A Review of Shunting Effect in Resistance Spot Welding

Efekt bocznikowania prądu podczas zgrzewania rezystancyjnego punktowego – przegląd zagadnienia

Abstract

Studies on shunting effect in resistance spot welding (RSW) have not been widely performed and limited researches were devoted to some aspects of it. Shunting effect in RSW occurs when the electrical current passes through the preceded spot welds in the case of multi-spot welding. The amount of this current depends mostly on weld spacing, and to some extent, on the number and size of previous spot welds. The phenomenon causes some changes in the quality of shunted weld, such as nugget diameter decrease with consecutive reduction of mechanical strength due to changes in electrical current distribution and temperature distribution. Recently some efforts have been made to develop equations for determine the relationship between the input welding parameters and the quality of spot welds. However, the problem needs deeper research and analysis. The paper reviews different approaches performed for simulation and analysis of shunting in RSW.

Keywords: resistance spot welding, shunting, review

Streszczenie

Badania efektu bocznikowania prądu przy punktowym zgrzewaniu rezystancyjnym (RSW) nie były dotąd szeroko prowadzone i niewiele badań było niektórym jego aspektom. Zjawisko bocznikowania w trakcie RSW pojawia się w sytuacji przepływu prądu elektrycznego przez poprzedzające zgrzeiny w przypadku zgrzewania wieloseryjnego. Wielkość prądu bocznikowania zależy głównie odległości pomiędzy zgrzeinami i w pewnej mierze od ilości i wymiarów poprzedzających zgrzein. Zjawisko to powoduje różnicę jakości bocznikowanej zgrzeiny, poprzez zmniejszenie średnicy jej jądra zgrzeiny, co skutkuje obniżeniem wytrzymałości mechanicznej. Zmiany te są skutkiem zmian rozkładu prądu zgrzewania i temperatury. Ostatnio podjęto starania dla opracowania równań opisujących zależność pomiędzy parametrami wejściowymi zgrzewania z bocznikowaniem prądu a jakością zgrzein. Zagadnienie to wymaga jednak głębszych badań i analiz. Niniejsze opracowanie stanowi przegląd prac o różnym podejściu do symulacji i analizy RSW z efektem bocznikowania prądu.

Słowa kluczowe: zgrzewanie rezystancyjne punktowe, bocznikowanie prądu, stan zagadnienia

Introduction

Spot welding is the most often applied means among different types of resistance welding. This process is used for joining sheets, wire on sheet, and wire on wire in the regular scale or small scale RSW.

One of the most important points in spot welding different structures is the mechanical strength of the product in the working conditions. Much of the attention in research is usually devoted to the welding parameters and material aspects, but less care to such weld attributes as geometry and pattern of spot welds. But one of the important phenomenon which has been the subject of not sufficient studies in the past is a shunting effect. This effect appears when two or more weld spots exist in a row. Since many products contain a number of spot welds close to each other, problems related to shunting are usually solved in practice on the trial-to-error basis. Therefore more research and analyze is needed on this harmful phenomenon.

In the successive parts of the paper a specific literature review on shunting effect is given and discussed along with some suggestions for future research in the field.

Shunting Effect

Location of previous spot welds causes the quality of the new spot. The main reason for this event is just shunting current; i.e. the current passing through the preceded spot [1]. Although the other areas of the sheets are touching each other and may let some electrical current to pass, but the oxide layer and the lack of electrode pressure have significantly reduced shunting in these sections.

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Figure 1 shows the concept of shunting and flow of electrical current for the three consecutive nuggets. This change in electrical current distribution is the first effect of shunting. In a consequence a change of temperature distribution occurs which finally interferes with properties of the new nugget. One of the most explicit results observed is the reduction of the next spot nugget diameter associated in turn with changes in mechanical properties of the weld. All of the main welding parameters (welding current course, time schedule, electrode force, electrode geometry, etc.) and specific material properties (bulk resistance, surface conditions, etc.) influence shunting to a broader and more complex manner than a single spot weld. Furthermore, other factors such as electrode life, electrode alignment, and workpiece gripping may also affect the shunting mechanism. Investigating all of these effects will make an experiment matrix complex to handle [2].

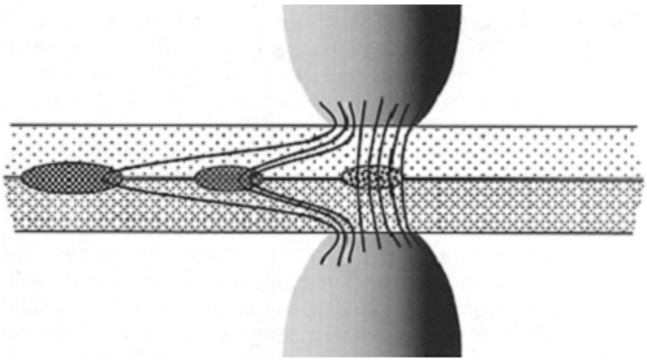

Fig. 1. The schematic of mechanism of shunting effect [1]
Rys. 1. Schemat mechanizmu bocznikowania prądu [1]

Experimental Investigations

Among experimental studies related to shunting effect, the one of the oldest is related to the research done by Hard et al. [3]. The report of this study proves that the tensional and shearing strengths of welds produced in the consecutive series of spots located in a certain distance are far less than these for single spot welds. In addition, they provided a method for measuring the shunting path, but the direct relationship between the electrical current and shunting level which is needed to reduce the shunting effect is not included into the study. The other experimental test was performed by Blair [4] who considered the effect of some factors such as welding machine impedance, spot weld distance, sheet width, and sheet temperature on shunting. Impedance is usually rather an unstable parameter in the course of RSW, therefore his results would be affected by this instability. Nippes et al. [5] investigated also in the experimental way some aspects of shunting phenomenon in series of spot welds to explore the impact of selected factors such as distance, electrode geometry, material preparation, and electrode force. Johnson [6] tried to find a minimum distance in order to reduce shunting effect in spot welding to some extent. In the experiments performed by Howe [7], several types of steels of various thicknesses and surface conditions were studied to understand the shunting effect. Since the weld spacing was larger than those specified by International Institute of Welding [8], he concluded that weld spacing was not a very efficient factor. But it should be noticed that experiments in this study were not designed to determine the minimum weld spacing regarding to shunting effect.

Wang et al. [9] in their experiments and analysis considered the effect of material, surface conditions, welding sequence, and other parameters on shunting current in steel sheets spot welding. An important result was the prove of reduction of the nugget size in the shunted welds due to shunting current. In addition, experimental results show weld spacing and surface condition to have the dominant effects on shunting. It is mentioned that in welding metals with large bulk resistivity relatively small weld spacing is sufficient to avoid shunting effect. Therefore, a smaller weld spacing could be applied when welding steels when compare with spot welding aluminum alloys. Electrode force is told to be inversely effective in the shunting level inside the critical spacing. Higher thicknesses of materials welded need more spacing as it is harder to deform them and increase the contacting area.

Metallographic cross-sectional images revealed useful information in addition to the weld size. Figure 2 shows a shunt weld with four subsequently made shunted welds [2]. As it is seen in the subsequent welds (second to fifth from the left), the dimensions and shapes of weld nuggets and heat affected zones (HAZs) are changed. The HAZ in shunted welds became more asymmetric versus shunting nugget. In addition, due to the higher heat concentration in shunting nugget, the grains are larger than those seen in shunted nuggets.

Other factors such as surface roughness and electrode pressure were also introduced to be effective in shunting, however the spacing between welds was the most important factor. The material used in Wang's research was steel, therefore the results cannot be generalized for other metals.

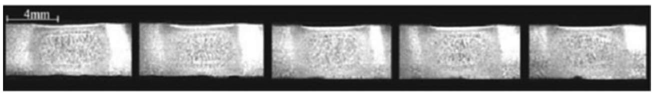

Fig. 2. Cross-sectional view of shunting and shunted welds made on a 2 mm bare mild steel with 8 mm weld spacing [2]
Rys. 2. Widok przekroju poprzecznego zgrzeiny bocznikowanej i zgrzein bocznikujących w stali niestopowej o grubości 2 mm [2]. Odległość pomiędzy zgrzeinami 8 mm.

In another research of Wang et. al. [10], monitoring of resistance spot weld quality including shunting was investigated using electrode vibration signals under abnormal welding conditions. Figure 3 shows the effect of shunting current on the amplitude of vibration measured for multi-spot distant from each other. The sequence of welding of the spots starts from A to C. As it is claimed in this study, there exists the relationship between amplitude of vibrations and actual electrical current passing through the given spot. Therefore the amplitude for spot C was less than that for spots B and A as it is seen in the diagram (Fig. 3). The extent of research on shunting in this study is limited to this experimental comparison of vibration amplitudes with electrical current not increasing the knowledge on shunting mechanism.

The effect of location of spots in multi-spot welding is an important issue which was investigated in studies by Senkara and Zhang [11,12]. They considered metallurgical and mechanical aspects of cracking during single and multi-spot welding of AA5754, experimentally and analytically. One of the most important results of this study is the discovered fact that cracking takes place during the cooling stage of spot welding, at only one side of the new nugget not adjacent to the previous weld. The main reason of such cracks appearance between the spots, reported in the study, is the existence of mechanical constraining from the previous spot weld. Cracks propagate from that side of the new nugget which is free because the thermal tensile stresses are not constrained by any barrier. It is not clear if shunting has an impact onto the generation of such cracks during the spot welding process.

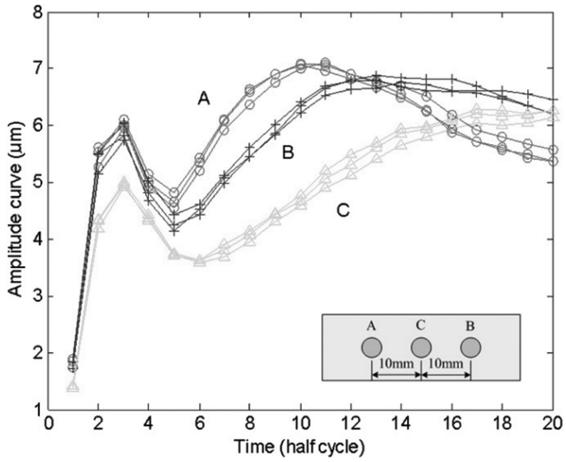

Fig. 3. The electrode vibration amplitude curves under shunting conditions at a current of 9.8 kA for three consecutive welds. [10]
Rys. 3. Krzywe amplitudy wibracji elektrod w warunkach bocznikowania prądu zgrzewania o wartości 9.8 kA dla trzech kolejnych zgrzein [10]

Analytical Modeling

Among a very limited analytical models produced to date for RSW process with shunting effect a recent approach performed by Li et al. [2] is presented. The concept of the study was to determine the heat amount required for production of sufficient nugget size and HAZ. As it is shown in figure 4, a simple geometry of the system was assumed for shunting mechanism.

Electrical current applied should be sufficient both to produce enough heat to make shunted nugget and the excess wasted due to passing through the shunting path. The main purpose of developed equations was to calculate minimum weld spacing required to avoid the shunting effect. The factors affecting this minimum distance were introduced as sheet thickness and contact resistance. Welding time was told to be also effective in reduction of shunting minimum weld spacing.

Figure 5 shows the effect of welding time on the minimum possible weld spacing, referred as the weld pitch. As it is seen from the Figure, welding time reduces this possible minimum weld spacing due to the fact that by increasing welding time the amount of heat generated at faying surfaces increases, and therefore weld spacing could be reduced when compare with shorter welding time. This conclusion is valid for a particular material of given thickness in a certain range of welding time. Although the concept of such analytical approach is appreciated in terms of intuitiveness, the dependence on temperature is not fully introduced in the equations as they mostly rely on assumed nuggets' geometry and the tracts used by electrical current passing through the sheets. However, as it is claimed, results of calculations confirm with experimental data. The model needs further validation since the experimental studies seem to be not sufficient due to the lack of the variety of materials and parameters' range being investigated.

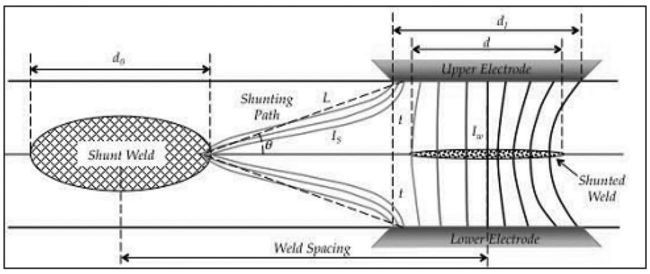

Fig. 4. Schematic of shunting in resistance spot welding according to [2]
Rys. 4. Schemat bocznikowania prądu w zgrzewaniu rezystancyjnym punktowym wg. [2]

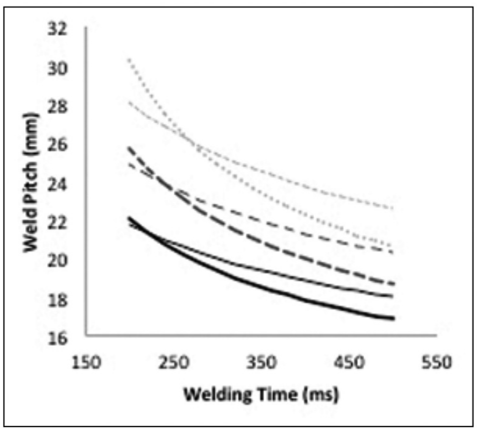

Fig. 5. Dependence of minimal weld spacing on welding time and current for mild steel [2]
Rys. 5. Zależność minimalnego odstępu pomiędzy kolejnymi zgrzeinami od czasu i prądu zgrzewania dla stali niestopowej [2]

Finite Element Analysis (FEA)

There exist many FEA studies on resistance spot welding in different fields commenced in 1960. They include such researches as simulation of thermal and electrical distribution (Huh [13], Archer [14], Greenwood [15], Tsai [16]), prediction of the electrical and thermal contact properties and contact radius (Loulou et al. [17], Okuda [18]), growth of nugget and thermal deformations (Nied [19] ,Gould [20], Ma [24]), or electro-thermal and mechanical analysis (Zhang [21], Hou [25], Hamedi [26]), to number only a few. Although most of these studies have included different thermal, electrical and mechanical aspects of the RSW process, not many utilized models for finite element analyzing of shunting effect [22-23,27]. Since there is no symmetry in the configuration in that case because of the existence of shunting current, 1D or 2D axisymmetric models used in previous FEA studies for single RSW are of less use. However, the general electrical, thermal, and mechanical equations used in these studies can be utilized for analyzing shunting mechanism after some modifications of equations and boundary conditions.

One of the interesting FEA in the field is related to the finite element electro-thermal analysis performed by Chang

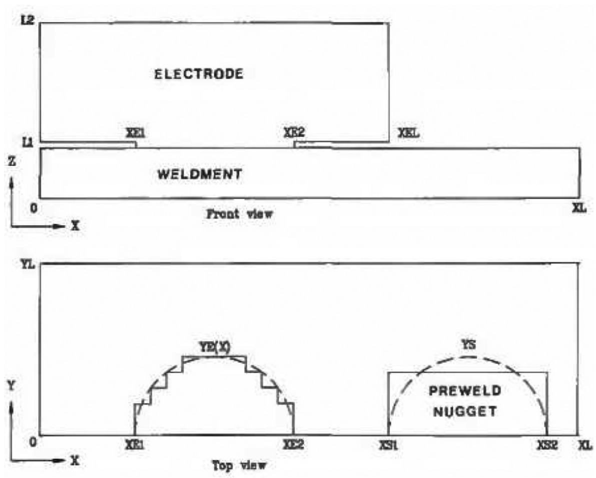

Fig. 6. Projective views of electrode and weldments geometry for finite element modeling applied in [22]
Rys. 6. Geometria elektrody i zgrzein zastosowana do modelowania metodą elementów skończonych w [22]

[22] with an experimental test added for verification of the model. His study is appreciated as one of the first numerical solutions for shunting. The model shown in Fig. 6 indicates many simplifying assumptions in geometry however the main concepts are implemented. New boundary conditions for main electrical and thermal equations used in this analysis were introduced to include shunting parameters such as spacing, and shunting nugget size.

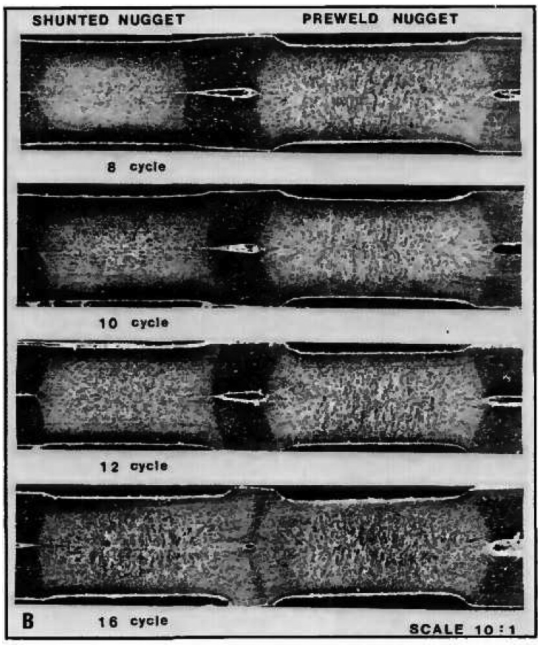

Fig. 7. Cross-section of specimens showing nugget geometry variation with weld time [22]
Rys. 7. Przekrój poprzeczny próbek wykazujących zmianę geometrii jądra zgrzeiny w czasie zgrzewania [22]

Experimental results obtained in this study point out that the shape of shunted welds differ from shunting ones (Fig. 7). As welding time is increased, more asymmetry is seen in the shape of shunted nugget with its tendency to shift towards the shunting nugget. Although, in general, increasing welding time should decrease the effect of shunting as more heat is generated at the faying interfaces, presented results stand in opposition to this. However, for the materials of relatively low electrical conductivity, non-negligible heat generation in the bulk occurs and therefore increasing the time of electrical current to pass via the shunting path yields to increase temperature next to the shunting nugget. Figure 8 (a) and (b) indicate the results of electrical voltage and current, and temperature distribution, respectively. Numerical calculations are compatible with mentioned experimental data.

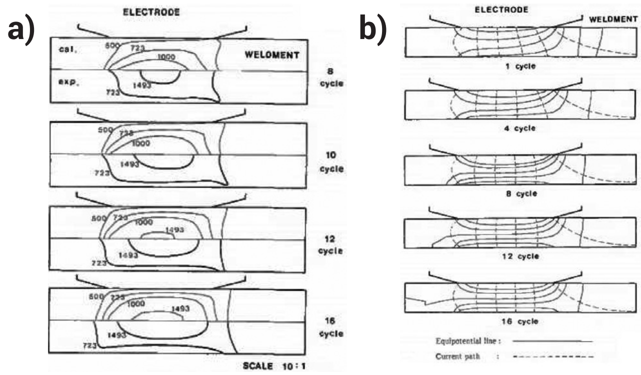

Fig. 8. Variation in distribution of temperature (a) along with electrical voltage and current distribution (b) in shunted nugget obtained by FEA [22]
Rys. 8. Zmiana rozkładu temperatury (a) oraz rozkładów napięcia i prądu (b) w czasie zgrzewania dla jądra zgrzeiny bocznikowanej, uzyskane metodą elementów skończonych [22]

Conclusions

An attempt has been made to present a review of comprehensive literature available on shunting effect. The results of study could be summarized as follows:

Although many experimental, analytical and numerical efforts has been made to evaluate RSW performance in terms of diverse variables in welding of different alloys, specially steels and aluminum, the knowledge of shunting effect is still unsatisfactory. The large number of variables and their mutual interactions along with lack of some credible materials properties and their dependence on temperature make such studies difficult.

Main approach is focused on reduction shunting by determine the minimum spacing between spots for the given material thickness and welding schedule. Vast majority of publications is devoted to steel than to other materials.

Although numerous FEA were performed to explore RSW, they were mainly concentrated on single spot analysis by the use of 1D or 2D axisymmetric models which could not be useful for shunting effect modeling in 3D orthogonal space. In the numerable FEA studies devoted to shunting, simplifications in electrode shape and configuration are usually significant.

In analytical approaches toward the shunting, welding zone and HAZ are considered to be the one entity. Such assumption reduces the precision of results since these areas consist their own temperature distribution which alter material properties during the process.

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