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INFLUENCE OF THROAT AREA ON THE RESISTANCE SPOT WELDING PROCESS

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Key words: resistance welding, throat area, workpiece, welding-cable length, alternating welding current, voltage drop, contact resistance, impedance

Abstract: The paper describes an experimental study made in order to establish how the welding-cable length in resistance spot welding affects welding parameters and the welding process itself. A common alternating-current welding device for welding with a current frequency of 50 Hz was used to investigate optimum welding parameters with welding cables of different length and with workpieces of different materials. It was found that longer welding cables produce increases in ohmic resistance and inductive resistance. Higher ohmic resistance produces thermal losses and a lower welding current in the secondary circuit. Inductive resistance, however, produces reactance in the secondary circuit of the welding transformer, which means a loss as far as resistance welding is concerned.

Vpliv velikosti okna med elektrodami na proces elektrouporovnega točkovnega varjenja

Ključne besede: elektrouporovno varjenje, okno med varilnima elektrodama, varjenec, dolžina varilnih kablov, izmenični varilni tok, padec napetosti, kontaktna upornost, impedanca

Izvleček: V članku z gornjim naslovom je z eksperimentalnimi raziskavami pokazano, kako dolžina varilnih kablov pri elektrouporovnem točkovnem varjenju, vpliva na varilne parametre in na sam proces varjenja. Na klasični varilni napravi za varjenje z izmeničnim električnim tokom s frekvenco 50 Hz smo raziskali optimalne varilne parametre za različno dolge varilne kable in za varjence iz različnih materialov. Ugotovili smo, da se s podaljšanjem varilnih kablov povečata ohmska in induktivna upornost. Pri večji ohmski upornosti nastopijo toplotne izgube, v sekundarnem krogu pa teče varilni tok nižje jakosti. Zaradi induktivne upornosti se v sekundarnem krogu varilnega transformatorja pojavi jalova moč, ki za uporovno varjenje v celoti predstavlja izgubo.

1. Introduction

Considering the number of welds produced, resistance spot welding is undoubtedly the most frequently applied welding process in all production technologies, particularly in batch production of cars, household appliances, and electrotechnical elements. Increasing demands for product quality and traceability in their usage make manufacturers introduce new methods of monitoring and recording of welding parameters in the course of welding and their storage after welding. The most important parameters in resistance spot welding are the welding current, the weld time, and the electrode force. The welding parameters are selected with reference to material properties and thickness and a workpiece shape. It is on the workpiece size and shape that depends the throat area. A frequent difficulty encountered in resistance spot welding are welding cable lengths and different throat areas. The degree of obstruction of the throat area depends on the size and shape of the workpiece and the position of the weld spot at the workpiece, which is different for each weld spot. The size and shape of the throat area and its obstruction by the workpiece affect the welding parameters, particularly the welding current. This should be taken into account when elaborating a welding technology. The greatest influence on the welding current is exerted by the length of cables at the secondary side, i.e., impedance of the cables. In practical applications it often happens that cables more than one metre or even several metres long have to be used because of the workpiece size. They may or may not be placed across the workpiece. This means that the throat area is fully or partly obstructed by the workpiece or it is unobstructed. This affects the welding parameters and the welding process.

2. Problem to be addressed

Figure 1 schematically shows the resistance spot welding process. Through both workpieces a welding current of high density is flowing. Because of ohmic resistance, particularly contact resistance, between the two workpieces, a part of the material will heat up to its melting point and the electrode force will produce a spot weld at a lap joint or a parallel joint. The figure also shows relative resistance occurring when the current is carried through the electrodes and the workpieces. It may be observed that the contact resistance between the workpieces is several times higher than the resistance in the workpieces themselves and much higher that the contact resistance between the electrodes and the workpieces. The alternating current with a frequency of 50 Hz is supplied by a welding transformer which is the main element of a resistance welding machine. The entire circuit at the secondary side consists of the welding cables, i.e., electrode holders, the electrodes and two or sometimes more workpieces. In this circuit, physical-chemical processes are going on. In the electrode holders, i.e., in the welding cables, they will produce ohmic and inductive resistances which affect the welding current.

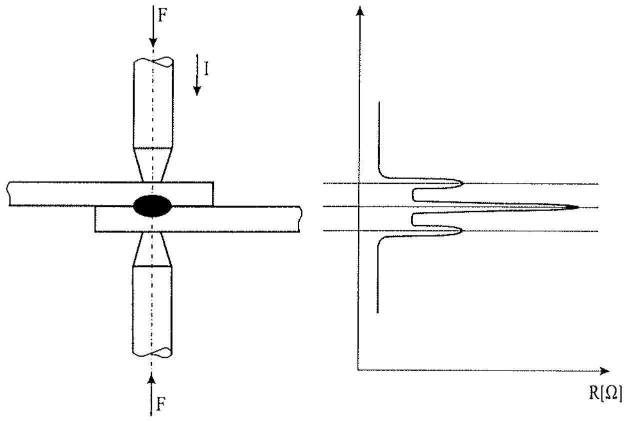


Fig. 1. Schematic representation of resistance spot welding.

In general, the welding current can be set by setting the number of windings and the conducting period of the thyristors at the primary side of the transformer. Presetting thus provides an alternating welding current in the secondary circuit which is a function of the impedance of the entire circuit. The alternating welding current generates an alternating magnetic field. Consequently, voltage is induced in the workpieces which are mainly made of ferromagnetic materials, e.g. steel, and are positioned in the throat area. The induced voltage generates eddy currents in the workpieces. The latter again generate an alternating magnetic field which, however, interferes with the alternating welding current in the secondary circuit of the welding machine.

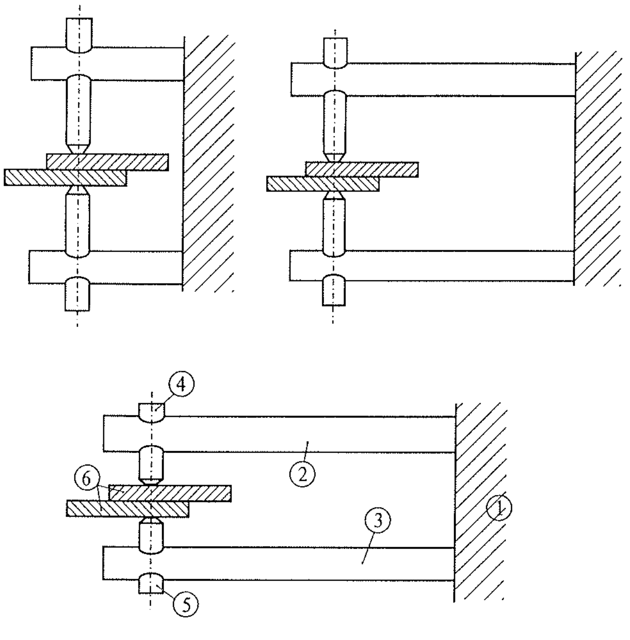


Fig. 2. Different throat areas in resistance spot welding machines. 1 - resistance spot welding machine, 2 - upper electrode holder, 3 - lower electrode holder, 4 - upper electrode, 5 - lower electrode, 6 - workpieces.

Figure 2 schematically shows three throat areas of different shapes in resistance spot welding. In practice a number of different sizes and designs of resistance spot welding machines are used. But the throat area and shape are affected only by the size and shape of the workpieces. It is important, however, that the welding parameters are changed if the product or the workpiece shape is changed. The properties of the material to be welded have to be taken into account as well.

Figure 3 schematically shows fully obstructed and unobstructed throat areas. Two cross sections of the electrode holders shown in Fig. 4 are indicated too.

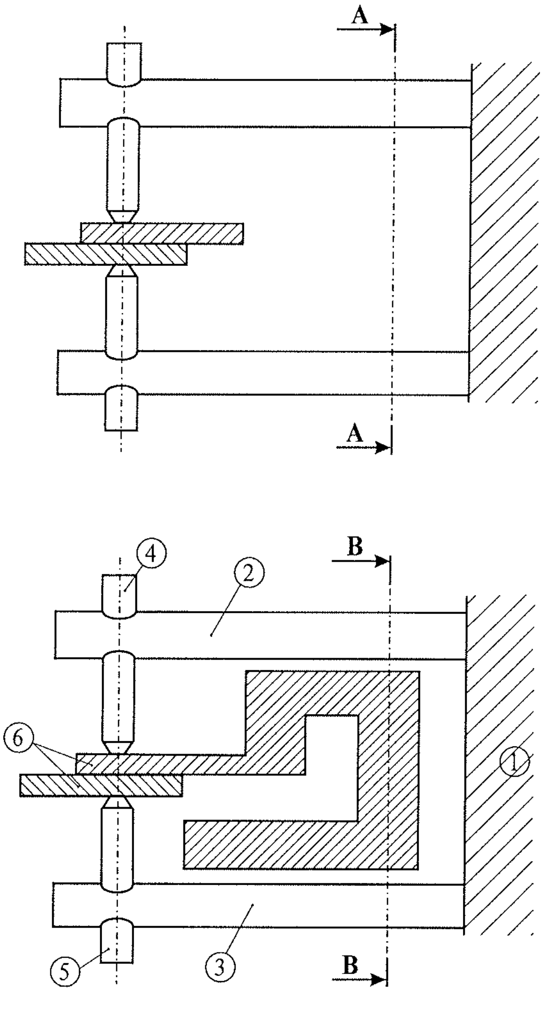
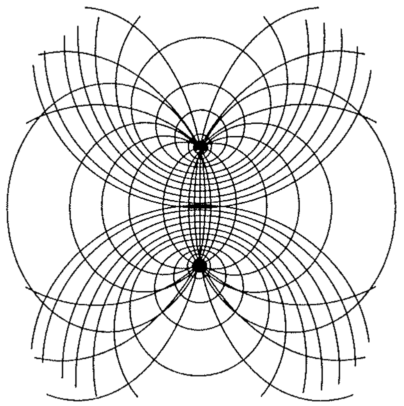


Fig. 3. Unobstructed throat area and throat area obstructed by a workpiece. 1 - resistance spot welding machine, 2 - upper electrode holder, 3 - lower electrode holder, 4 - upper electrode, 5 - lower electrode, 6 - workpieces.

Magnetic fields (Fig. 4) are shown for an unobstracted throat area and for the one obstructed by the workpiece. A change of permeability due to the presence of metal ferromagnetic material produces a change in the magnetic field intensity in the throat area. A non-uniformly distributed magnetic field is obtained which produces very complex physical processes in the entire secondary circuit of the welding machine. The alternating magnetic flux produces eddy currents in the workpiece. The latter will heat the workpiece and produce an additional magnetic field which will hinder the flow of the welding current in the secondary circuit.

SECTION A-A (fig. 3)



SECTION B-B (fig. 3)

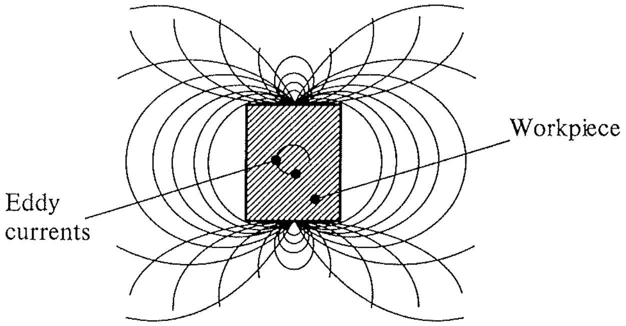


Fig. 4. Influence of workpiece in throat area on distribution of magnetic field intensity.

3. Experimental work

For the experiments a common industrial resistance spot welding machine was used. Welding was accomplished with a 50 Hz alternating current, different lengths of welding cables at the secondary side of the machine and different throat areas. A cross section of all the cables used was equal to 150 mm^2. The aim of the investigation was to find out the influence of the cable length on the welding parameters and the welding process itself.

In the experiments, the cable length, the welding current (using different conducting periods of thyristors) and the material to be welded were varied. Figure 5 schematically shows a unit with measuring instruments to measure the welding current and a voltage drop at the primary and secondary sides of the welding transformer. To measure the current and voltage at the primary side, common measuring instruments showing high accuracy and reliability were used. The primary current was measured with a current probe with a measuring range of 0.3 A to 700 A. As an alternating current of high intensity was flowing at the secondary side, a Rogovsky coil was used. The Rogovsky coil consisted of 3300 turns in two layers which surrounded an alternating magnetic field generated due to the flow of the alternating welding current. The welding current intensity was obtained by measurement of the voltage induced in the Rogovsky coil, the knowledge of the voltage ratio of the transformer, and mathematical integration.

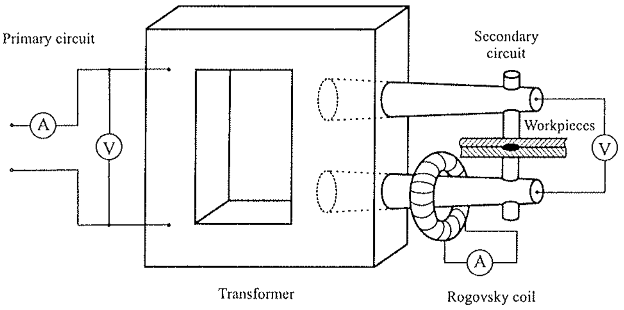


Fig. 5. Schematic of resistance spot welding machine with a measuring chain for measurement of welding parameters.

Because of the above-mentioned phenomena, ohmic and induced resistances occurred in the cables during welding, which hindered the current flow. Ohmic resistance gave rise to heating of the cables. Consequently, in the whole circuit, a lower welding current was carried. Inductive resistance produced a lag between the current and the voltage, which produced a reactive power. In resistance spot welding, this represents a pure loss.

4. Analysis of results

A change of the cable length entails a change of the welding parameters since in the secondary circuit ohmic and inductive resistances increase, which affects the welding current. Figure 6 shows the welding current (secondary side of the transformer) as a function of the cable length and the conducting period of the thyristors. The materials welded were steel and aluminium sheets of various thicknesses. The majority of the experiments to study the influence of the throat area, i.e., the cable length, on the welding parameters were performed using a 3 mm thick sheet. The optimum welding parameters for different cable lengths were studied using a 1 mm thick sheet. In all cases two sheets were welded together in a lap joint.

Figure 6 indicates, which is quite understandable, that an increase in the conducting period, the welding current increases too. It is, however, less understandable that long-

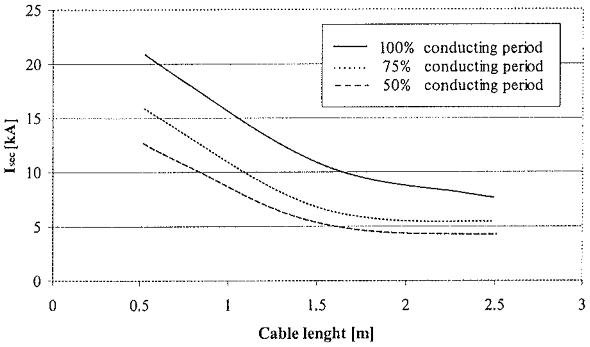


Fig. 6. Influence of cable length and conducting period of thyristors on welding current at the secondary side in resistance spot welding of steel sheet with a thickness of 2 x 3 mm.

er welding cables strongly reduce the welding current. For example, when the cable length is increased from 0.5 m to 1.5 m, the welding current drops by a half of its previous value. When the cable length is increased from 1.5 m to 2.5 m, the current drop will be, however, much smaller. This can be explained by several physical principles. It is certain that the cables and their vicinity become saturated with the magnetic field. Thus with longer cables, their influence is relatively smaller.

Figure 7 shows the influence of the cable length and the conducting period of the thyristors on the welding current at the primary side of the transformer. It is evident that with an increase of the cable length from 0.5 m to 1.5 m, the welding current at the primary side drops in an almost linear manner. When the cable length is increased from 1.5 m to 2.5 m, however, this drop is by only 30 %. This indicates that the actual losses at the secondary side could be calculated from the welding-current drops at the secondary side and primary sides.

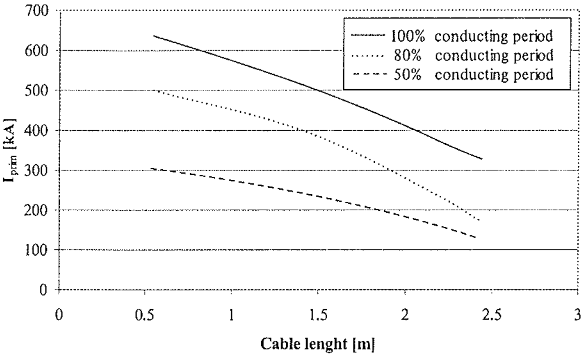


Fig. 7. Influence of cable length and conducting period of thyristors on welding current at the primary side in resistance spot welding of steel sheet with a thickness of 2 x 3 mm.

Based on the experimentally obtained results, the optimum welding current was determined with the optimum weld time for steel sheets of 1 mm in thickness (1 mm + 1 mm), and for different cable lengths. Figure 8 shows three curves for three cables of different length. The curves plotted make it possible to determine the optimum conducting period of the thyristor, i.e., the optimum welding current, and the optimum weld time.

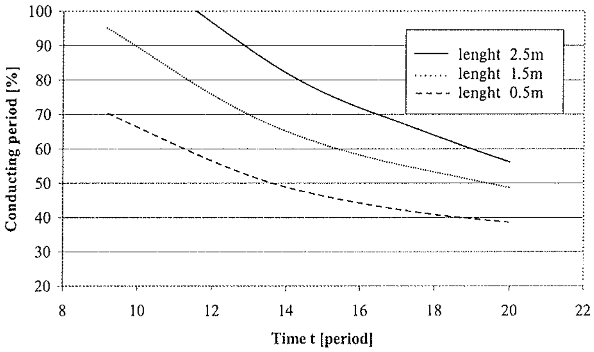


Fig. 8. Optimum welding current and optimum welding time with cable lengths of 0.5 m, 1.5 m, and 2.5 m in resistance spot welding of 1 mm thick steel sheet (1 mm + 1 mm).

Similar diagrams were plotted for other steel sheet thicknesses and an aluminium sheet. The kind of material used has a strong influence on the curve slope since different materials show different electric resistance and different contact resistance, i.e., the material properties having the strongest influence on the welding parameters. Workpiece thickness as well has a strong influence on the optimum welding current and weld time, yet no so strong as the kind of material, i.e., its ohmic and contact resistances.

5. Conclusions

The experimental work performed and the measurements of the welding parameters using different throat areas, i.e., different cable lengths, in resistance spot welding make it possible to draw the following conclusions:

1. the throat area, i.e., the cable length, has an important influence on the welding parameters, particularly the welding current;
2. longer welding cables in welding of large-size workpieces increase ohmic and inductive resistances in the circuit at the secondary side of the welding transformer;
3. higher ohmic resistance produces welding-current drop;
4. with the inductive resistance the reactive power occurs instead of the useful power, which is a pure loss in resistance welding;
5. with longer welding cables, it is necessary to determine the optimum welding current and the optimum weld time for each sheet thickness and for each material separately;

6. in addition to the cable length, the optimum welding parameters are affected by the kind of material welded;
7. the total or partial obstruction of the throat gap by the workpiece affects the welding parameters; this influence, however, is relatively small and should be taken into account only with very exacting structures.

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