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GUIDELINES FOR AUTOMOTIVE COMPONENT REPAIR USING ADDITIVE MANUFACTURING IN INDUSTRY 4.0: DESIGN AND PROCESS PERSPECTIVE

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Abstract:

The advancement of Industry 4.0 technology requires industries to continuously compete in applying these technologies practically within existing processes. The remanufacturing process as one of the recovery approaches under Circular Economy strategy, is currently thriving on improvement by leveraging Industry 4.0 technology. The application of automated repair through additive manufacturing (AM) is one such opportunity to enhance remanufacturing capabilities with a variety of design options and alternative repair methods. However, AM's potential as a repair option will be hindered due to challenges in terms of the geometric complexities, process requirements, material compatibilities and process accuracy. Hence, this study focuses on the development of guideline for repair of automotive component through AM process. The development of guideline is crucial to provide newly information and steps involved when conducting the repair using AM technology. The study is mainly focusing on remanufacturable of piston part in a crankshaft component as the case exemplary and Powder Based Fusion (PBF) of metal AM technology is used for verification purposes through experimental works. In overall, this study provides a design guideline involving repair process by using the AM process. The guideline would be useful for the designers, industries and remanufacturers to enhance the

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implementation of repair and remanufacturing process by adopting AM technology.

Keywords:

Additive Manufacturing, Repair, Design Guideline, Remanufacturing

Introduction

Additive manufacturing is currently gaining interest among the industry practitioners which in-line with the Industry 4.0 directions and goals. The high efficiency of automated process in AM that is commonly known with the fabrication of new part can be benefited in the repair process of the damaged part (Lee et al., 2022). The conventional repair process such as welding and machining process possesses some limitations, for instance, the metallurgical changes and changes in shape of the components due to thermal applications in welding (Rahito et al., 2019; Aziz et al., 2021). Due to these issues, the advancement in repair process is necessary through additive manufacturing process that can be considered as automated repair process. The initiative could encourage for industries to move from linear economy business model to the circular economy business model.

There are eight (8) AM technologies under ASTM F2793-12A which include Binder Jetting, Directed Energy Deposition (DED), Material Extrusion, Material Jetting, Powder Bed Fusion (PBF), Sheet Lamination, Vat Photopolymerization and Cold Spray method (Vaezi et al., 2020; Kaufui & Hernande, 2010). However, not all technologies are suitable for repair applications where the detail assessments are required to match with the AM requirements. The DED process and PBF process are usually considered as the potential AM process in repair due to its high accuracy and flexibility compared to other AM technologies (Vaezi et al., 2020).

Despites of having potential in repair process, the implementation of AM in repair has faced several challenges in terms of the geometric complexities, process requirements, material compatibilities and process accuracy (Kandukuri et al., 2021; Zhang et al., 2015). The bonding at the interfacial zone requires the heterogeneity between the original part and melted additive materials during the AM process (Kok et al., 2018; Zghair & Roland, 2017). It is crucial to obtain high quality of the repaired part that can be fully operated after the repair process to its original function to meet the requirements of remanufacturing process (He et al., 2020). Nevertheless, the advancement of AM technology possesses some limitations in terms of economic perspective where the high investment is required to undertake the decision with the process. Therefore, it is crucial to establish a proper guideline for repair using AM process to systematically outline the tasks involved in the process and necessary strategies can be considered before commencement of the process.

In this study, a design guideline involving design and process aspects are developed to support the application of AM in repair process. The literature review in next section discusses the latest research mainly on the issues, challenges and strategies in repair process using AM. Next, the methodology describes the steps involved in repair through AM based on the selected automotive component, piston part in a crankshaft component. The findings are then summarised in the guideline form and finally, the concluding remarks of overall study are provided in conclusion.

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Literature Review

The automated repair process is capable to enhance the efficiency of remanufacturing process which encourages data integration to be linked with the enabling technology (Kandukuri et al., 2021). The conventional repair process is usually conducted manually that involves welding process, machining process and surface treatment process. The consideration of AM in remanufacturing could leverage the environmentally friendly process where the reduction of energy and materials consumption could be achieved (Kandukuri et al., 2021). Hence, align with the direction of remanufacturing as a circular economy strategy, the repair through AM would support the initiative to move towards sustainable process.

The strategies in implementing AM as a repair process requires thorough evaluation even at the early stages of design process. The consideration at the design stages is able to facilitate AM process towards smooth and efficient due to its new application for repairing the part (Meyer et al., 2023; Rahito et al., 2019). In general, the considerations at the design stage involves four main phases: part orientation, build preparation to develop the support, and revision process. The integration of design for additive manufacturing (DfAM) and design for remanufacturing could support the implementation of the repair process through AM. For instance, research by Kandukuri et al. (2021) used ETRIZ matrix tool to compile and modify existing guidelines for remanufacturing and AM to embed the feasibility of AM in reman at the design stage. Meanwhile Rupal et al. (2020) focused on DfAM related to geometric tolerance and manufacturing assemblability to consider the assembly conditions with the mating features in metal AM applications.

On the other hand, a wide range of metal AM technologies requires details assessment to ensure the technologies can be applied in the repair process. The requirements of AM process which includes the parameters, the part size and materials specifications need to be matched with the repair conditions which is based on the type of damages of the component. Potentially, the laser-based AM technology can be applied in repair are PBF process and DED process where these two processes are highly relevance on the market compared to other AM technologies (Barroqueiro et al., 2019). Besides, the process should possess high accuracy which become a challenge in repair application to adding features throughout AM process. Hence, such guideline that focuses on the repair for AM from the design until the process implementation would provide useful information on how to strategize from the beginning.

Methodology

The overall methodology in this study consists of four (4) main steps which started with gathering relevant information and requirements through literature review. Then, the CAD simulation was performed on the selected remanufacturable automotive component to simulate the AM repair process before performing the actual AM process. Finally, the overall guidelines which outlines the design and process flow of the AM repair process was established in this study. The following Table 1 lists the software and metal 3D printing machine used in this study. The study has been conducted at the 3DGens Sdn Bhd which provides the facilities starting from CAD simulation until the AM process.

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Table 1: List of Equipment and Software

Equipments/Software	Descriptions
Software	1. Anys Spaceclaim 2. 3D Scanning-Eiscan Pro Series 3. QuantAM 4. Shining 3D
AM Machine	Metal 3D Printing Machine - RenAM 500E

The following Figure 1 shows the overall methodology involved outlines step-by-step procedures in developing the design guideline for repair using AM. A crankshaft piston has been chosen as a remanufacturable automotive component in this study. Throughout the study, it is crucial to ensure the selected component is suitable to undergo AM process once verified through CAD simulation in Step 3. The afterward procedures were mainly involved in pre-processing and post-processing for AM process where the major considerations to ensure efficient AM process to repair the damaged part according to the specified parameters.

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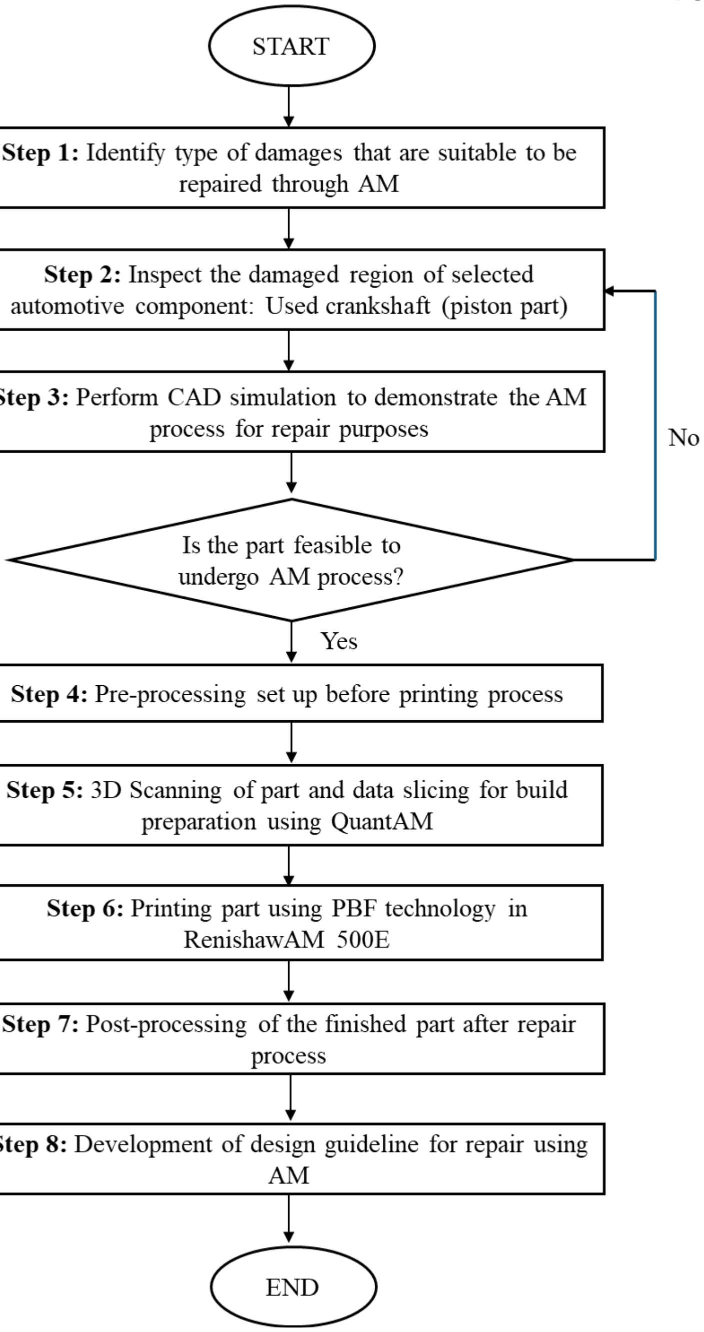

Figure 1: Overall Methodology

Results and Discussion

The findings of the study are mainly focusing on the development of guidelines for AM repair through the CAD simulation and experimental works. The considerations in both simulation and experiments will be discussed and finally, the AM repair guidelines are presented comprising the process flows of the repair through AM process.

CAD Simulation for AM Repair Process

The simulation of repair process was conducted using CAD simulation through QuantAM software. The process starts with pre-processing to remove the damaged area of the component

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through machining process. The jig is then installed to secure the position of the damaged-free component during repairing process using AM. Once the component is properly located at the jig, the preparation of AM process is begun by finding the starting point of printing process in QuantAM software. The simulation of direct deposition through AM process is started until the desired shape is achieved. The simulation results show that the AM process is capable to execute the repair process by depositing new surface onto the original component that can be as a preliminary guide to undergo an actual AM process (Obeidi, 2022). For the verification purposes, the actual AM process is accomplished in the subsequent experimental works.

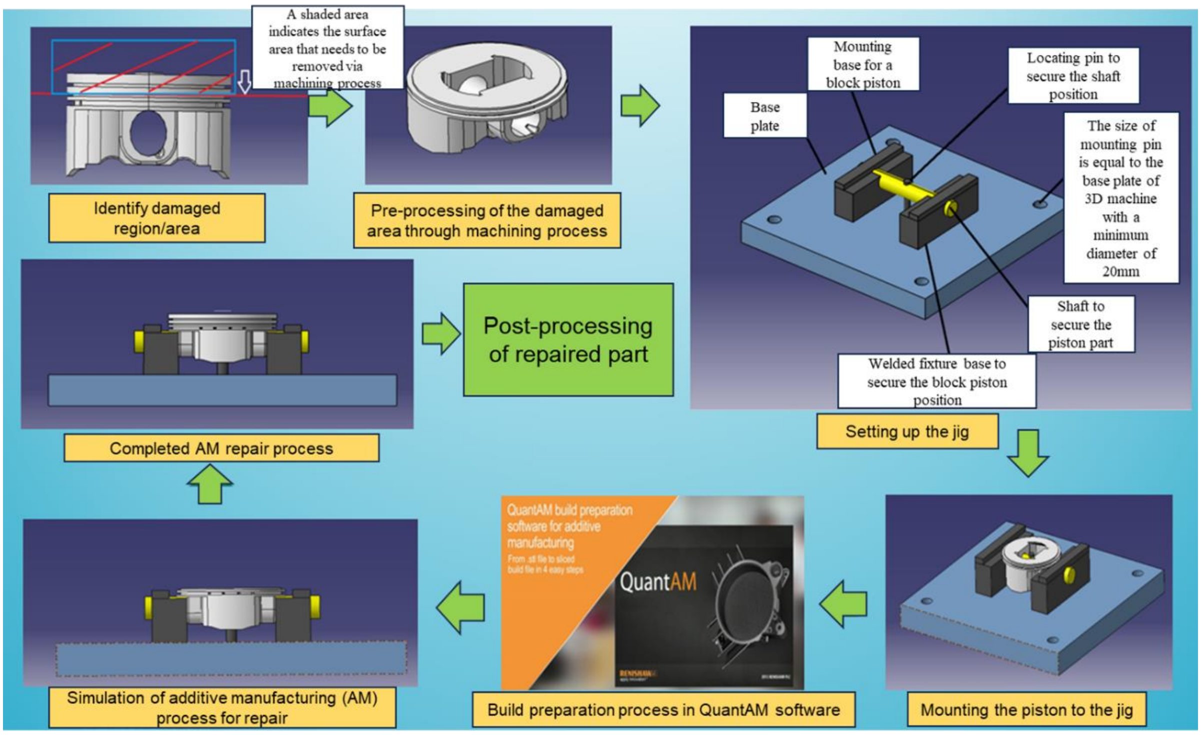

Figure 2: CAD Simulation of AM Process

Verification of AM Repair Process Through an Experimental Works

For verification of the AM repair process, four main steps were involved as follow:

1. Identification of the damaged area of the component

The damaged area or region need to be first identified to decide whether it is repairable or non-repairable types of damage. The types of damage that are usually suitable to be repaired include cracked damage and broken part (Aziz et al., 2022; Lee et al. 2022) This is a crucial stage where the quality of repaired part is determined based on the suitability of the type of damages to be repaired using AM process. Based on the inspection during the experiment, the piston has shown the broken part at the upper part of piston which requires the pre-processing of removing the damaged area through machining process. The following Figure 3 shows the works involved in the first step.

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Figure 3: Inspection of Damaged Area and Part Pre-Processing

2. Acquisition of the original data

As depicted in the following Figure 4, the acquisition of the raw data before printing process is one of the crucial steps in the verification. The 3D scanning process was accomplished to gather the data that is approximately equal to the original data by using the Eiscan Pro Series software. The Reverse Engineering approach was applied to remodel the piston model through CAD Anys Spaceclaim software based on the data acquired from the scanning process. The accurate scanning data is important at this stage to attain the accurate dimensions for printing purposes (Leach et al., 2019; Zhang et al., 2015).

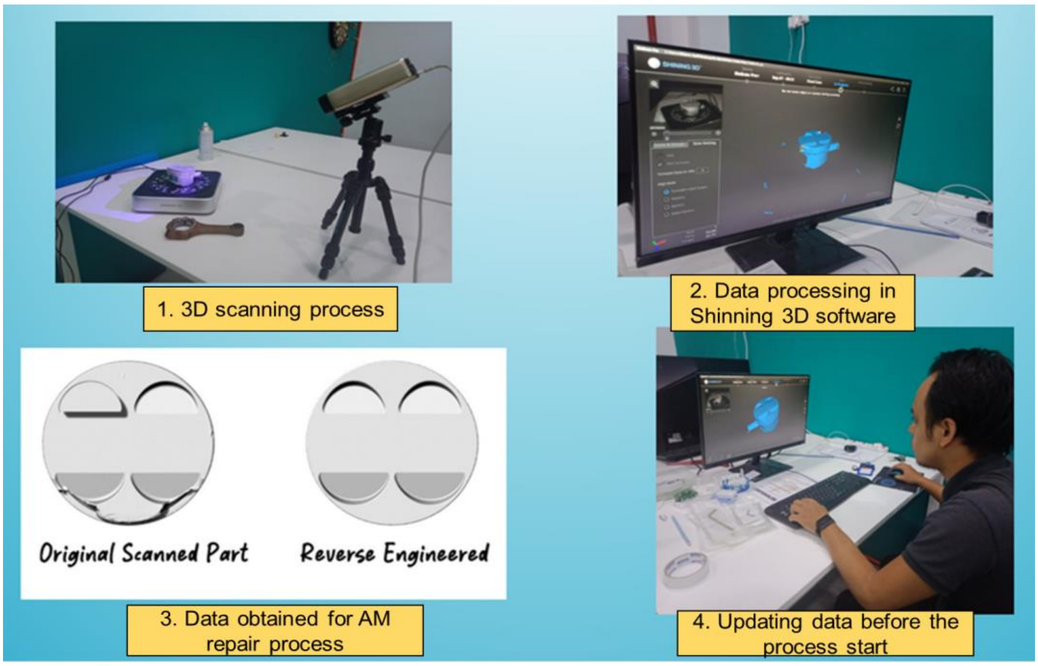

Figure 4: Acquisition and Processing of Original Data

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3. Build preparation process

An STL file created from the updated 3D CAD model is sent to the QuantAM software to proceed with the build preparation before printing process. This is one of the important steps in AM process to ensure the accurate dimensions can be attained from AM process. At this stage, the component was positioned properly, the support structure is developed and revised the overall part orientation before printing process as depicted in following Figure 5. Once the prepared data is verified, the STL file is exported to RenawAM 500E machine for printing. The details guideline at this stage is provided in the next section in Figure 9.

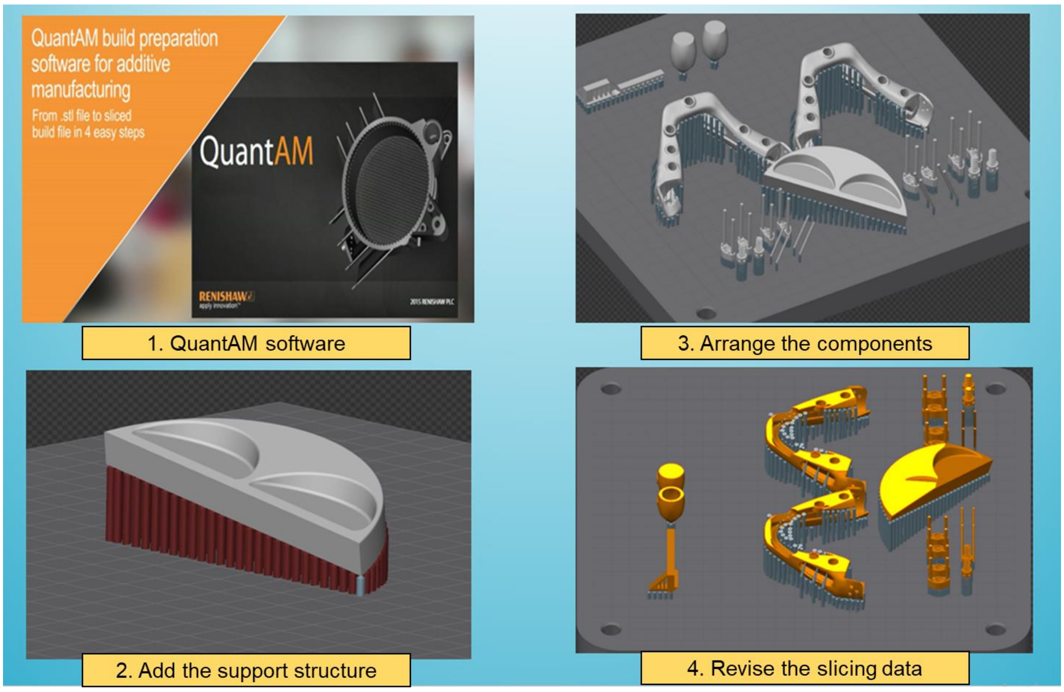

Figure 5: Build Preparation Process in QuantAM

4. AM repair process using PBF technology

The repair process of AM was performed using the PBF technology of Renishaw 500E machine. The process was successfully accomplished with the repaired part which requires welding process to bind with the original component. The welded part was machined in CNC machine and manual finishing process was accomplished using the saw and sandpaper. The capability of using AM technology in repair applications would become a breakthrough to advance in the automated repair process. Nevertheless, the repaired parts need to be tested to ensure the quality of the part is equal as offered in the original part (He et al., 2020). Thorough analysis is also necessary to be conducted in future to further examined the influence of AM process parameters towards the printability and bonding capability in repair application (Oh et al., 2019).

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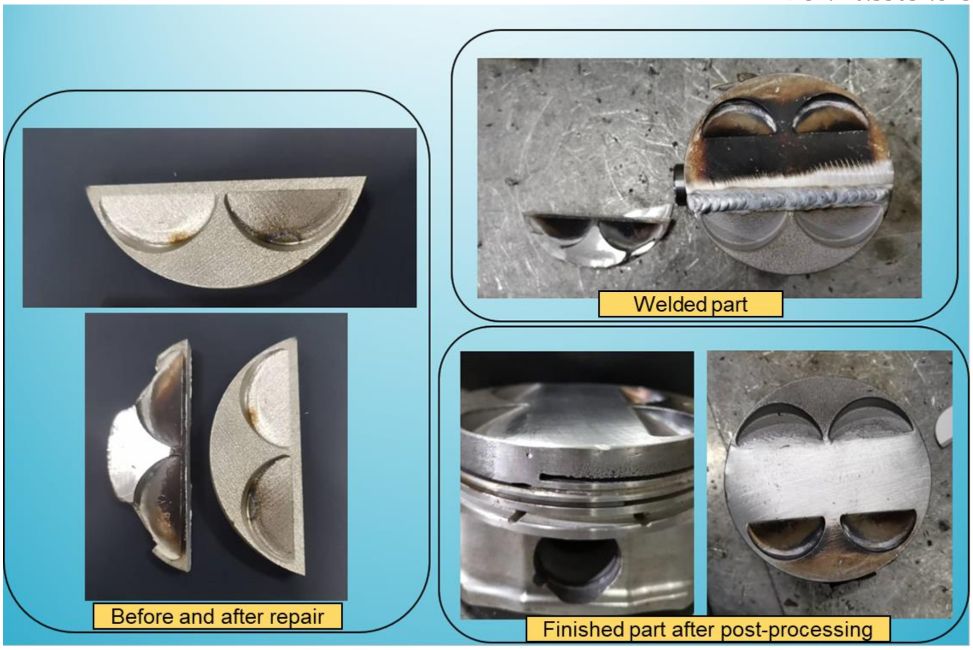

Figure 6: Repaired Part: Before and After AM Process

Guideline for AM Repair Process from CAD Simulation and Experimental Works

Based on simulation using CAD software and verification in experimental works, the guidelines considering the design and process flows can be proposed from this study. The guidelines outline general steps involved starting from identifying the suitable damages that can be repaired through AM until to the post-processing of the finished repaired part as presented in the following Figure 7, Figure 8, Figure 9 and Figure 10 respectively.

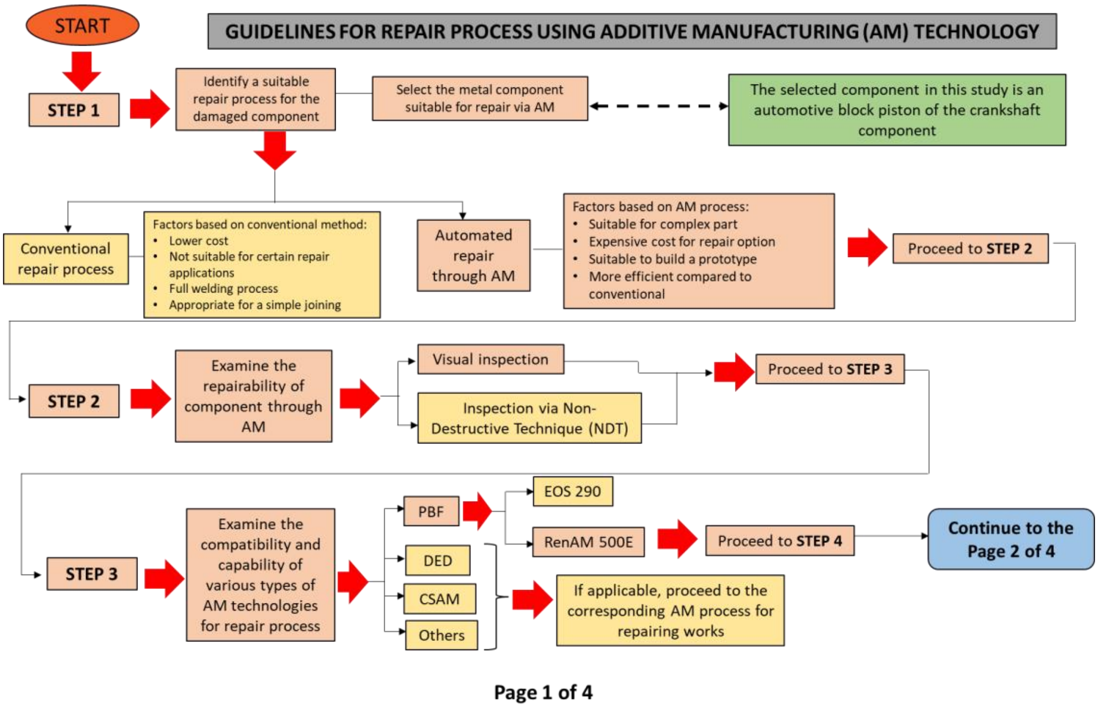

Figure 7: Step 1 to Step 3 - Guidelines for AM Repair Process (Page 1 of 4)

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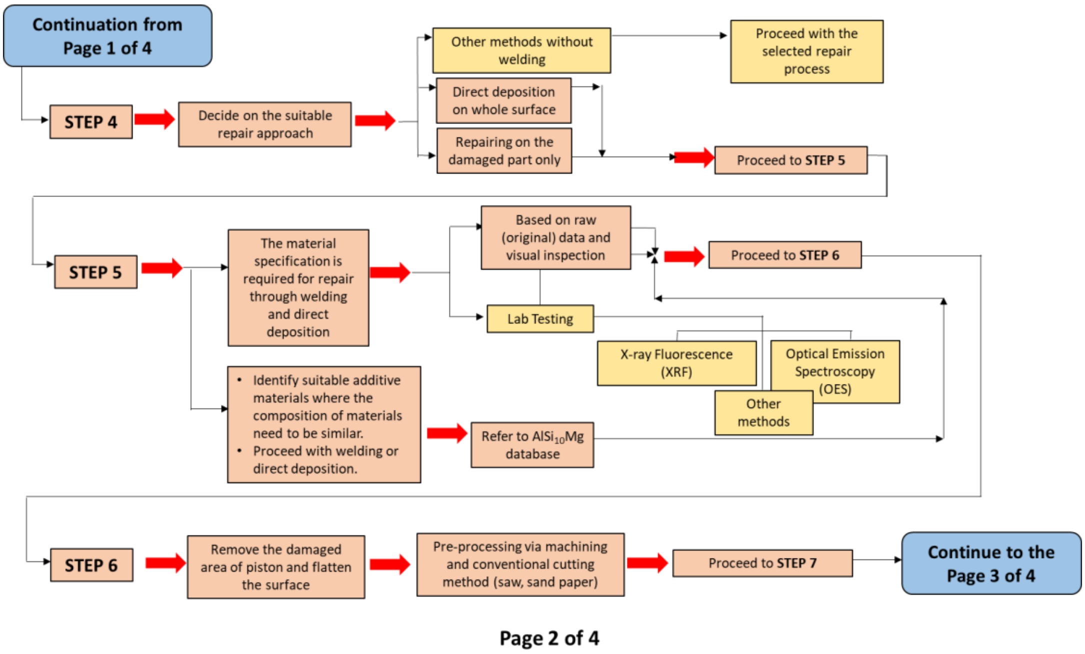

Figure 8: Step 3 to Step 6 - Guidelines for AM Repair Process (Page 2 of 4)

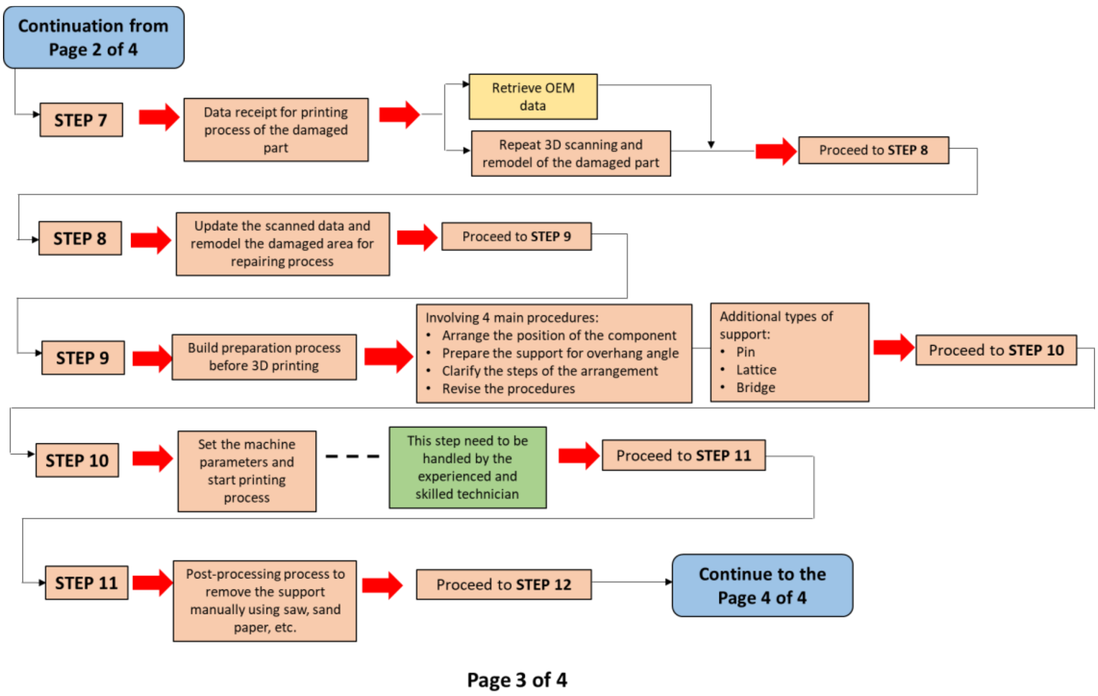

Figure 9: Step 7 to Step 11 - Guidelines for AM Repair Process (Page 3 of 4)

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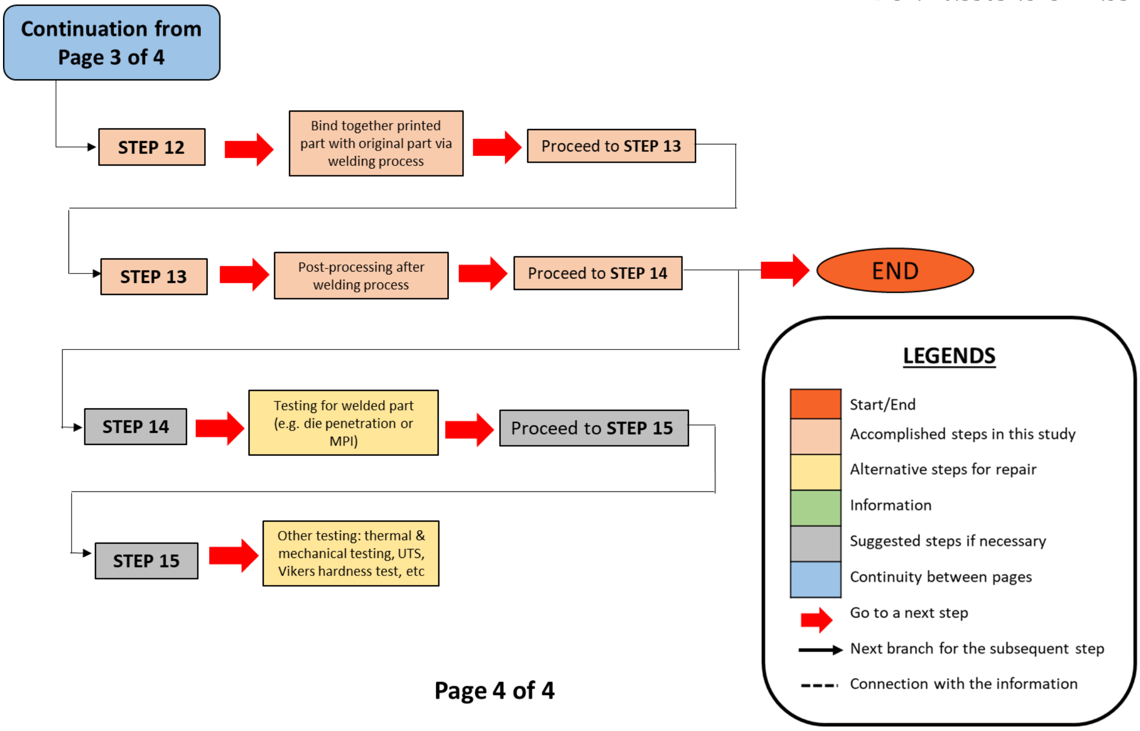

Figure 10: Step 12 to Step 15 - Guidelines for AM Repair Process (Page 4 of 4)

The proposed guidelines could facilitate the practitioners in providing the know-how to conduct the newly repair alternative using AM technology. The detail considerations and evaluations are necessary to be considered even at the early stage of the design to ensure proper and efficient repair through AM process can be achieved.

Conclusion

In overall, this study has discussed on the guidelines of the process flows for repair in AM through the simulation in CAD software and verified the accuracy of the processes involved in experimental works. It is recommended to expand the study to undergo several tests to guarantee the quality of the repaired part. The tests include:

- Magnetic Particle Inspection: To ensure the quality of welding process for joining.
- Mechanical testing: To examine the mechanical properties of the piston which fulfils the piston's design requirements.
- Hardening process

Once the repaired piston part passes the tests and meets all the standard requirements, the piston can be reassembled into the engine block and reused in the next life cycle. On the other hand, some modification can be proposed by adapting new technology in AM, for instance DED and cold spray technologies. Therefore, this study has successfully developed the design guideline that can be considered to support in improving the efficiency of the remanufacturing process through the automated AM repair process. The guideline would facilitate the industries especially for the remanufacturer and aftermarket industries to conduct the repair process using AM as early as possible at the design and evaluation stage before proceeding to the actual process. Hence, accurate decision can be made in conducting this newly approach of repair process to attain an efficient repair process using the AM technology.

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