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Spot Welding using Induction Heating

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Abstract

Spot welding is a widely popular welding technique with immense applications in the automotive industry. Currently, spot welding is carried out using resistance welding. In the present study, a new approach proposes the use of induction heating to achieve strong and quick spot welds in aluminum specimens due to its excessive use in the automotive industry and body in white to improve fuel economy and vehicle performance. The procedure is accomplished through the heat and hit methodology in the form of a portable stapling device. Varying loads and current settings determine the strength of the weld. This paper also shows the critical assessment of thermal losses and the new developments in heat insulation of mild steel pallets which are used to stamp the aluminum sheets in order to carry out the spot welding.

Keywords: *Induction Heating, Spot Welding, Aluminum Sheets, Hot Stamping*

1. Introduction

Spot welding is a versatile joining technique used in the automotive industry. Typically, the body of a car has about 5000 spot welds [1]. In view of the cost and the weight of the vehicles, most automotive companies aim at using lighter materials. Hence, aluminum is a suitable choice for manufacturing car parts. Transport alone accounts for 27% of aluminum consumption and is expected to grow over the next few years. Every kilogram of aluminum used in a car body brings down the overall weight by one kilogram. This even leads to a significant cut down in fuel consumption and CO_2 emissions. Moreover, it improves the vehicle's mileage, acceleration, shock absorption, braking and is easier to spot weld as compared to heavier materials [2].

In comparison to resistance spot welding, induction spot welding presents various advantages, which lead to its gaining momentum in the automotive industry. Resistance welding involves passing a current through the work piece, the resistance offered by the material will lead to heating and eventually melting. When the material melts, the current stops flowing and hence welding takes place. This approach however requires large amounts of current to be used especially if the metal to be welded (ex: Aluminum) has high conductivity which results in lower efficiency, whereas induction spot welding requires less electricity and is, therefore, an economical choice for the manufacturing units [3]. Furthermore, passing electricity through delicate components might also lead to damage. Induction spot welding supports a variety of materials including both ferrous and non-ferrous and provides focused heat, localized to a specific area, which leads to higher accuracy.

The primary goal of this research is to reduce the amount of electricity supplied to an even greater extent in order to weld aluminum sheets using induction heating. This can be achieved by using a mild steel block. Low carbon mild steel containing high iron content is classified as ferromagnetic material. Strong magnetic properties, along with high resistivity make it an ideal choice of material for the stamping block. It acts as a heat reservoir when placed in the induction coil, which can later be used to melt the surface in contact when stamped against the aluminum sheet in order to create a spot weld.

2. Principles of Inductive Heating

Inductive heating is an energy-efficient method of heating a wide variety of materials in different shapes and sizes. It causes heat generation inside the electrically conductive work piece without any physical contact. The setup consists of an induction coil connected to a high frequency alternating current source. When the current flows through the coil, it produces an intense alternating electromagnetic field. The temperature of the work piece placed inside the coil increases rapidly due to faraday's law [4]. The depth of the penetration of the heating effect depends on the frequency of the alternating current. High frequency leads to a shallower depth. This phenomenon is known as the skin effect. Since there is no direct contact with the coil, the surface of the work piece remains uncontaminated. Inductive heating shows good reproducibility, prolonged life of fixturing, and favorable compressive residual stresses [5].

3. Materials and Fabrication

The experimentation was carried out using a multi-turn, single-place copper coil. Due to high coil efficiency and suitability with cylindrical work pieces, a helical coil was employed to use [6]. For scanning or progressive heating, a coupling distance of 0.19 cm is recommended. The aluminum specimens used to carry out the induction spot welding are in form of sheet strips. A cylindrical mild steel block is used for the purpose of stamping after passing it through the induction coil. Table 1 gives the physical properties and dimensions of the materials. The temperature-dependent properties such as thermal conductivity and thermal expansion of the aluminum sheet are shown in Table 2.

Table 1: Physical properties and dimensions of the materials

Parts	Materials	Dimensions	Specific Heat (J/g°C)	Resistivity (Ωm) at 20°C
Sheet Strips	Aluminum	Length=23.5mm Width=13.2mm Thickness=0.8mm	0.89	2.65×10^{-8}
Coil	Copper	Inner Dia=18mm Outer Dia=20mm No. Of turns=10 Length=74mm	0.385	1.68×10^{-8}
Stamping Block	Mild Steel	Diameter=8mm Length=80mm	0.5024	10^{10}

Table 2: Temperature dependent properties of aluminum sheets

Temperature (K)	Thermal Conductivity (W/m.K)	Temperature (°C)	Thermal Expansion
300	237	20	1.2e-5
400	240	100	1.33e-5
500	236	300	1.38e-5
600	231	600	1.77e-5
800	218	825	2.06e-5

4. Effects of Pre-treatment

The surface of the base metal used in the process of induction spot welding can impose certain threats on the strength of the weld. This could cause safety and economic failures if neglected. Therefore, pre-treating metals before welding is a necessity to achieve high-quality and long-lasting welds. Surface impurities such as dirt, oil, rust, etc. reduce the effectiveness of the weld which can lead to disassembling, cleaning, and re-welding the metal. This adds to the already expensive process [7].

Pre-treatment of steel: The surface is first cleaned using acetone solvent to remove dirt or oil. Tools such as sandpaper and angle grinder are used to get rid of stubborn impurities like corrosion or oxidation.

Pre-treatment of aluminum: Aluminum poses greater difficulties in pre-treatment due to its higher thermal conductivity. Initially, it is cleaned using non-chlorinated solvents to remove dirt or grease. Aluminum is highly reactive with oxygen and thus forms an oxide layer quickly. This layer protects it from corrosion but creates problems for welding. Glass blasting is an environmentally friendly method for surface treatment. Apart from this, chemical treatment is carried out using pickling with NaOH to prepare the metal surface for welding [8].

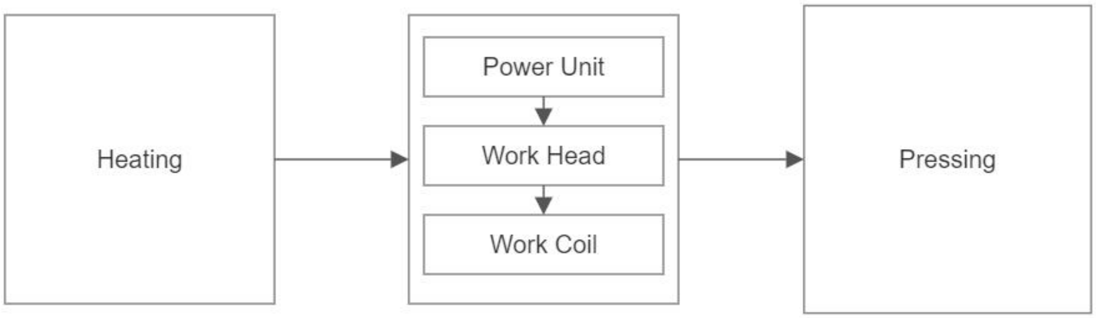

Figure 1: Block diagram of proposed methodology

5. Experimental Setup

The method used for spot welding aluminum sheet strips based on the principles of induction heating consists of three phases (Figure 1). In phase I, power is supplied to the induction module while simultaneously passing the mild steel pallet through the copper coil maintaining an appropriate coupling distance. The gradually progressive heating brings the mild steel pallet to a red-hot state. This is followed by phase II, wherein the hot pallet is hit against the aluminum sheets at the desired location in order to create a spot weld. The time lag between these two phases is kept minimal to avoid heat leakage to the environment. The aluminum sheet strips can also be pre-heated to make the process more efficient. The final stage, phase III, of the mechanism is pressing the mild steel pallet at the spot until the weld cools down to make the weld stronger.

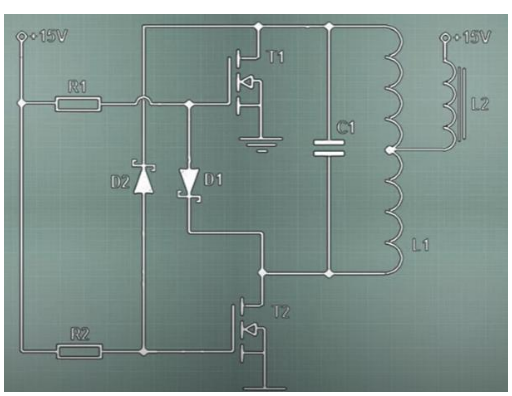

Figure 2: Induction Module Circuit Diagram

6. Heat Insulation

The biggest challenge in order to reduce the amount of electricity required to create spot welds is heat loss. The efficiency of this process is inversely proportional to heat dissipation. The two major causes behind higher current consumption are conductive heat losses through aluminum plates and mild steel and radiative heat losses through the air gap between the mil steel pallet and heat insulator. The method adopted to minimize the loss of heat via radiation and conduction is to pack the mild steel pallet with an appropriate insulator while leaving one face open for hitting the aluminum sheet. Table 3 enlists various heat insulators along with their thermal conductivity and maximum withstand temperature. Based on experimental results and thermal analysis, porcelain beads were considered the appropriate choice for heat insulation. The mild steel pallet was tightened inside the cut-out made in the porcelain bead according to the dimensions of the pallet in a way that leaves the hitting part of the pallet open for a successful weld. This resulted in a tremendous reduction in the heat lost and made it easier to punch the pallet on the aluminum plate with a better grip.

7. Calculation

The heat required to melt the surface of the aluminum sheet strips remotely in order to weld them together is calculated considering external factors of heat loss. The aluminum sheets are assumed to be at room temperature (300C) before initiating the process. The optimal temperature to which the aluminum sheets must be heated for smooth melting and welding is taken to be 8000C. The calculations are worked out in reverse order to obtain the actual final temperature to which the mild steel pallet must be heated. These results will help us to identify the power required for the induction module. It is notable that this research is based on minimizing the power consumption and hence the equations are derived after close examination of the effects of using porcelain beads as a heat insulator.

A. Heat required by the aluminum plates

$q_{al} = mc\Delta T$
$= 2.7 g/cm^3$
$c = 0.9 J/g^oC$
$m = \delta V$
$m = 2.7 g/cc \times \pi \times (0.5)^2 \times 0.08 cc$
$= 0.169 g$
$T = T_f - T_i$
$= 800-30$
$= 770^oC$
$q_{al} = 0.169 g \times 0.9 J/g^0C \times 770^0C$
$= 117.56$ J
Qal= 235.129 J

B. Heat Loss

1) Conductive heat loss through aluminum plates

$Q = \lambda A\Delta T$
$= 205 W/mK \times (2\times10) cm^2 \times 770^0C \times 10^{-4}$
$= 315.7$ J

2) Conductive heat loss through mild steel

d = 8mm
l = 80mm
$Q = \lambda A\Delta T$
$= 45 W/mK \times (\pi\times8^2/4) cm^2 \times 770^0C \times 10^{-6}$
$= 1.7416$ J

3) Radiative heat loss through air gap between mild steel and porcelain beads

$Q = A(T^4 - T_c^4)$
$= 5.6703\times10^8 W/m^2K^4 \times 0.32 \times (2\pi\times15\times80\times10^6 \times (800^4 - 30^4))$
$= 140.09$ J

C. Net Heat = 235.129 + 315.7 + 1.7416 + 140.09
= 692.66 J

D. Heat required by mild steel

$q_{ms} = mc\Delta T$
$m = \delta V$
$m = 7.85 g/cc \times (\pi \times \frac{o}{.}) \times 0.08 cc$
$= 31.56 g$
$q_{ms} = 31.56 g \times 0.502 J/g^0C \times T$
$= 15.846 J \times T$
On equating,
$692.66 = 15.846 \times T$
$T = 43.71^0C$
Final temperature for mild steel = 800 + T
$= 843.71^0C$
Heat, $Q = mc\Delta T$
$= 31.56 \times 0.502 \times (843.71-30)$
$= 12891.705$ J

E. Power

$P = Qt$
$= 12891.705 \times 15$
$= 859.4$W

8. Conclusion

The present study deals with the hot stamping of aluminum sheets using a mild steel pallet to create quick and strong spot welds based on the principles of induction heating. The configuration is developed based on the usability of these aluminum sheets in the automotive and aerospace industry. The system is designed considering the thin aluminum sheet required extensively in car parts and aircraft. Basic experiments influence the design of the punching machine and the choice of insulation adopted. The calculations show the optimal power required to carry out welding is less than 1000 W and thus minimizes the wastage. Even though this study reveals how power consumption can be reduced significantly, there is still scope for future work to optimize the efficiency of this process. One major field that needs to be explored to make hot stamping predominant in the automotive and aerospace industry is sheet heating prior to the stamping process. Once the aluminum sheets are treated to make their surfaces ready for welding, they can be heated to the desired temperature. This might have an appreciable impact on the final results and performance of the process. Apart from sheet heating, this process can also be customized to be carried out in aluminum alloys as well as hybrid joints. Further investigation and process parameter optimization will lead to revolutionizing the manufacturing industry and replacing resistance spot welding with induction spot welding.

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