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Assessment on Potential Damages of Automotive Brake Caliper Using FMEA Method for the Application of Remanufacturing Process

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KEYWORDS

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ABSTRACT

The repair and restoration stage in remanufacturing is one of the vital phases to ensure the remanufactured component is qualified during the testing stage. The reliability of the component can be evaluated at the very early stage of remanufacturing process, by adopting the FMEA method. The FMEA method is a tool that facilitate the evaluation of reliability of component related to potential failures and damages of the component. An automotive brake caliper is selected as a case exemplary in this study. The FMEA method will be used to confirm the applicability of DED process as one of the repair processes where not all type of failures or damages are suitable to be repaired through DED process. Therefore, this study presents the identification of potential damages or failures of brake caliper and further, analyse the reliability of the component and identify the possible corrective action can be taken. The study shows that the failure modes of a brake pad is irreparable cases that requires part replacement whilst for brake caliper housing shows as having some potential to be repaired using DED process. However, further investigation related to the strength of the component is required to support the FMEA results.

1. INTRODUCTION

The remanufacturing initiative for end-of-life vehicle (ELV) could promote the sustainability of the components through the extension of the component's life cycle. It is vital to carefully assess the reliability of the used component to be remanufactured, to guarantee the quality of the component to be similar or better than the OEM component [1]. The used component usually will undergo several processes starting from inspection, disassembly, part reprocessing, reassembly, and testing [1][2]. The reliability assessment is commonly related to the failures or damages occurred to the component, in which the assessment can be conducted at the early phase of the remanufacturing process, particularly during inspection phase.

In-line with the Industrial Revolution 4.0 (IR 4.0) pathway, the automated repair alternative specifically through additive manufacturing (AM) process is discovered as one of the promising alternatives in ensuring efficient repair and restoration process and leads to more sustainable process [3]. In order to proceed with the selected AM process, it is crucial to conduct the pre-assessment related to its feasibility to perform the repair process by considering of types of damages and quality of repaired component. Hence, Failure Mode and Effect Analysis (FMEA) method will be used in this study. FMEA approach is a quality tool used to evaluate the reliability and quality of the components specifically based on the potential damages or failures of components [4]. The corrective action identified based on the listed potential failure modes could be as a guideline to proceed with a next step.

Therefore, this study is aimed to conduct the evaluation on the potential failures or damages that could be occurred on the remanufactured brake caliper component. The FMEA method

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will be used in this study to verify the applicability of Directed Energy Deposition (DED) process as one of the automated repair processes that provide significant advantages in current technology trends.

2. Literature Review

2.1 DED process as a repair alternative for remanufactured component

The repair process is one of crucial phase in remanufacturing that requires additional attention by the remanufacturer. Any repairable damages that have been identified through inspection process need to undergo suitable repair process based on the severity of the damages. The general classification of structural repair works consists of two main classes which include conventional repair and automated repair [5]. The conventional repair like in welding process is generally focusing on the manual repair that is highly dependent on skilled workers. Whilst the automated repair is an approach which alternatively eliminate human intervention during the operation and give higher efficiency compared to conventional [3] [6]. Recently, the automated repair through additive manufacturing (AM) process has received much attention among the researchers due to its advantages compared to the conventional repair process. Its advantages in repair technologies include in-situ repair, cost savings and low carbon emission compared to conventional process

The Directed Energy Deposition (DED) as one of the AM processes will be considered in this study as the repair approach for the structural repair of a brake caliper. It is fusion based process where the laser beam is used to melt the additive materials that could be either in powder or wire feeding systems and deposited onto a substrate [7]. The DED process allows high geometric precision, as well as enable good mechanical performance during repair [3] [8]. Despite of offering these advantages, the application of DED process as a repair option is rather new and requires thorough assessment to evaluate its applicability and feasibility on remanufactured component. Therefore, this study proposed the assessment through FMEA method to identify the potential failures or damages that applicable to be repaired through DED process.

2.2 FMEA Approach

Failure mode and effects analysis (FMEA) is an approach to identify the potential problems with new or existing designs [9]. Failure mode is referred as a possibility of failures of a part to perform its function. In FMEA, the evaluation of the components can be conducted thoroughly in every sub-system or sub-components by following the steps shown in Figure 1 [10].

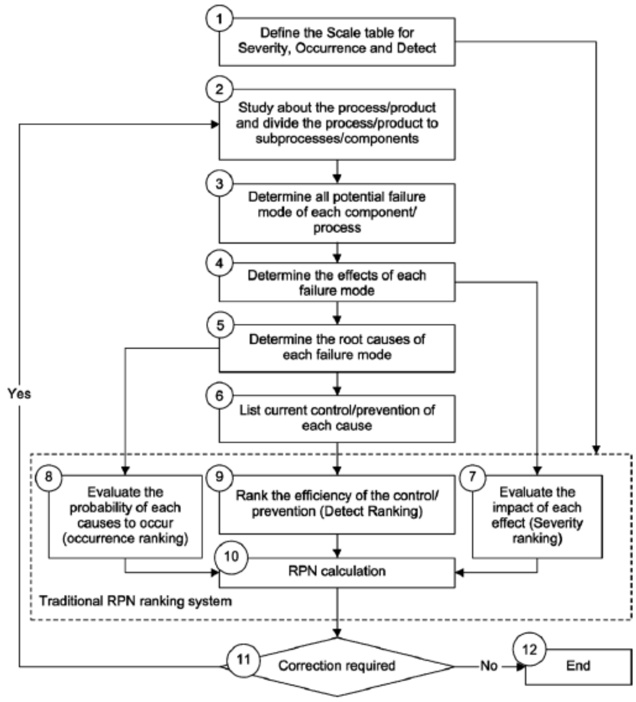

Fig. 1. FMEA procedure [10]

Based on the Figure 1, there are three main factors are considered in FMEA: severity (S), occurrence (O), and detection (D). The scale table need to be first defined for each of the factors. Table 1, 2 and 3 shows the rating scale of the factors respectively [9] [11].

Table 1. Rating for severity of failures

Effect	Rank	Criteria
No	1	No effect
Very slight	2	Customer not annoyed
Slight	3	Customer slight annoyed
Minor	4	Customer experiences minor nuisance
Moderate	5	Customer experiences some dissatisfaction
Significant	6	Customer experiences discomfort
Major	7	Customer dissatisfied
Extreme	8	Customer very dissatisfied
Serious	9	Potential hazardous effect
Hazardous	10	Hazardous effect

Table 2. Rating for occurrence of failures

Effect	Rank	Criteria
Almost never	1	Failure unlikely. History shows no failure
Remote	2	Rare number of failures likely
Very slight	3	Very few failures likely
Slight	4	Few failures likely
Low	5	Occasional number of failures likely
Medium	6	Medium number of failures likely
Moderately high	7	Moderately high number of failures likely
High	8	High number of failures likely
Very high	9	Very high number of failures likely
Almost certain	10	Failure almost certain

Table 3. Rating for detection of failures

Effect	Rank	Criteria
Almost certain	1	Almost certain to detect
Very high	2	Very high chance of detection
High	3	High chance of detection
Moderately high	4	Moderately high chance of detection
Medium	5	Medium chance of detection
Low	6	Low chance of detection
Slight	7	Slight chance of detection
Very slight	8	Very slight chance of detection
Remote	9	Remote chance of detection
Almost impossible	10	No chance of detection; no inspection

The FMEA tool is a team-based methodology which requires the discussion session to assign the score for each of the identified mode of failures. The Risk Priority Number (RPN) value is calculated as the final measurement of each failure mode which represents the combination of three factors as shown in equation (1).

$$RPN = Severity \times Occurrence \times Detection \quad (1)$$

The value of RPN indicates the risk value ranging from minimum value of 1 which represents minimum risk, to maximum value of 1000 which represents maximum risk. However, the value of RPN is usually requires further assessment and should not be fully rely on the RPN value alone.

3. METHODOLOGY

This section is specifically explaining about the step-by-step procedures on implementation of FMEA for automotive brake caliper as depicted in Figure 1. It is important to carefully examine each of the possible failure modes of the component. Hence, the next sub-section 3.1 provides the explanation of the brake caliper component.

3.1 Case Exemplary of Automotive Brake Caliper

The brake caliper is one of the major components in braking system that consists of three standard sub-components: housing part, brake pad part, piston part. To examine the damages or failures, the consideration for each part of brake caliper component will take place. The housing or also called as core of brake caliper is a remanufacturable component, that serves as cover to protect the brake pad and brake piston component. It possesses high durability and strength to fulfil its functions and thus, suitable to be reused in the next life cycle [12]. Figure 2 shows the standard sub-components of brake caliper.

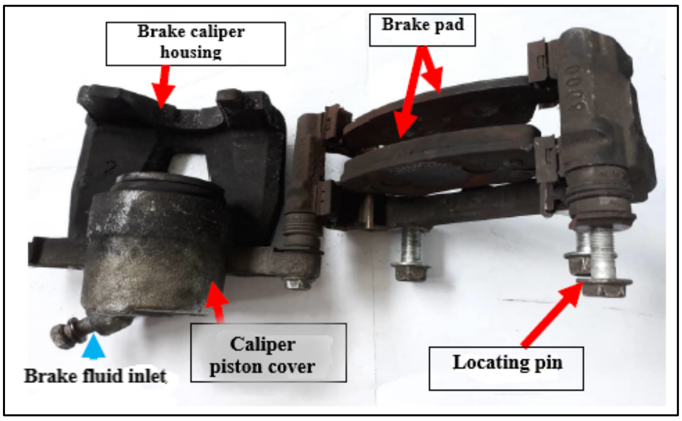

Fig. 2. The opening structure of brake caliper that consists of two main sub-components: brake caliper housing and brake pad

3.2 Identification of mode of failures or damages of brake caliper

The expected Failure Modes for brake caliper were identified based on the common potential damages found in brake caliper. Table 4 shows the common failure modes of the brake caliper component.

Table 4. Potential failure modes or damages of brake caliper

Failure modes	Descriptions	Effects
Crack	A material failure that exhibits ductile fracture characteristics which begin with minor cracks and slowly propagated with appreciable gross deformation.	Uneven wear of brake pad.
Fractured	A brittle fracture that characterized by rapid crack propagation.	Braking failures
Wear	Brake pads are worn thin	Unusual noises: squealing, grinding and metallic scraping noises
Melted	A damage occurred due to a constant pressure applied by stuck caliper to a brake pad and will cause the car's braking system to get extremely hot	A chemical burning smell near one of the front wheels
Corroded	- Type of surface damage that occurred due to a lack of brake fluid flushing in regular intervals which promotes the corrosion in piston bore - Corrosion of outer part of brake caliper housing due to the deterioration of a material because of its interaction with its surroundings or environments	- Unusual noises - The caliper is sticking and needs attention

It is noted that due to high durability of brake caliper housing, the component is not commonly prone to damages or failures. Contrary with a brake pad component that highly prone to the wear damages due to constant friction between two surfaces during the braking operation. Therefore, by benefiting the use of FMEA approach, other failure modes could be predicted at the early stage of remanufacturing process, which facilitate the decision on identifying suitable repair during the part inspection.

Other than failure modes, the root of causes for each of failure modes also need to be identified which discussed in the next sub-section 3.3.

3.3 Identification of root of causes of brake caliper

The Root Cause is identified based on the listed modes of failures, to facilitate the scoring process of each failure in terms of Detection, Severity and Occurrence in FMEA matrix. Table 5 shows the root of causes for each of failure modes identified in previous section 3.2.

Table 5. Root of causes for each of failure modes

Failure modes	Root of causes
Crack	- Low brake fluid - Failed locating pin that become seized or difficult to remove
Fractured	- High impact during accident - Improper handling that leads to a breakage of brake caliper
Wear	- Constant friction between two surfaces of pad and rotor - Thermal generation during braking
Melted	- Constant friction between two surfaces of pad and rotor - Thermal generation during braking

Failure modes	Root of causes
Corroded	- Damaged rubber seals - Environment and surrounding (humidity, dry condition)

4. Results and Discussions

After the identification of failure modes and root of cause, the allocation of score for each of elements in FMEA can be conducted. The assignment is usually accomplished by the experts in a team that familiar with the mechanisms and characteristics of the component. Table 6 shows the overall results indicate the score values for Detection, Severity, and Occurrence for each of failures. At the second last column in Table 6 shows the RPN values that represents the multiplication of those elements.

Table 6. FMEA results

No	Parts of brake caliper	Failures or damages	S	O	D	RPN	Corrective action
1	Brake caliper housing	Fractured	10	3	1	30	1. Repair through DED process 2. Part replacement
		Minor crack	9	4	4	144	1. Repair through DED process 2. Part replacement
		Corroded	8	6	3	136	1. Painting or coating for outer surface 2. Regular brake fluid changes
2	Brake pad	Wear	7	7	2	189	1. Part replacement 2. Regular inspection
		Corroded	8	6	3	162	1. Part replacement 2. Regular inspection
		Melted	9	6	3	162	1. Part replacement
		Fractured	10	5	1	50	1. Part replacement
		Crack	9	5	4	200	1. Part replacement 2. Regular inspection

**The maximum (highest) RPN value is 10 x 10 x 10 = 1000.*

As shown in Table 6, the value of RPN for each of failure modes were obtained. However, the decision made is not simply based on the value of RPN [9]. Lower value of RPN is not necessarily indicate that low priority should be given to the corresponding failure modes. For instance, compare failure modes of corroded brake caliper housing and fractured housing, corroded has nearly four times RPN of fractured due to high value of occurrence and detection respectively. Failure by fracture would cause high severity that leads to safety risk and complete system failure.

Harpster [13] proposed the rational way to interpret the results of FMEA by not relying on the higher value of detection scores which indicates either no design changes is required or improper inspection process. The following Figure 3 shows rational way to interpret the result of FMEA.

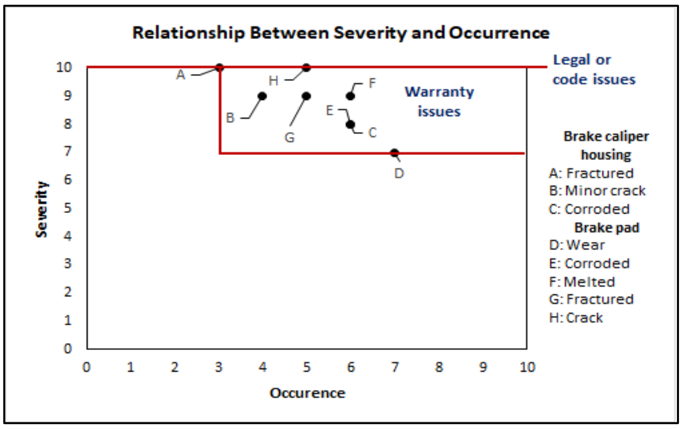

Fig. 3. Interpretation of FMEA results

Based on the results obtained in Figure 3, the interpretation of FMEA results can be made on the basis to give more priority to the failure modes that require immediate corrective action. Those failure modes located at the borderline of legal issues require more attention to prevent the failures to occur. Nonetheless, the fractured failure in caliper housing could be possibly occurred due to external impact during accident or improper handling as listed in the Table 5. Therefore, DED process is seen as the potential repair process that could deposited the alloy as additive material onto the fracture surface [8].

In addition, this study has been extended towards the investigation of the strength of component through simulation using the Finite Element Analysis [14]. The comparison of three different configuration 3D model of brake caliper; original, damaged, and repaired brake caliper through DED process have been developed for analysis purposes. Following Figure 4 shows the example of 3D model for each of configuration that has been developed in this study.

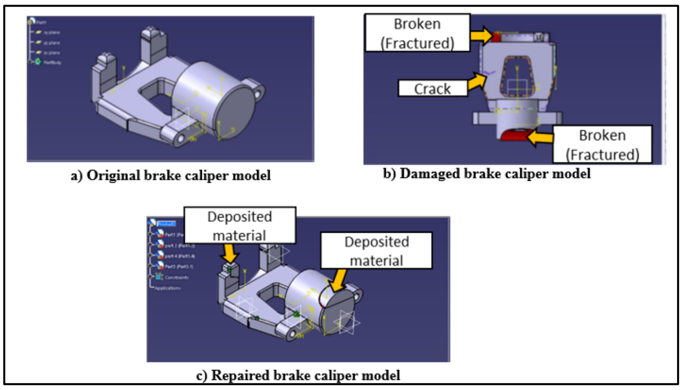

Fig. 4. 3D models of brake caliper with three different configurations [14]

It is important to achieve the results in such a way that the strength of repaired brake caliper is higher or equal than the original brake caliper. This is according to the rules of thumb in remanufacturing where the quality of the remanufactured part should be equal or better than the OEM part [15]. Thus, through this FEA simulation, the applicability of DED process as one of the alternatives listed in FMEA is verified. Nevertheless, this paper is solely focusing on the assessment of potential damages or failures for a brake caliper component through FMEA approach. The assessment is vital to consider the DED process as a new approach for repairing the part based on the related mode of failures.

5. CONCLUSION

Overall, the FMEA method was used in the study as the tool to evaluate the reliability of the brake caliper component. The assessment is important to find the potential of DED process as a repair process for remanufactured component based on the identified failure modes or damages. The FMEA method provides a systematic approach to evaluate the potential failure modes at the early stage of design process, or specifically remanufacturing process. Therefore, the assessment could be further extended to the detail investigation on the applicability of DED process as the new alternative in repair and restoration of remanufactured component.

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