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A CASE STUDY OF A NEW SPOT WELDING ELECTRODE WHICH HAS THE BEST CURRENT DENSITY BY MAGNETIC ANALYSIS SOLUTIONS

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At the present time work of spot welding is being broadly used at automotive applications which need serial production process and at part unification. In order to create a high quality spot welding time of welding, electric current intensity, junction, stress, and diameter of electrodes point must be considered earlier, Geometry of electrode point and current density are important for increasing quality at spot welding. In this study, Enose, Bnose and parabolic (ParaCap) type electrode geometries have been considered during design processes. Meanwhile, CMW 73, CMW 100, CMW 353, Elkaloy D, Elkaloy 20, Copper alloyed electrode types have been analyzed by using a magnetic analyzes software. The results helped to determine the best suitable electrode type which gives the best current density amongst different alloys and electrode shapes for the spot welding machines which have same diameter of electrode point.

K e y w o r d s: welding electrode, dc conduction analysis, current density

Nomenclature

- Q – Heat energy
- I – Current intensity
- t – Welding time
- R – Electrical resistance regarding to stress
- l – Electrode length
- σ – Conductivity
- a, b – Inner and outer radius
- J – Current density
- E – Electric field
- ϕ – Electric potential
- P – Power

1 INTRODUCTION

Spot welding is one of indispensable joining methods in many areas of industry at part-joining. Because of its reliability, spot welding has been happened the most used method in industrial applications which need serial production.

Resistance spot welding is a welding process that more than two parts are being welded to each by heating and stressing. In order to form a qualified weld connection, stress, time of welding, electric current intensity and diameter of electrode point must be taken into account [1].

Welding stress and diameter of electrode point create a metallurgical and thermodynamics effects within the connected parts during welding process. On the other hand, time of welding is related with electrical current intensity. Likewise intensity of welding current is related with electrical and electronics characteristics of the machine as well. One of the important factors which define electrode sizes is electrodes current carrying capacity.

It is known that a comprehensive description of electrical contact resistance regarding to contact geometry is given by Timsit [2]. Chan and Scotchmer have stated that the electrodes have parabolic point geometry (paraCap) have larger using life rather than standard (dome) electrodes [3]. Bowers et all. have investigated the geometrical factors which are being used in resistance spot welding. They have put forth that the suitable electrode design is attached to thermal / mechanical rigidness and the uniformed current density over electrode. They have also pointed out that electrode surface angles around 90° would make current density to become smooth on electrode surface [4], [12].

In this study, for three types of electrodes which are in three different geometrical shapes, the electrode structure which gives the best geometrical shape with the best suitable material have been endeavoured to fix amongst the different kinds of alloys. Therefore, three types of electrodes used broadly in industry have been investigated for this reason. Several alloys change of current density according to electrode types has been put forth. Beyond this, the effect of resistance changing to current density has also been investigated.

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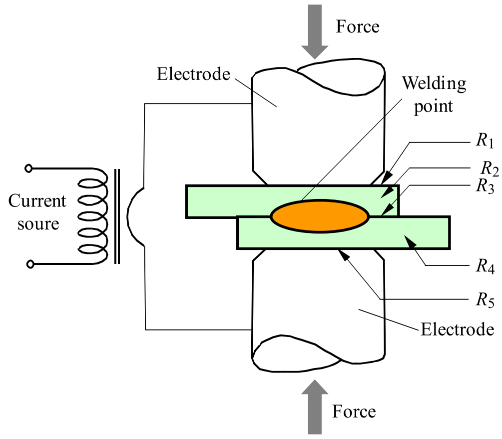

Fig. 1. Spot welding

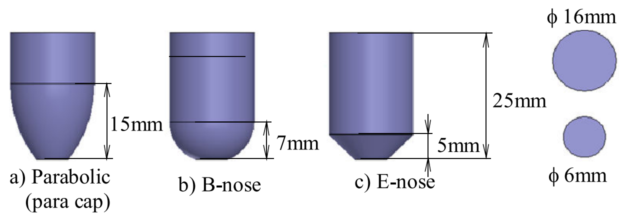

Fig. 2. Different geometrical shapes for the electrodes

Table 1. The alloys materials for the electrodes

Definition	Alloy	Conductivity (S/m)
CMW 73 Cast Wrought	Copper, Beryllium	2320000
CMW 100 Wrought	Copper/ Nickel/ Beryllium	5800000
CMW 353 Wrought Cast	Copper/Nickel/ Chromium	7540000
Elkaloy D Cast	Copper/ Aluminum	8700000
Elkaloy 20 Wrought	Copper, Al_2O_3	14500000
Copper Cast Wrought	Pure Copper	29000000

2 RESISTANCE AND HEAT CALCULATIONS

Once, a spot welding is being started as shown in Fig. 1, a warm-up occurs during weld application. The warm-up (heating) energy is changed as proportional with value of resistance related with time and current passing through this resistance. This relation is determined as

$$Q = I^2 f(R) t\,. \tag{1}$$

The most crucial factors which affect occurring heat inside the welding zone are electrical resistance of material, contact resistance, stress, plate thickness, weld time, and intensities of voltages and current. Electrode geometry significantly affects electrode using life and quality of welding together with the parameters told above too.

3 ELECTRODE DESIGN

The electrodes used in spot welding machines are get deformation in their shapes in course of time; in order to they are faced to high temperature and high stress. Afterwards their geometries are being vitiated (damaged) too. The most deforming is happened at point of electrode since that warmup effect is seen at electrode points. As result of this, electrode height is changed. That means that electrode geometry is damaged. The damaged electrode geometry affects value of current density dropped at electrode surface. Finally, capacity of welding is affected as negatively [5].

The fact that the electrodes have different geometrical structure is used in many spot welding works. The geometries and the sizes of the electrodes used in this study are given in Fig. 2.

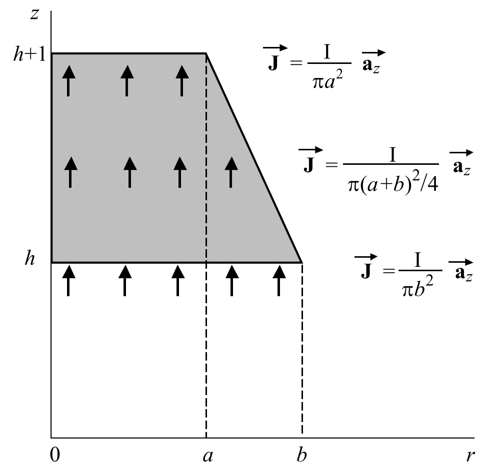

Fig. 3. Values of conical resistance and current density of the conductor placed in $r\,z$ plane

A welding electrode essentially is a conical resistance. This conical resistance is a conductor that it has inconstant section along the current passing way. In fact, it has three components called as self, dominant and spread. The resistance is skewed in a conical shape. Because, the electrodes which are affected by potentials, and the finite sizes of conductor causes to disruption of current flowing lines which do not continue to get their forms as parallel [6]. The resistance of conductor in conical shape is given as

$$R = \frac{1}{\sigma \pi a b}\,. \tag{2}$$

Current density (J) is described as proportion of current passing through a conductor (I), to conductor sectional area (A) is

$$J = \frac{I}{A}\,. \tag{3}$$

If an electrode structure shaped as E-nose is placed in $r\,z$ coordinate plane as shown in Fig. 3, it is seen that current density of conical conductor would not become homogeneous rather than current density of cylindrical

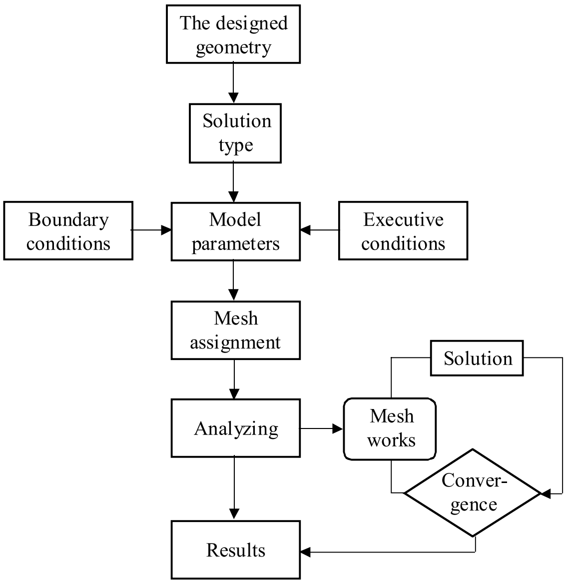

Fig. 4. The work flow-chart of the software used in the study

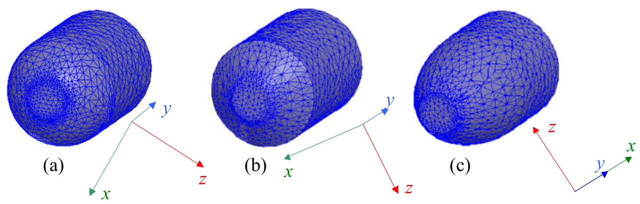

Fig. 5. The mesh views of B-nose (a), E-nose (b), Parabolic electrodes (c)

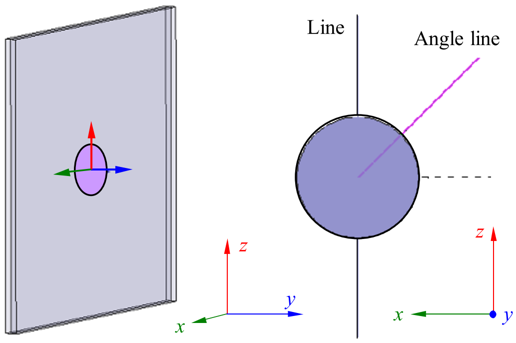

Fig. 6. A gap surface placed within the material to be welded

conductor [7-10]. Here, current density shows an increase towards to electrodes point portion.

When welding electrodes are made from pure copper materials, they show a well conductivity. In this case, their rigidities and softening temperatures are low. Therefore, coppertellurium, coppercadmium, copper chrome and coppertungsten alloys are used for producing electrodes in order to work at high current intensity, high stress and high welding speeds [8]. In general, increasing alloys rigidity also raises its electrical resistance. Thereof, selection of a certain alloy for any application is realized based on thermal and electrical specifications varied according to its mechanical features. In this manner, electrodes used for aluminum welding must have high conductivity instead of high pressure endurance.

Generally, several kinds of alloying and lining processes are done for increasing their using life as minimizing deformations of the electrodes used in spot resistance welding [9]. The alloys used in the study are given in Table 1.

CMW100 Coppernickelberyllium alloy seen in Table 1 has got the highest mechanical rigidity as 100 Brinell. High rigidity value means that deformation at electrode would become less during welding. This alloy can keep its mechanical specifications up to +455 °C. The best alloy which can keep its mechanical specifications in high temperature is Elkaloy 20 copperaluminum alloy. This alloy can keep its mechanical specifications up to +800 °C and it has rigidity value as 75 Brinell at the temperature.

4 CURRENT DENSITY AND RESISTANCE CALCULATIONS BY FINITE ELEMENTS METHODS

Finite elements methods must be taken into account for doing a real 3D structure of a system [9] during analysis. Using finite elements methods embedded in CAD software will save costs and time as well. The work flow-chart of the software used in the study is seen in Fig. 4.

The software called as Maxwell 3D separates analysis region to a great number of tetrahedral zones for determining electrical or magnetic fields in analyze of nonsmooth geometrical models [12]. Every tetrahedral element node and electrical potential in middle of edges are related as polynomial. Solving polynomials make analyzers to reach to the result [11]. The tetrahedral zone meshes for several electrode types are given in Fig. 5.

In order to obtain a more accurate solution, the mesh can be refined on the section of adjacent to the electrode face in this region [2]. Current density at the electrode surface was calculated as the product of electrical conductivity and the gradient of the potential at the electrode surface. The potential gradient at the electrode surface was determined from voltages at small displacements from points along face [12], J current density is created for a potential gradient and it is proportional to electric field. This value is

$$J = -\sigma \nabla \phi = \sigma E \,. \tag{4}$$

Under steady state conductions, the amount of charge (ρ), leaving any infinite small region must equal to the charge flowing through region

$$\nabla \cdot J = -\frac{\partial \rho}{\partial t} = 0 \,. \tag{5}$$

The field quantity which is solved by DC conduction is called as electric potential (ϕ), is given in the following equation

$$\nabla \cdot (\sigma \nabla \phi) = 0 \,. \tag{6}$$

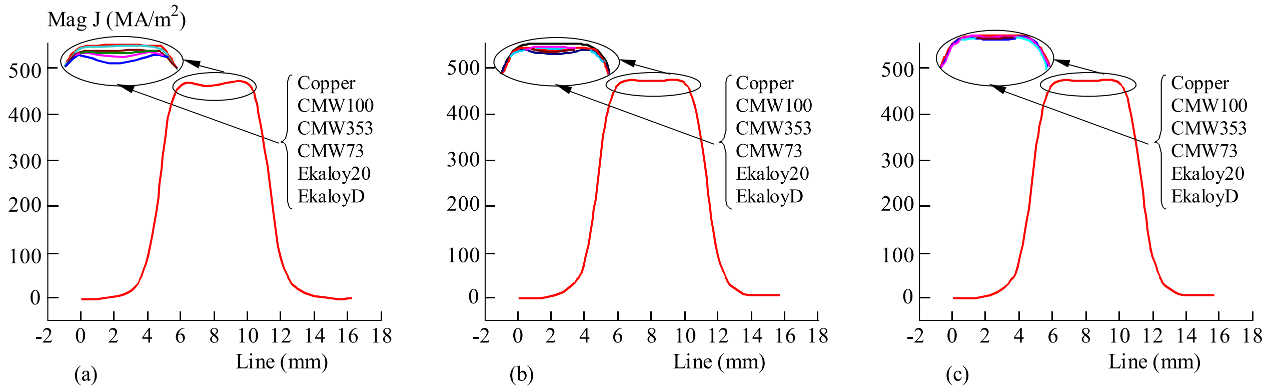

Fig. 7. Current density versus Line for three types of alloys (B-nose, E-nose, Parabolic in order)

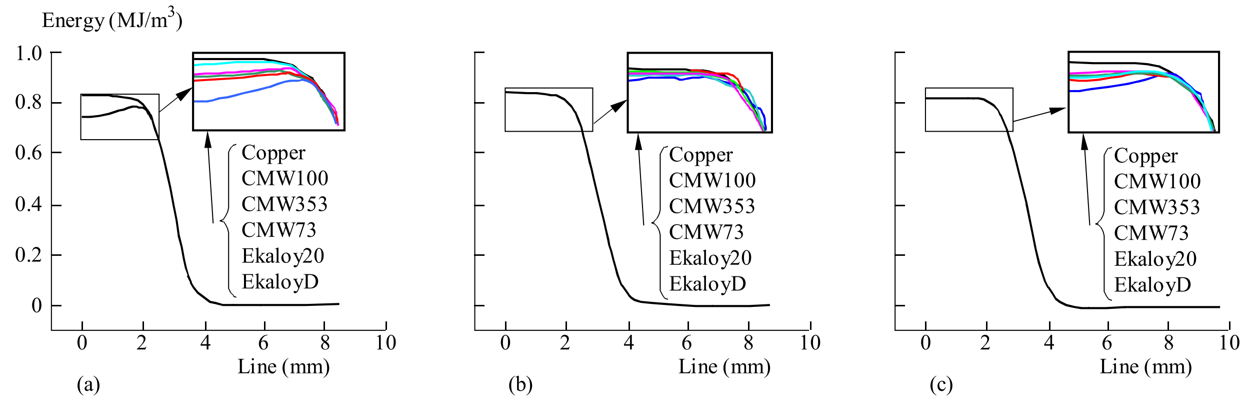

Fig. 8. Energy versus Line for three types of alloys (B-nose, E-nose, Parabolic in order)

The resistance between two terminals is calculated as analytically given

$$R = \int_C \frac{\mathrm{d}s}{\sigma(s)A(s)}\,, \tag{7}$$

$$R_{dc} = \frac{P}{I_{dc}^2}\,. \tag{8}$$

Here, the power can be calculated by taking integral of electric field and current density along volume. This case can be shown as

$$P = \int_v^\rho E^\rho J \mathrm{d}v = \int_v^\rho \frac{J}{\sigma} \mathrm{d}V\,. \tag{9}$$

The power calculation and values of resistance for the materials have been done as analytically by Maxwell Calculator in the equations above. In this application, 18 kA current have been passed throughout $2 * 1$ mm rustproof (stainless) steel parts without applying force. 6 mm diameter circular surface have been described between two sheet metal plates as shown in Fig. 6.

As shown from Fig. 6, routes of Line and Angle-Line have been designated in this surface. Change of current density has been found out by using the route of Line. Angle-Line has been used along radius for examining the change of energy.

Selection of the proper electrode material is very important to assure correct current carrying capability. Some other factors which affect spot welding materials selection are resistance, electrode pick-up and sticking. Both are a result of overheating of the electrode and work piece. The severity of these conditions can be reduced through proper electrode selection and proper welding machine set-up. The goal of these changes or adjustments would be to arrive at the ideal interface temperature between the electrode and work piece [14].

Many alloys are now available to produce spot welding electrodes with each having its own advantages depending on the application. There are differences in the electrical conductivity, hardness (wear resistance) and annealing (softening) temperature of these materials. Of course, the ideal electrode material should have the compressive strength of steel and the electrical conductivity of silver, but no such material is available. Therefore, the application will dictate the importance of high conductivity versus electrode life and long service between dressings [13].

The current density change along the route of Line is obtained as high for the B-nose type electrode structure depending upon alloy type as shown in Fig. 7. If it is taken account to the curves, Copper and Elkaloy 20 (at 8 mm have a smooth current density; the values of the current densities are obtained as 4.76728×10^8 A/m^2 for Copper

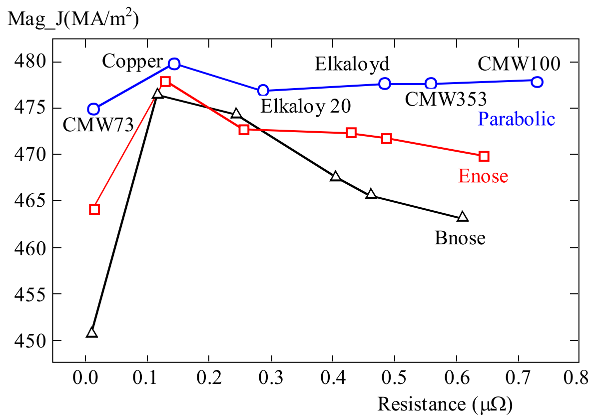

Fig. 9. The change of current density versus material resistance

Table 2. The Values of Resistance for Electrode Materials

Alloy Genres	Resistance Values ($\mu\Omega$)		
	B-nose	E-nose	Parabolic
CMW 73	0.015	0.016	0.018
CMW 100	0.612	0.648	0.729
CMW 353	0.47	0.49	0.56
Elkaloy D	0.408	0.432	0.486
Elkaloy 20	0.245	0.259	0.291
Copper	0.122	0.129	0.145

and as 4.73961×10^8 A/m^2 for Elkaloy 20. On the other hand, a rapid decrease through center has been seen in CMW 73 alloyed electrode type. The current density for this alloyed electrode is obtained as 4.50438×10^8A/m^2. The current density change for the other alloys has been proceed amongst the middle values.

In E-nose type, while Copper alloyed electrode has a 4.77828×10^8 A/m^2 current density, CMW73 has 4.64048×10^8 A/m^2 current density. A decrease as 0.01 A/m^2 for Elkaloy 20 alloyed electrode has been happening, an increase as 0.003 A/m^2 for Copper alloyed electrode has been obtaining. CMW353 and CMW73 alloyed electrodes have a 0.06 A/m^2 increase. The increase here is available for the other electrode types too. It is seen that there would become an irregularity of current density along the route of Line in the alloy of CMW 73.

The current density at the structure of parabolic type electrode is obtained as 4.7986×10^8 A/m^2 for Copper alloyed electrode. The irregularity of current density has been decreased at the type of CMW 73. It is said that a smooth current density would occur for the all alloys.

All the resistance values of the alloys have been calculated analytically by using (9) and by help of Maxwell Calculator. The values calculated have been written in Table 2.

It is seen that the energy change along the route of Angle-Line would become high in B-nose type electrode structure as shown in Fig. 8. It must be taken account that the energy density are being decreased from center towards to surface.. The Copper electrode has an energy density as 8.32×10^{-7} J/m^2 and Elkaloy 20 electrode has an energy density as 8.21506×10^{-7} J/m^2. CMW 73 alloyed electrodes energy density is about 7.41421×10^{-7} J/m^2. Even though both of the Copper and Elkaloy 20 alloyed electrodes energy densities show a smooth characteristic, it is seen that energy density in the surface of CMW 73 type alloyed electrode has increased. The energy change has been realized in middle values at the other alloys.

In E-nose structured electrode type, it is seen that the copper alloyed electrode would have an energy density as 8.35×10^{-7} J/m^2. In the same type, it is seen that there would have an irregularity along the route of Angle-Line for the CMW 73 alloy. CMW 353 alloyed electrode has an energy density as 8.13932×10^{-7} J/m^2. Rest of the other electrode types exhibits same characteristics with the CMW 353 alloy.

In parabolic structured electrode type, energy densities of Elkaloy D, CMW 100 ve CMW 73 alloys have been approached to each others. Beyond this, a small irregularity towards to the circle at energy density has been formed. The energy density of the Copper has been increased to the value of 8.42×10^{-7} J/m^2. It has been also seen that there would become an augmentation (up to 8.25059×10^{-7} J/m^2) at the energy density of CMW 73 alloy along the route of Angle-line.

5 FINDINGS

The change curves of maximum flux density versus the resistance along the inter gap within the two materials to be spot welded has been A gap surface placed inter the material to be welded have been obtained. Figure 9 shows the change of R versus B.

From Fig. 9, whatever the electrodes structured from any alloys are used, the Copper made electrode in this geometry has high current density. The biggest change amongst the three types of electrode structures has been developed by the CMW73 alloy.

However, the parabolic structured electrode type has the change of current density versus resistance change. In case different types of alloys are being used in this electrode structure, it has seen that the current density at the point to be spot welded would become more rather than the other types.

6 CONCLUSIONS

In this study B-nose, E-nose and Parabolic structured but made by different alloys and mostly used in industry have been investigated on account of current density and energy density. The values of resistance for these electrodes and alloys have been calculated by computer aided design software. The change at current densities based upon the resistance values have been put forth. The results obtained in the study can be listed as below:

1) The current density according to alloy type hasnt been changed more at parabolic structure.
2) The current density change has been observed at E-nose and B-nose structured electrode types based upon alloy types.
3) If two are compared, E-nose structured electrode gives better current density rather than the B-nose electrode.
4) In case Copper or Elkaloy 20 is used amongst the three models, current density would become higher; this case would increase welding quality. Nevertheless the physical endurance and electrode deformations must be paid attention.
5) The change of current densities amongst the three electrode types come forward.
6) The parabolic structured types rather than dome structured types will be widely used for studies on different alloyed materials in future. It is suggested that deformation, penetration and mechanical endurance of materials must be examined.

In case parabolic structured and copper alloyed electrode is used at spot welding process, it is expected that penetration to material would increase. Besides this, the current density at this electrode is obtained more comparing to the others. That means that the less force is needed for getting same welding efficiency. The current density at parabolic structured type (ParaCap) but made from different alloys is greater than the structured E-nose and B-nose types.

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