTR to have a local maximum at about 400 °C on galvanized steel sheets, but observed a steadily decreasing quantity on uncoated steel sheets. Using the same technique as Rogeon et al. [6], the local maximum was not confirmed by Raoelison et al. [9] later on uncoated sheets. Galler et al. [7] performed in situ measurements of the absolute resistance in a welding machine, using current pulses of up to 16 kA, and calculated the specific DTR by an implicit numerical technique. Rogeon et al. [6] and Raoelison et al. [9] used a dedicated, heated press, and an external current source delivering 1.5 A for their experiments. Kim and Eagar [15] used a dedicated press and thermography to assess current and electrode force effects on the interface temperature of galvanized sheets, but provided no resistance data.

Numerical simulation has become a convenient method in various contexts of spot welding research [16–23], but always requires appropriate transition resistance data, which is sometimes not available. For example, Nodeh et al. [18] have set the specific DTR to a constant value, Shen et al. [19] relied on the data provided by Richard et al. [4], Moos and Vezetti [20] used data published by Song et al. [5], and Fan et al. [17] and Eshraghi et al. [22] worked with resistance data included in the Sysweld software. All of the previously noted works examined either uncoated or galvanized steel sheets.

Although data on the transition resistance of aluminized 22MnB5 exists in the literature, the data either was measured only for a certain electrode force [24], at room temperature with small current [24,25] or in terms of the absolute resistance [25,26]. Accordingly, general information on the specific transition resistance characteristics of aluminized 22MnB5 as a function of pressure and temperature is currently not available.

It is a generally-known fact that in the spot welding process, enough process heat will be released by means of the DTR in order to yield a significant temperature increase at the contacts. Later on, this heat will increase the bulk resistance around the contacts, and therefore indirectly promote further heat release in the bulk material [27]. Recent works showed that first melting in spot welding of aluminized 22MnB5 occurs much earlier than in other steels due to the increased DTR of the materials coating [24,28] and results in very demanding process characteristics under factory conditions [29]. Additionally, it is assumed that the DTR of aluminized 22MnB5 is significant up to relatively high temperatures due to the coatings high melting temperature [25]. Accordingly, the transition resistance of this coated steel type is one of the most significant influence factors on its welding behaviour.

2. Materials and methods

The basic approach used in this work is presented in Fig. 1. In order to obtain data on the dynamic transition resistance of the sheets between the electrodes, appropriate measurements were carried out. Of course, the resistance values being measured are superimposed with a portion of the bulk resistance. In the following, they therefore will be understood as the apparent, absolute transition resistances (ATR).

Using the same boundary conditions, the experiment was numerically repeated using an FEA technique, delivering another dataset on the ATR of the weld. In the FE analysis, the KMK model represented the specific electric resistance at the contact faces of the weld (see Section 2.2 for details). The parameters of the KMK model were iteratively adjusted by using a bisection method for the numerically computed ATR data to comply with the measured ATR data to the best possible extent. With the adjusted parameters, the specific transition resistance of aluminized 22MnB5 as a function of temperature and pressure is derived from the KMK model.

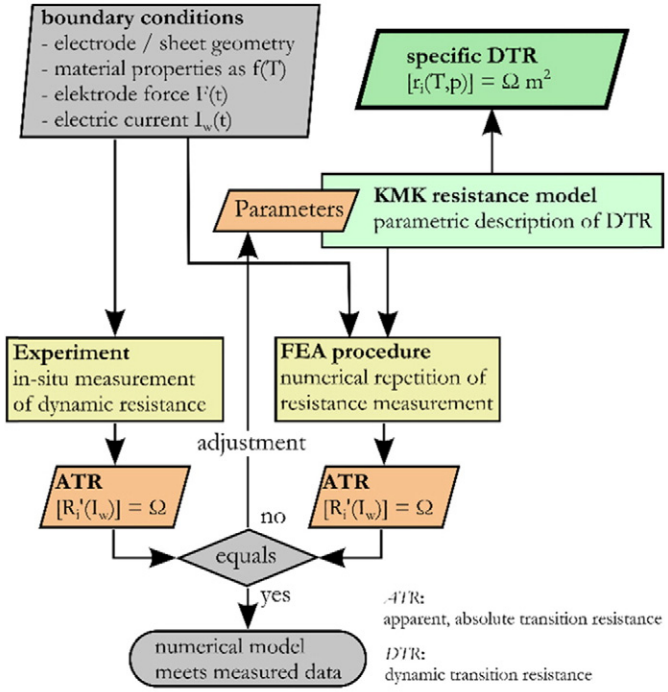

Fig. 1. Procedure to determine the specific, dynamic transition resistance.

By using this approach, it is neither necessary to measure the true contact area at the weld nor to compensate for the bulk resistances of electrodes and sheets, as both are considered in the numerical simulation as well.

2.1. Experimental

Resistance measurements on aluminized 22MnB5 were carried out in situ by using an XC-Type spot welding gun [30] equipped with a DC-type inverter power source clocked with 10 kHz. The inverter had a programmable current control. The welding machine was equipped with electrode tips of the type ISO 5821-B0-16-20-40-6-45. A welding current ramp of $\dot{I}_W = 500\ A{\cdot}ms^{-1}$ up to $I_W = 12\ kA$ was applied on the two sheets between the electrodes, while current and potential at the respective voltage taps on sheets and electrodes were recorded (cf. Fig. 2).

Application of the voltage taps was done by means of strong clamps and soldered junctions, while the data was recorded with a sampling

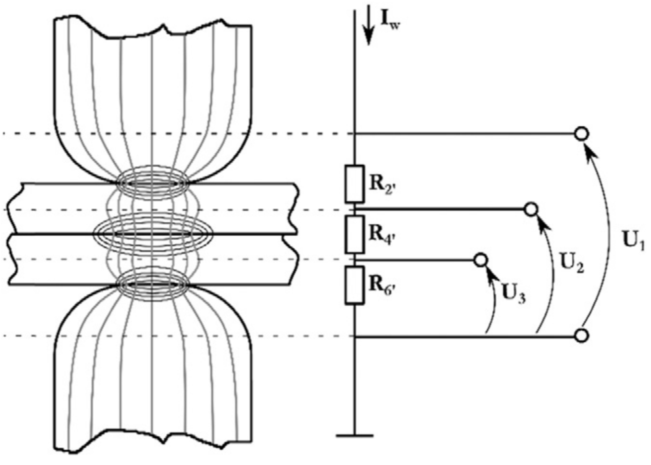

Fig. 2. Localization and denotation of resistances and voltage taps; illustration of current flow and potential isolines based on Gengenbach [31].