# Welding Products Defects Analysis with Fault Tree Analysis and Failure Modes and Effects Analysis

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In manufacturing companies, high number of defects translates to high costs. Some types of products that have defects can be reworked to minimize wastes. However, not all types of products can be reworked, especially welding products. Companies need to find ways to reduce defects before they occur. Reduced defects mean better sustainability, both in economical terms and in ecological terms. This paper discusses the results of a field study conducted in an automotive company that uses Resistance Spot Welding (RSW) in its processes. Fault Tree Analysis (FTA) and Failure Modes and Effects Analysis (FMEA) method is used in identifying causes of defects and in developing action plan to reduce Risk Priority Numbers (RPN) as a way to reduce defects and defects-related costs.

**Keywords:** FTA; FMEA; Resistance Spot Welding

## 1 Introduction

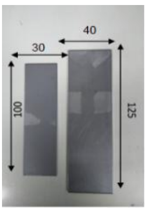
Motor vehicle production process in the automotive industry is not only about producing more quantity, but also about maintaining and improving the quality of the product so that consumers feel satisfied with the product. According to the Indonesian National Standard / SNI 19-8402-1991, quality is the totality of features and characteristics of products and services that can satisfy both stated and implied customer needs [1].

Quality product results depend on production process. The process of making a product has its own quality control depending on the process. Car production has several processes, and one of the processes of making a car is the welding process using Resistance Spot Welding (RSW). RSW is a process of combining two or more materials in the structure of a car or commonly known as Body-in-White (BIW). There are around 4000-6000 spot welding on the car [2]. The results of RSW will not always be in accordance with the provisions of quality that already exists or can be called defect. One of the results of a defect from resistance spot welding is crack.

This research was carried out in an automotive company in Indonesia. Based on experiments conducted in the company laboratory using RSW on a galvanized steel, the percentage of welding product defects in the forms of nugget diameter cracks is more than 15 percent. Spot welding defects can reduce the quality of the car, so the results of the defect will be analyzed using the Fault Tree Analysis (FTA) method and the Failure Mode and Effect Analysis (FMEA) method. FTA is a deductive technique [3] that is graphical and logical which can evaluate the probability of an event or accident as a result of failures of a system's components [4] by using symbols that is easy to understand [5]. FMEA is a simple and economical methodology [6] that enables the documentation of failure modes and their causes, effect, control, and ranking; therefore, it is important for the automotive industry to implement FMEA because it can provide point of action before errors occurs and avoid rework and corrective action [7]. The combination of FMEA and FTA provides more detailed information than separate applications of the two methods [8][9].

## 2 Materials and Methods

In this Resistance Spot Welding (RSW) research, the equipment and materials used are KDC30-1056N Welding Gun, pendant, force gauge, and galvanized steel. This research uses SCGA270D galvanized steel material with two different thicknesses, 1.2 mm and 2.0 mm and have different material dimensions that follows the JIS G 3136 standard. Material that has a thickness of 1.2 mm, follows a dimension of width 30 mm, length 100 mm. As for material with a thickness of 2.0 mm, following dimensions of width 40 mm and length 125 mm, as can be seen in Fig. 1.



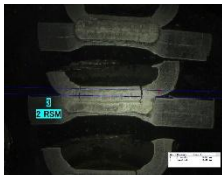




**Fig. 1.** Material Dimensions
**Fig. 2.** RSW Result

**Fig. 3.** Weld Nugget Crack.

In this research, 72 spot welding experiments was carried out. An example of RSW Result can be seen in Fig. 2. After the spot welding process, the next step is to evaluate the weld nugget to see the results of the process. From 72 spot welding experiments, there are 12 results that have cracks in weld nugget. Illustration of the weld nugget crack can be seen in Fig. 3. The results of these defects are analyzed using the Fault Tree Analysis (FTA) method and Failure Mode and Effect Analysis (FMEA). In developing the FTA and FMEA analysis, intervews are conducted with 4 welding experts who have worked with the company for more than 6 years.

Fault Tree Analysis (FTA) is a top down analysis that provides a visual representation of how equipment failures, human errors and other factors lead to an accident or event [10]. The beginning of the FTA step is to identify a system failure mode from the top event problem. The top event is developed by several branches that bring to several sub-events which shows the possible causes of an event [11]. FTA maximally shortens the time required to find faults and failures; upon the occurence of a fault, we only need to observe the FTA diagram to detect, localize, and remove it in the shortest period of time [3].

Failure Mode and Effect Analysis (FMEA) is a method that focuses on defects prevention [12]. FMEA uses the Risk Priority Numbers (RPN) of defects that gives prioritization on which defects that needs to be focused in order to have production process with minimal defects based on value of the RPN; defects or failure modes with higher RPN needs higher attention [13]. RPN has 3 risk factors, namely Severity (S), Occurance (O), Detection (D) that is rated on a scale of 1-10 for each failure mode using the ranking guidelines [14]. The formula of the RPN [15] can be seen in Equation (1).

$$\text{RPN} = \text{Severity (S)} \times \text{Occurance (O)} \times \text{Detection (D)}$$

FTA and FMEA are methods that can be used in attempts to assess risks or failures. FTA and FMEA is already used in numerous studies. Several of them is described in the following. Medvesek et. al. [3] used FTA to analyze heavy fuel oil supply. Povolotskaya &

Mach [8] used FTA and FMEA to analyze adhesive joining process. Aravinth et. al. [13], Tripathi et. al. [15] used FMEA to analyze welding. These studies have shown that FTA and FMEA is very beneficial in assessing risks and developing actions to lower process failure.

## 3 Results

### 3.1. Fault Tree Analysis (FTA)

The FTA method is used to analyze to cause of Resistance Spot Welding nugget cracks. The potential factors causing the cracks are Condition, Equipment, and Material. These potential factors, intermediate events and basic events are determined through field study and discussion with company welding experts. The results can be seen in Fig. 4.

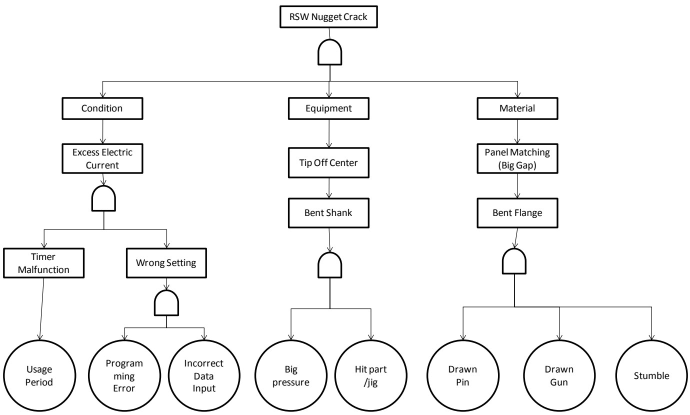



**Fig. 4.** Fault Tree Analysis on Spot Welding Crack Results.

### 3.2 Failure Mode and Effect Analysis (FMEA)

After finding the causes from FTA analysis results, the FMEA method was conducted and the results can be seen in Table

1. The recommended actions and the RPNr, which is the RPN value after the recommended actions are implemented, can be seen in Table 2.

**Table 1.** Failure Mode and Effect Analysis for the Weld Nugget Crack.

| Failure Mode | Effect | S | Cause | O | Control | D | RPN |
|---|---|---|---|---|---|---|---|
| | | | EQUIPMENT | | | | |
| Tip Off Center | Bent shank | 8 | E1. Big pressure | 6,5 | Welding conditions inspection | 8 | 416 |
| | | 8 | E2. Hit part/jig | 7 | Equipment condition inspection | 8.5 | 476 |
| | | | CONDITION | | | | |
| Excess Electric Current | Timer Malfunction | 9 | C1. Usage period | 7 | Electric current inspection | 8.5 | 535.5 |
| | Wrong setting | 9 | C2. Incorrect data input | 5.5 | welding conditions inspection | 8.5 | 420.75 |
| | | 9 | C3. Programming error | 5 | welding conditions inspection | 8.5 | 382.5 |
| | | | MATERIAL | | | | |
| Panel Matching (Big Gap) | Bent flange | 7 | M1. Drawn gun | 6.5 | Material position check | 9 | 409.5 |
| | | 7 | M2. Stumble | 7 | Material inspection | 9 | 441 |
| | | 7 | M3. Drawn pin | 6.5 | Datum pin check | 9 | 409.5 |

**Table 2.** Failure Mode and Effect Analysis based Recommended Actions.

| Failure Mode | Effect | Recommended Action Plans | S | O | D | RPNr |
|---|---|---|---|---|---|---|
| | | EQUIPMENT | | | | |
| Tip Off Center | Bent shank | E1. Check and adjust pressure | 5.5 | 2.5 | 8 | 110 |
| | | E2. Check equipment and replace damaged equipment | 6 | 2.5 | 8 | 120 |
| | | CONDITION | | | | |
| Excess Electric Current | Timer malfunction | C1. Measure the electric current before using | 6.5 | 2 | 8 | 104 |
| | Wrong Setting | C2. Check the setting of the spot welding process and reset it | 6 | 2.5 | 9 | 135 |
| | | C3. Check the setting of the spot welding process and reset it | 6 | 3 | 9 | 162 |
| | | MATERIAL | | | | |
| Panel Matching (Big Gap) | Bent flange | M1. Learn correct material position during the process of spot welding and re-arrange material position | 5 | 2 | 8.5 | 85 |
| | | M2. Check material and replace material with new ones | 5 | 2.5 | 9 | 112.5 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | if damage occurs | | | | |
| | | M3. Check the datum pin and replace the datum pin with a new one if there is damage | 5 | 2.5 | 9 | 112.5 |

## 4 Discussion

### 4.1 Fault Tree Analysis

The first result that has the potential to cause spot welding crack results is equipment. The description of the factors that have the potential to cause defects by equipment is due to the tip off center (the electrode is not right at the spot welding). Failure caused by tip off is not center is bent shank which can be caused by large pressure, hit part / jig.

The potential cause of defects in the condition section is the excess of the electric current caused by three factors, namely timer malfunction and wrong settings. The cause of the defect on the timer factor is corrupt due to the usage period which results in a functional decrease of the timer. Whereas in the wrong setting factor, the cause is the incorrect data input and incorrect the program used for setting the electric current parameter.

The last part of the cause of the defect due to crack is the material part. The potential cause is matching panel which can be caused by bent flange. The bent flange caused by drawn gun, stumble, and drawn pin. This FTA analysis uncovered events that lead to welding nugget crack. This is the data that will be used in the following FMEA Analysis.

### 4.2 Failure Mode and Effect Analysis (FMEA)

The FMEA Analysis in Table 1 is based on the FTA Analysis. The basic events in the FTA Analysis which can be seen as the bottom events in Fig. 4 is inserted as the Cause in the FMEA

Analysis. The cause with the highest RPN is the Usage Period which is the cause of Timer Malfunction. Action plans are developed for each of the causes in order to decrease the RPN. Action plans that are developed are basically simple actions that only require checking and measuring. However, the implementation of these simple action plans give meaningful results. The results of comparison between RPN and RPNr is shown in Fig. 5. RPNr is the value of RPN after recommended actions are implemented. It can be seen that after the recommended actions are implemented, the RPNr is quite low, very different from the original RPN.

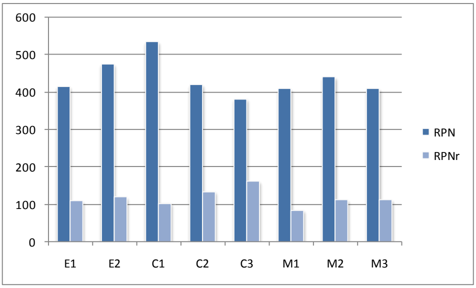



**Fig. 5.** Comparison of RPN and RPNr

## 5 Conclusions, Limitations, and Future Research

From this research, it is concluded that the combination of the FTA and the FMEA method can find the failure modes in a systematical way. The results of the FTA is the failure modes. The failure modes is then analyzed with FMEA. This research has developed action plans that result in lowering the Risk Priority Numbers (RPN) of the Failure Modes. However, the research results is not without limitations. Further welding experiments have not been conducted to prove that lower RPN numbers do result in lower number of weld nugget defects. It is recommended that future researches include empirical researches that can prove lower RPN numbers mean lower number of defects. It is also recommended that future researches use economic engineering approach, such as cost-benefit analysis, in the research.

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