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An Investigation to Determine the Impact of Defects in Metal Sheets Welding in the Automotive Industry in South Africa

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Abstract

Resistance welding has three major defects that affect the quality, and profitabilitiy of the automotive industry that manufactures and assembly body parts. The sustainability of the industry is determined by the quantity of defects for each component in mass production. The automotive industry produces similar parts but not identical for five different automotive industries. Each assembly company requires a certain quantity per week to meet its production line demands. The defects such as porosity, burnthrough and miswelds are common in resistant welding operations. These defects affect the delivery time of finished products because of rejects and rework.The study aims at establishing the root causes of these defects before developing solutions. The solutions would have a positive impact to the productivity of the automotive industry.

Keywords
Reistance spot welding, porosity, miswelds, burnthrough, sustainability

1. Introduction

Welding is a permanent metal joining process or localised casting of pieces of the same metal**.** The process is characterized by welding defects which are external or internal depending on the welding conditions. External defects such as porosity, spatter, cracks, and overlaps are visually detected by magnetic particle inspection or dye liquid penetrants. Internal weld defects such as penetration, fusion, and slag inclusions are not visible at the weld's surface but are seen through ultrasonic or radiographic testing (Alib 2019).

Figure 1 shows a schematic diagram of the resistance welding of two metal sheets. The force to bring the sheets in contact is applied by the electrode. The moment the two sheets are in contact, the circuit is complete allowing electricity conduction. The resistance metal sheets interface generates high heat that instantly melt the spots in contact to a common molten metal pool. Upon solidification the sheets are welded together.

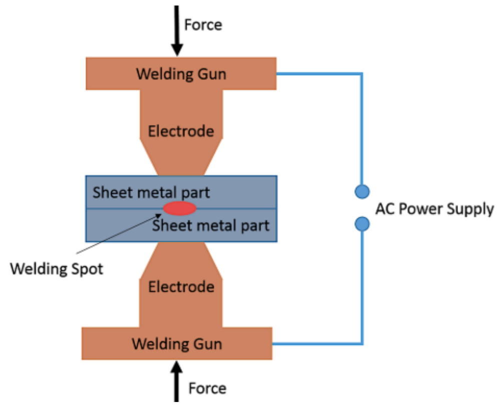

Figure 1. Welding defects (Iraki and Link 2021)

There are several types of welding methods used depending on the materials, function of the component and the required strength in tension, compaction, twisting and bending. Spot welding is a resistance welding method done at localised points of metal sheets and plates. It is applied extensively in the Automotive supply chain industries where metal plates are used on the body, chassis and mountings (Foivos Psarommatisa 2024b).

The steel sheets and plates used in the automotive industry are made of low carbon steels. In spot-welding process, the protrusion on the surface is heated and rapidly deformed and form a molten zone at the interface which is forged to form the weld spot of high strength. For a weld the protrusions can vary according to the strength required.

The resistance spot welding technique is used in the assembly process in automotive industry where fatigue strength is critical on the stress concentrated nuggets. Today 0.5 -3mm thick ultra-high strength steels is used for vehicle bodies for weight saving and crash safety. Such thin sheets tend to develop some defects when there is a slight change of welding conditions (Tomoyuki Fujiia* and Ojimad 2011).

The study by (Oprea and Constantin 2025) showed that the breaking force increased from 10.9 kN for samples with three protrusions to 11.4 kN for samples with five protrusions, for the same values of welding parameters. For increased safety on impact, the fatigue and impact strength is increased by increasing the nuggets.

1.1 Aim

The paper seeks to analyse the common spot weld defects experienced in the automotive industry that uses low carbon steel sheets. The analysis will be used to reduce welding defects in other sheet metal manufacturing industries.

1.2 Research Questions

The research questions and objectives in Table 1 will be responded to in the study to find the root cause and develop a solution to the problem.

Table 1. The research questions and objectives

	Research Question	**Objective**
RQ 1	What are the causes of defects in Spot welding?	To identify the common defects
RQ 2	What are the root causes of these defects?	To determine the root cause of defects
RQ 3	What operating conditions are suitable for good quality welds?	To set SoPs

1.3 Scope

The study will consider the three types of defects namely burn through , porosity and miswelds that are predominant in the sheetmental industry in the ASC in South Africa (SA) .

1.4 Significancy

The study is significant in establishing the standard operating procedures (SoPs) for spot welding to reduce waste and cost of manufacturing automotive chassis and bordy parts.

1.5 ISO compliancy

The study will consider the quality standars ISO 9000 and environmental standards ISO 1400 in the manufacturing process and disposal of waste. ISO 14001 specifies requirements for an environmental management system (EMS) that can be applied to spot welding workshops and how they manage the manufacturing process, the waste produced and prevent pollution of water bodies. The safety of the operator and other users is also critical since resistance welding uses high electric current densities and heat above $2000\ C^0$. Use of leather cloves and helments is mandotory in welding to prevent serions burns and arc eye.

2. Literature Review

In the literature the focus is on the three defects common in metal sheet and plate spot welding on mild steel, their cuases, remedies and prevention. Resistance spot welding (RSW) uses an industrial AC power supply where a transformer boosts the voltage and increases the current and welding pressure on the joint by the electrodes. The current flows through the contact surface of the joint and the adjacent area, generating resistance heat to melt the local metal, ultimately achieving a metallurgical combination of the workpiece (Yuxin Wu 1 2025).

Resistance spot welding applies Joule's law of heating to join thin sheets of steel, titanium, aluminum, magnesium. The the heat generated is directly proportional to the square of the welding current. The law is

$$Q = I^2Rt$$

where Q is the heat output at time t, I is the current, R the resistance.

The holding time t ranges from 0.01 to 0.8 s depending on metal thickness

Spot welding of non-ferrous metals such as aluminum and magnesium is a challenge because of their high surface oxidation rate and thermal conductivities. This calls for high chemical cleanliness on the surface of the joint to minimise impurities and oxidation products (Tanmoy 2022).

Figure 2 shows two sheets that are being dspot welded at a single point using copper electrodes an an AC current. The electrodes apply the force to cause contact.

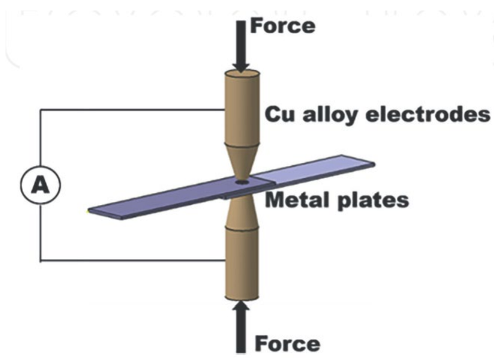

Figure 2. The schematic diagram of RSW (Tanmoy 2022)

Spot welding has defects due to incorrect settings of current, force, and time. Periodic checks and adjustments to optimize the welding parameters are necessary depending on the working conditions of the welding machine to compensate for the erosion of the electrode head. The defects compromise the quality and strength of spot welds a concerns in automotive, aerospace, and marine industries (Mohammad Amin Ganjabi1 · GholamHossein Farrahi1 2023).

The modern industry has adopted data-driven methodologies in manufacturing processes using reliable tools that give real-time data on the operational status of advanced automated systems. The data is used to develop digital systems that make decision based on real-time insights using sensors and visual Andon lights. The visual Andon lights system was developed using electronic components, programming techniques, and additive manufacturing technologies (Krist ́ of Lajber 2017).

Figure 3 shows an automated RSW system that uses the visual Andon lights to prevent errors. If a defect is about to occur the yellow light will show and the operate must correct the anomaly. If the operator delays or fails to correct the anomaly, a red light will show, and the machine stops before a defect is made.

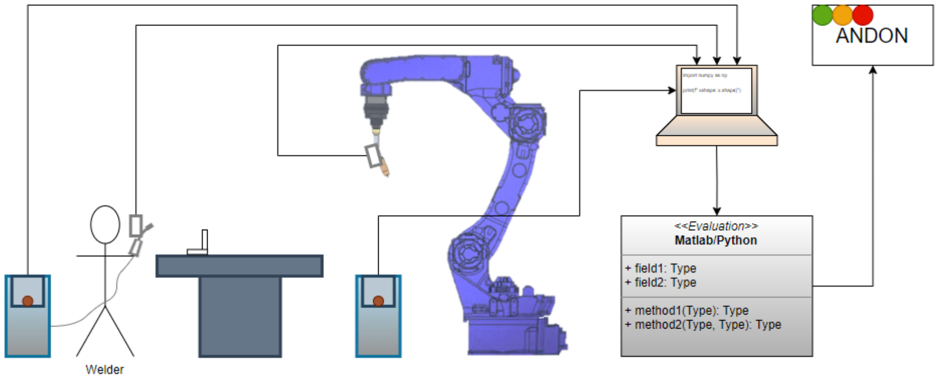

Figure 3. The RSW system with Visual Andon lights(Krist ´ of Lajber 2017)

(Musa Bayır 2023) highlighted that RSW requires early defect detection to reduce rework costs, and consumtion of excessive amounts of materials and improve sustainable production. The welding quality must be controlled to increase the efficiency and sustainable performance of production lines. Analysing data from machine history the ASC can control and predict the welding parameters that cause defects develop a model that is error proof.

The ASC in SA thrives to attain zero defects by applying the continuous improvement (CI) Lean Manufacturing philosophy of zero tolerance and total quality. The RSW in the automotive industry uses the Robotic technology and Jidoka where sensors predict the quality of next spot weld using Andon lights. It predicts where the RSW will form a defect and the operator identifies the root cause and prevent it by adjusting the settings. The model is validated by a series of simulations of the RSW tool to obtain the 3 Andon light requirements (Foivos Psarommatisa 2024a) .

Figure 4 shows a resistance welding flow chart that has zero defects because of using Andon lights. Andon lights use the Jidoka intelligent sensors that detects a defect before it happens to reduce and in most case eliminate the likelihood of defects.

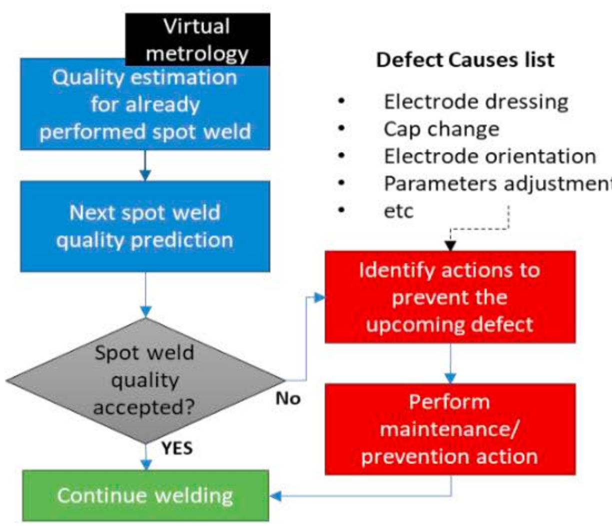

Figure 4. RSW Intelligent flow chart for zero defects (Foivos Psarommatisa 2024a)

To reduce weight and increase efficiency most auto parts are made from aluminium castings with high sensitivity for hydrogen-induced weld porosity. The castings show porosity defects in mixed spot-welded materials where the nugget penetration depths are low. RSW applies a forging force on the electrode that reduces weld spot porosity significantly, while a current downslope leads to an increase in porosity (Reisgen1 2025).

3. Methodology

The method used involves use literature, work study and observations of the spot welding processes in the ASC. Extraction of statistical data from noticeboards is used in quality management system (QMS). Interviews and discussions are used widely in the industry. The engineers technicians and artisans in welding are involved in the discussions, observations and work study.

4. Results

The results obtained are in the form of numerical used to plot graphs , qualitative for discussions and pictorial from the samples of defects obtained.

Numerical Result

Table 2 shows the defects incurred on the body mounting on a day shift in August 2025. Porosity, mis welds and burn throughs were recorded at 14 positions in the mounting bracket. Porosity caused by gas pockets was found in 35 places at positions 33, 40, 17,34 and 32. The Mis welds recorded were 51 and happened in positions 17, 35,40, 18, 39, 37,44, 43, and 33. Burnthroughs recorded were 8 at positions 33,43,34, and 40. Positions 33, 34, and 40 had all the three defects.

Table 2. Numerical results for porosity, mis welds and burn through defects

DEFECT	QTY	REAR STEP BODY MOUNTING	POSITION
Porosity	15	05-Aug-25	33
MISWELDS	3	05-Aug-25	17
Porosity	4	05-Aug-25	40
MISWELDS	7	05-Aug-25	35
Porosity	13	05-Aug-25	17
MISWELDS	8	05-Aug-25	40
MISWELDS	3	05-Aug-25	18
BURNTHROUGHS	2	05-Aug-25	33
MISWELDS	11	05-Aug-25	39
Porosity	1	05-Aug-25	34
MISWELDS	7	05-Aug-25	37
MISWELDS	5	05-Aug-25	44
MISWELDS	3	05-Aug-25	37
MISWELDS	3	05-Aug-25	43
Porosity	2	05-Aug-25	32
MISWELDS	1	05-Aug-25	33
BURNTHROUGHS	1	05-Aug-25	43
BURNTHROUGHS	2	05-Aug-25	34
BURNTHROUGHS	1	05-Aug-25	40

Graphical

Figure 5. shows the position 33 which had the highest defects with porosity 21, misweld 11 and burnthrough 9.

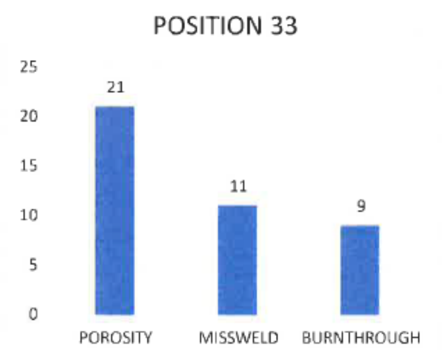

Figure 5. Defects at position 33

For the month of July the positions and defects found were used to plot the pareto curve shown in Figure 6. The mumber of defects on positions 17,28,39 and 33 were not acceptable due to the high costs of producing scrap. This called for a thorough investigation to get the root cause of the defects and surbodinate the constrain by continous improvement. Positions 32, 18, 38 and 43 had few number of defects which needed to be eliminated by continous improvement.

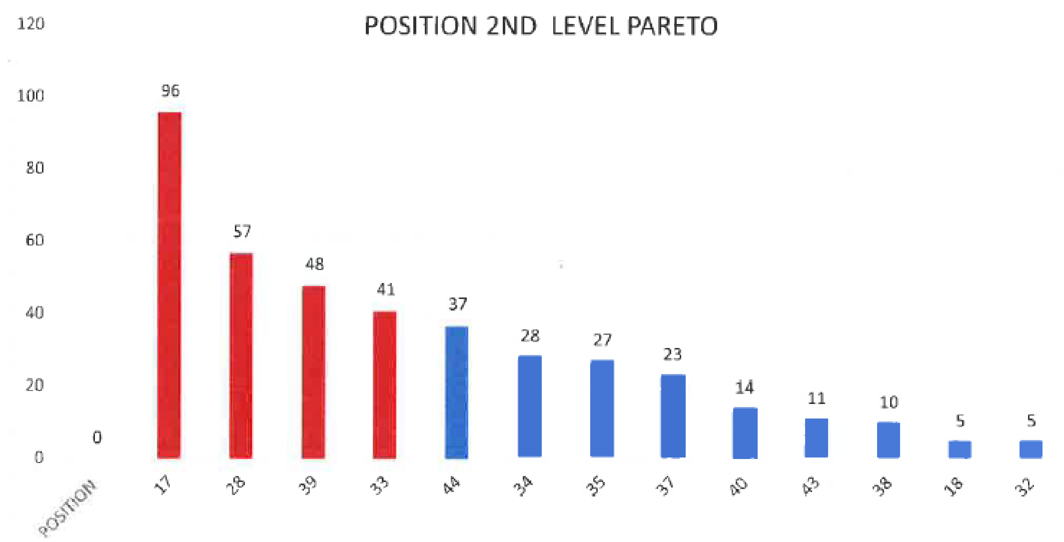

Figure 6. Defects discovered on each of the positions

Pictorial results where obtained from the ASC data base of the common defects in RSW at the automotive industry. Three defects are common in the spot welding process at different positions when welding using a robot.

Porosity

These are holes from gas pockets when carbon dioxide, hydrogen, and steam bubbles are trapped in the weld. The entrapped gases are either uniformly distributed found in a specific location to weaken the weld joint and increase the risk of damage due to fatigue. In the automotive industry, the strength of the weld is compromised and result in leakages in fuel tanks (Figure 7).

The causes of porosity are numerous. Contamination of filler wires, insufficient gas flow and consumables, moisture on the filler wire or work surface and impurities like rust, oil are prime causes of porosity. The filler road must be clean and used at an appropriate current density. The use of correct low hydrogen electrodes is recommended for welding clean and bright medium carbon steels.

Porosity

Figure 7. Porosity defects of welds in auto parts manufacturing

Miswelds

Misswelds occur when the weld metal does not reach the joint's root due to lack of penetration. In automotive components like radiators thus causes mulfunctions such as poor circulation and insufficient cooling. On car seats it prevents the seats from being rooted to the base of the car which on impact can uproot the seat and endanger the life of the occupants in the vehicle. Figure 8 shows a misweld obtained at the ASC plant.

Missweld

Figure 8. Missweld defects in Auto parts manufacturing

Higher speeds mean less penetration of heat in the joint, which means your weld is more surface-level and less deep. Low current density, inappropriate edge design, and preheating cause this miswelds. A correct current density as per sheet thickness and material type requires an appropriate torch speed.

Burnthrough

Too high a current density will cause burn throughs in metal sheets which are less 8mm thick in the automotive segment. Figure 9 shows a burn through experienced frequently at ASC. This reduces the strength of that specific joint, causing it to break due to continuous vibrations while riding on the road or carrying loads. Slow torch speeds increase the heat applied into a given spot to cause a deeper penetration and high risk of melting away the material to leave a gap called burn-through when welding in a vertical or overhead position.

Burnthrough

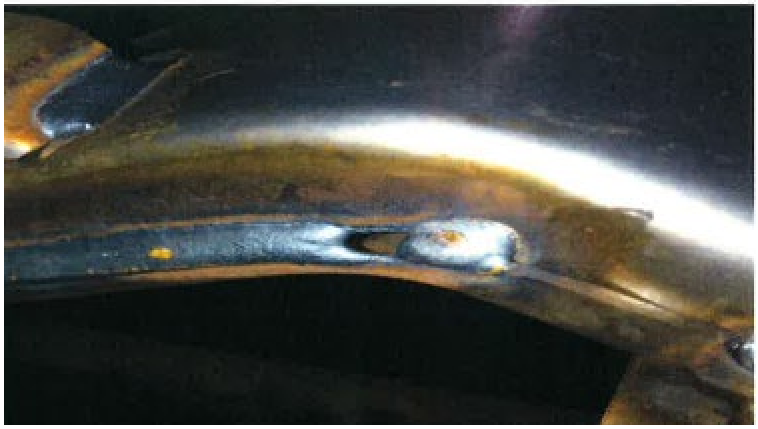

Figure 9. Burn through defect in auto parts manufacturing

Today metal body sheets are less than 3mm and internal plates range between 3-8mm for light vehicles and above 8mm for trucks, buses and vans. To reduce burn throughs welders must the correct current density metal thickness and avoid gaps, whilst distributing heat evenly in a specific area

Root Cause analysis

To Avoid Weld Defects the operator must have the necessary skills, quality equipment, and proper training to drive quality results. The operators and welders receive training and education to improve their skills, be up to date with the trends in the industry and reduce the likelihood of errors. This is achieved when the industry invests in high-quality, superior welding machines and equipment, consumables that provide precise control over welding parameters and could help reduce the risk of weld defects. The equipment must be maintained and calibrated regularly to keep them in perfect condition whilst consumables and material sheets are defect free (Figure 10).

Some clamps accumulate spatter and dust due lack of regular cleaning and use of improper cleaning methods.
The parts from different suppliers vary in dimension and affecting clamp fit when the collaboration with material suppliers is not enough to develop good quality material sheets. The collaboration must include the production process, training of operators and setting up a feedback loop to maintain consistency in quality.

Clamps must be cleaned properly to remove grease, spatter, and prevent debris build up by reducing electric contact. To improve conductivity and smooth clamp movement, the clamps must be cleaned regularly using the appropriate degreaser. Frequent inspection to assess the wear and damage before welding is critical.

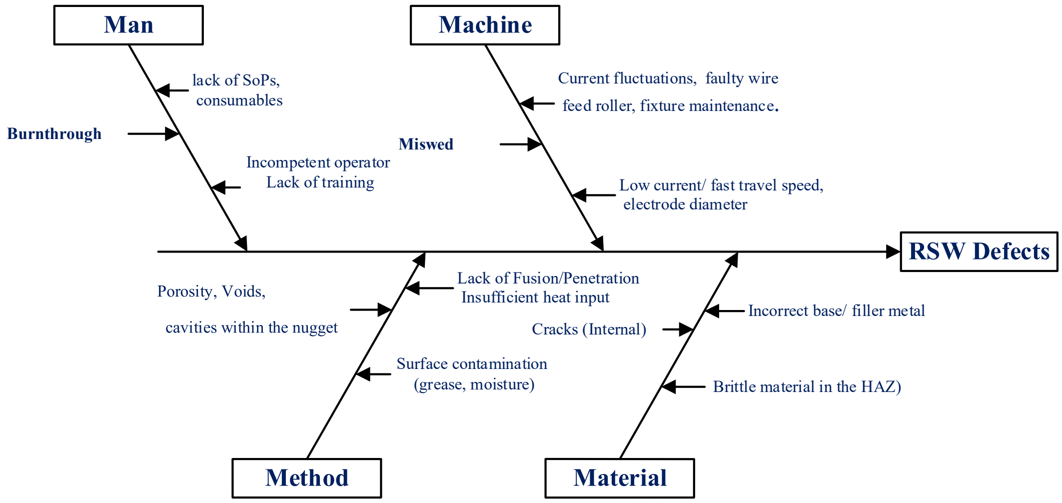

Figure 10. The root Cause diagram from study

5. Discussion

Process dynamic issues

Electrode degradation, misalignment, gaps, positioning errors, mounting tolerances, or bad conditions can cause poor welds (Figure 11).

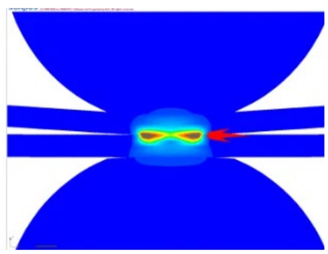

Figure 11. Process Dynamics

In cases where the process is started successfully and defects arise after some welds this is caused, poor settings and adjustments.

5.2 Design

Resistance welding focus on heating the desired localised weld interface melt the materials and cool them for solidification. Materials of lower resistance are used for welding electrodes. To enhance local heating, the electrode is coated by a high resistance material to improve heat distributions in with multiple weld interfaces, such as three-sheet spot welding shown in Figure 12.

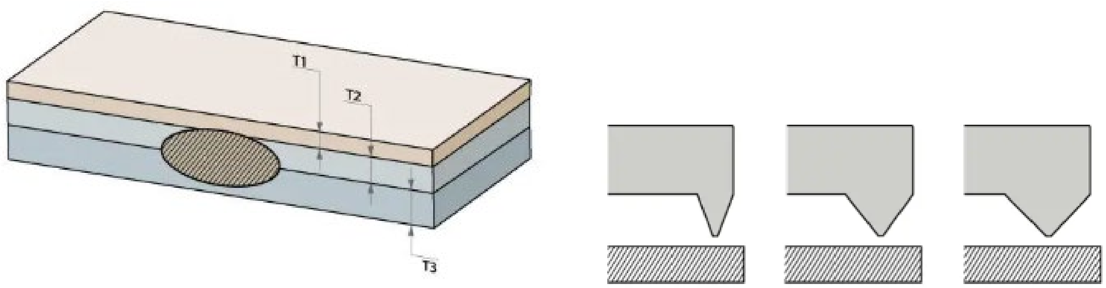

Figure 12. Spot welding Process Design

5.3 Process settings

When the process is running too close to the upper limit defects occur when the electrode and positions are not adjusted frequently. It is critical to set standards operating conditions for adjusting the process layout periodically.

6. Future Study

The study would like to explore the defects in RSW when different base materials of different thicknesses used in the automotive industry are wekded together. It is important to consider the defects when welding in different positions in terms of vertical and horizontal welding.

7. Conclusions

The cause of defects in RSW are predominantly caused by humans. Lack of adequate training always makes the operator to make incorrect setting of the current , pressure and resistant gap which result in burthrough or miswed. If the manufacturing process does not have standard operating procedures operators have high chances of making mistakes. When welding different base metals and thicknesses there must be SoP charts to guide the operator in the setting of current, time for specific materials used. The operator also lack good housekkeping when the welding environment is not clean. It is mangement responsibility to train all operators on the 7S principle to ensure good house keeping.

In places where the Jidoka sysstem malfunctions or is not there, methods of spotwelding must be improved by estimating the the electrode wear rate using machine history at different cuurentsmetal sheet thickness, physical , mecthanical and metaullurgical properties of both sheets. High resistant materials will quickly overheat and cause burnthroughs thus short holding times must be used. Low resistant alloy materials will require longer holding times because they take long tong to melt.

The investment in intelligent tools like the use Jidoka and Andon lights is decided by managemnt to improve productivity whilst making operations much simpler and more accurate and reliable. Intelligent machines are errorv proof if well calibrated. The visual andon lights encourages team work to quickly resolve the looming defect.

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