INTRODUCTION

Spot welding is a principle technique used in the automotive industry and has been for many years [1]. The destructive chisel and peel tests are used to examine the weld nuggets created on the production line. The main quality control tests are the destructive chisel test and peel test, which are carried out on welds obtained from the production line of the product [2, 3]. These have been supplemented by non destructive methods [4]. The failure rates are detected, examined and evaluated. If there is a substantial increase in failure rates then the whole batch of the product is rejected as faulty. Different metals require different welding force and current, thus the difference in the higher force and current used for a galvanized metal than uncoated steel. It makes a significance change in the energy used for the creation of each spot weld. The following report lay’s down a comprehensive view of electrode current selection and its variance over the whole span of the electrode tip. Also describing the advised analysis system for the selection of welding parameters for the spot welding procedure as the electrode tip wears. The unpredictability of the spot welding expulsion at different circumstances will be examined and monitored. Another concern for reducing sparks (splash) caused by resistance spot welding as it can prevent bumps on the bodywork that may cause further complications at later stages. SORPAS is used in order to compare practical tests and theoretical simulations from the practical tests data provided. Throughout the production run, the assurance continuity of nugget size depends on the definitions of optimum welding parameters and the implementation of suitable control for an acceptable spot welding quality. “Weld growth curves” and “weldability lobes” are two accepted methods by the industry to optimize the spot welding process [5]. The technique to form a weld is best exemplified by a weldability lobe which profiles the manufacturing tolerance. Both two and three-dimensional weldability lobes subsist, which are defined in terms of welding time, electrical current and electrode force. Figure 1 shows the spot welding machine operated for the experimental trial, a TECNA 4621 Pedestal Welder [6]. The Top arm is hinged to move down in an arc, while the bottom arm is fixed and contains various sensors used to monitor the welding process in real time [7].
The weldability lobe can only provide a snapshot of the welding currents range, because as the electrode tips wear the weldability lobe can drift. These two factors are controlled by the interaction between various parameters which control the temperature distribution in the metals during the welding thermal cycle. Galvanised steel typically has narrower lobes and greater electrode wear when compared with uncoated steel [8]. Recently however, a different concern has come to light namely energy consumption within the industry both financial and environmental repercussions [9]. This research greatly improves productivity since damaged tips can be identified and changes during the manufacturing process, rather than performing substandard welds. The quality of the weld is monitored in real time through its electrical properties, i.e. the current, voltage, etc.

2. CURRENT TECHNOLOGIES

In order to determine the efficiency of the existing technology, several experiments were conducted to monitor the step by step degradation in weld quality. The experiments were preformed on coated industrial 0.8mm sheets and the variables were current, voltage, force, water coolant and pressure. To check the quality of the weld destructive testing must be carried out – as shown in Figure 2. Jaguars’ common industrial practice is to chisel test all welds on a single car every three months.

The required sensors are placed in relevant positions for most effective detection – as shown in Figure 3. The current sensor (not visible) is a Rogowski (air cored) coil [10]. This sensor gives a voltage output proportional to the current induced through the arms of the spot weld machine. The voltage sensor consists of two leads connected to each electrode. This signal is then passed through a buffer/amplifier circuit into a data logger within a standard computer. The infrared sensor is a photoelectric infrared diode positioned at a distance of 60 mm and at 90° from the electrode tips and also passes through the buffer/amplifier circuit.

Top arm Bottom arm

Fig. 1: TECNA 4621 Spot Welding Machine

Fig. 2: Destructive Spot Welding Off Line
Through weld ultrasonic testing is also used with the system and is mounted at the top and bottom of the upper and lower electrode arms. The collected data passes through a preconditioning circuit before being fed into a data logger. Typically for 0.8 mm galvanized steel, 0.2 sec (10-50 Hz mains cycles) is used for the weld time, the pre-process data capture is 0.3 sec (15-50 Hz mains cycles) and the post-process capture is 0.5 sec (25-50 Hz mains cycles). This allows the data to be captured before the electrodes are in contact with the metal, during the process and after the electrodes are removed from the metal to provide a complete data set to create the ultrasonic profile.

3. SPOT WELDING SIMULATIONS
SORPAS [11] is professional weld simulation software and has been used by engineers in industry (including automotive, steel making, welding equipment, electronics and other metal processing industries) to support design and evaluation of material weldability combinations, as well as design and selection of electrodes and general optimisation of welding process parameters. It can be used to compare theoretical and practical results – see Figure 4.
Fig. 4: Comparison of nugget simulated in SORPAS with practical results and the Temperature Distribution

A weld growth curve is constructed by performing several welds at different power settings and taking the average size of the resultant nuggets. The input power will range from settings that produce no welds through to those that cause splash. The range of weld types preformed covers the following criteria: Fig. 5 shows the quality of the nugget weld of various welding conditions

- **No weld**: This occurs when there is insufficient current to melt the parent metal
- **Stuck weld**: This strictly refers to spot welding galvanised metal. The metal coating has a lower melting point and melts, but the parent metal does not. This results in the metals being stuck together with minimal mechanical strength.
- **Undersized weld**: This is where a weld created, but upon the destructive testing the nugget is smaller than required size, which according to BS1140 standards [12], is 3.5 times the square root of the thinner parent metal (in mm). This minimum requirement can be overridden by a particular requirement from the manufacturer, such as 4 times the square root of the thickness.
- **Acceptable weld**: This is the condition where the weld nugget is above the minimum size and below any maximum size (if specified) and does not result in splash (expelled metal).
- **Splash weld**: This is where some of the molten metal is expelled from the molten nugget, causing the electrodes to collapse in to the metal further, resulting in a thinner weld.

![Image of weld types](image)

Fig. 5: Representation of the quality of the nugget weld of various welding conditions

4. SORPAS SIMULATION

4.1. Weld Growth Curve

The Weld Growth Curve Simulation was carried out using standard coated stainless steel sheet thickness of 0.8mm, 2ltr/min water flow rate, 2.5bar pressure, current ranging from 2 to 11kA, with 0.5kA increments. The red points (see Figure 6) indicate splash at the interfaces between the sheets, the black points indicate no weld and the green points indicate the welds with a nugget. Figure 7 shows the quality of the nugget weld of various welding conditions.
5. THEORETICAL AND PRACTICAL RESULTS

5.1. Weld Growth Curve

Figures 7 and 8 show the differences between the theoretical and practical results of the weld growth curves (WGC). The theoretical WGC is resultant from the SORPAS simulation. The Simulation was performed on a typical passenger vehicle body of 1.0mm coated stainless steel sheet. The other welding parameters included 2ltr/min water flow rate, 3.5bar pressure, current ranging from 4 to 9kA, with 0.5kA increments. The black points indicate no weld and the green points indicate the welds with a nugget – as shown in Figure 7. The simulation performed on typical passenger vehicles body of 0.8mm coated stainless steel sheet, with welding parameter include 2ltr/min water flow rate, 3.5bar pressure and current ranging from 4 to 11kA, with 0.5kA increments. The red points indicate splashes at the Temperature Distribution Weld Nugget interfaces between the metal sheets, the black points indicate no weld and the green points indicate the welds with a nugget – as shown in Figure 8.

Fig. 7: Theoretical and Practical representation of the weld current vs. the diameter of the weld nugget
5.2. Expulsion in resistance spot welding:

Expulsion is a common phenomenon in resistance spot welding and is the ejection of molten metal during welding as shown in Figure 9. It occurs at the interface between the electrode tip and the work piece [14]. This can obviously affect the surface quality and electrode life, but not the strength of the weld if it is limited to the surface. In terms of weld quality, the expulsion is highly inconvenient since it involves loss of liquid metal from the nugget. There are several possible causes of expulsion including; an unexpected gap between the metals, dust particles between the metal surfaces, a greasy metal surface, a reactive chemical compound within the metal or coating, and an unnecessarily high current. Generally expulsion is increasingly expected when greater currents are applied; however, it is still possible to meet the weld nugget requirements in some circumstances.

5.3. Practical results (expulsion):

As shown in Figures 10, 11, and 12 the practical test carried out using standard coated stainless steel thickness of 0.8mm, and 2ltr/min water flow rate. The pressure was varied between 3.5bar, 4.0bar, and 4.5bar, with the current ranging from 4 kA to 9.5kA, at 0.5kA increments. The tests that carried out
involve a repetition of 1700 welds per set, where the electrode tips remained the same and replaced for new tips in each set after the 1700 welds.

The three different Figures prove that even though the same specifications are used in each experiment the nugget size produced differs according to the pressure/current combination used.

At Figures 10, 11 and 12, where the pressure was set at 3.5bar, 4.0bar and 4.5bar respectively, The number of nuggets produced that conform with the British Standard nugget size regulation were highest at the 4.0bar followed by 4.5bar and lowest at the 3.5bar pressure. It is concluded that the amount of current required to produce a British Standard nugget at the pressures of 3.5bar and 4.5bar is significantly higher. Therefore not only that the 3.5bar and 4.5bar do not produce a desirable yield, but these pressures are inefficient in terms of the energy consumption.

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**Fig.10: Practical representation of 3.5bar**

**Fig.11: Practical representation of the weld current vs. the diameter of the weld nugget at 4.0bar**

**Fig.12: Practical representation of 4.5bar**
6. Conclusion:

The relation between the weld growth curves produced by practical and simulation indicates that although there is an alternation in the results, the correlation is great enough for SORPAS to be adopted in providing the initial parameters for deployment in the industry. The core of this study was on the identification of different spot weld methods using SORPAS. The application of the software was invaluable in the process of spot welding; however its precision varies with the numerous experimental parameters. In the case of the automotive industry, an electrode tip life span can be far greater than recommended (approximately 500 welds) to produce an acceptable weld by reducing the current to the minimum value. Reducing the energy consumption for the welding process is another advantage triggering a positive impact both environmentally and financially, as well as decreasing the likelihood of expulsion. There is ongoing research to enable the process to consume even less energy by minimizing the electrode force as well as control the value of current in order to obtain the optimum condition for good weld. It is envisaged that the introduction of artificial intelligence will endorse for time reduction in weld time, as well as the improvements of monitoring systems that can be used on different spot weld machines. Reduced manufacturing downtime is another outcome of the improved deployment speed.

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