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Analysis of Automotive Component Design for Reparation using Additive Manufacturing Technology

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Abstract: Remanufacturing is the most value added end-of-life vehicle (ELV) recovery strategy in which remanufacturable components referred to as cores, are returned to their next life cycle in as new-condition. Remanufacturing which involved several important steps namely disassembly, cleaning, inspection, repair, reassembly and testing are normally carried out by skilled and experienced workers. Advanced additive manufacturing technology is capable of alleviating limitations in the manual repair and restoration of end-of-life cores. However, there are several challenges in the restoration process such as limited accessibility to the inner diameter of parts, the presence of grooves, sharp edges and corners, as well as limitations in the types of materials used as filler powder and design that does not facilitate restoration using AM process. To date, there are limited reports on how products should be designed for restoration using AM and also on the capabilities of AM to conduct various kinds of restoration on ELV cores. This paper presented and discussed common modes of failure in selected remanufacturable automotive components and the challenges in repairing these components using conventional methods in a local service company. The design of the components were studied in relation to the capability of Direct Energy Deposition technique for automated repair and restoration. Further, this study should be able to pave the way for the establishment of design guidelines for ease of repair and restoration using AM for product life cycle extension.

Keywords: Repair, end-of-life vehicle, remanufacturing, additive manufacturing, design for restoration

1. Introduction

Sustainability is an act to fulfill the ecological, economical and socio-political needs while considering the availability of natural resources for the future generations to fulfill their needs [1]. To date, several end-of-life recovery strategies such as reuse, recycling, refurbishing and remanufacturing have been implemented in many countries. The primary concern of these strategies is to recover material or functional components from end-of-life products. Moreover, effective implementation of these strategies will reduce cost and energy consumptions in producing finished goods for the manufacturing sectors [2]. In recent years, with the Circular Economy model that aims for products to be reused in their next life cycle in view of reducing the consumption of virgin materials and energy, value added strategies such as remanufacturing and upgradability have gained significance. With regard to product sustainability, end-of-life recovery has been considered as a significant part in the life cycle management of products. Besides, product-service systems also play an important role such as for the maintenance and servicing of damaged or dysfunctional products. Other than that, sustainable life cycle management is capable of reducing the usage of raw material by extending the life cycle of existing products that have reached their end-of-life (EOL) [1]. By considering these strategies in new product development, the needs of future generation will not be affected by the current new development.

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Remanufacturing is known as a process of restoring used or damaged components into like-new condition with a specification and quality similar to a newly-produced product together with a warranty to match [3], [4], [5]. As compared to other end-of-life recovery strategies, remanufacturing involved a series of activities namely disassembly, cleaning, inspection, restoration, reassembly and testing [6]. To date, most of the repair and restoration processes are carried out manually by skilled worker. By using AM for automated restoration, barriers such as lack of skilled and experienced workers can be minimized, the time taken for the process can be shortened and the environmental impact can be reduced. However, to date, the applicability of AM for repair and restoration in remanufacturing and how products should be designed for purpose of restoration using AM have not been widely reported. This paper aims to discuss the applicability of AM for repair and restoration of remanufacturable cores on selected automotive components and how cores should be designed to facilitate the restoration process.

1.1 Sustainable Product Development

Sustainable development has become a major challenge especially in the automotive industry [7]. This is because the end-life-vehicle is increasing by day all over the world that might be due to the increase in new vehicle production in countries such as China, US, Japan and others. Sustainability is an act to fulfill the current needs without affecting the future generation to fulfill their needs which is also about the elimination of systematic degradation for both social and ecological aspects [8]. The companies organized themselves to apply eco-design strategies that are focused on the integration of environmental consideration into the development of product, also for product recovery. According to Nasr et al. [9], these worldwide issues are aimed at striving for sustainable production which consumed few resources, created less waste and pollution while contributing to the social progress. Sustainable production is intended to change the concept of cradle-to-grave and bring forward cradle-to-cradle aspect in managing the product life cycle. Besides, this concept is proposed in order to reduce the depletion of resources, degradation of environment and negative impacts towards human health.

Sustainability of product development can be achieved by considering some of the strategies involved such as sustainable design which is Design for X where X are remanufacturing, disassembly and environment. Other strategies include product service system and sustainable life cycle management [1]. Design for X should be embedded during the early phase of design to enable products to be reused when reaching its end of life. Sustainability must be initiated from the grass root in order to minimize the consumption of natural resources. Reliance on renewable energy, pollution prevention and reduction, recycling and reusing of waste materials as well as reduction in wasteful resources have been identified as the principles of sustainability [10]. Several strategies must be implemented which include reuse and recycling of all wastes, avoiding pollution or emission of waste that can be harmful to the environment and also reliance on clean and renewable energy technologies [11].

2. Remanufacturing: Manual and Automated Repair and Restoration

Ijomah [3] defined remanufacturing as a resource-efficient process of returning old or used components or parts to newly-produced condition with specification and warranties same as new. The process consists of important steps such as inspection, disassembly, cleaning, repair, reassembly and testing as shown in Fig.1 (MTU Services Sdn. Bhd.).

Fig. 1 - The process of remanufacturing

Decisions on whether parts are remanufacturable or should be replaced with a new one depends on the decision made during the product design stage which is considered in Design for Remanufacturing (DfRem). During the design phase of a product, it is important to consider the sustainable design of product to be remanufactured [7]. Apart from the conventional processes of remanufacturing, there are possibilities to use advanced technology to carry out the restoration process. In Malaysia, the Ministry of International Trade and Industry (MITI) through its National Policy of Industry 4.0 has outlined the need for advanced technology applications in manufacturing. The National Policy of Industry 4.0 has identified AM as one of the enabling technologies for Industry 4.0 other than artificial intelligence (AI) and Internet of Things (IoT) which are needed to enhance the efficiency and competency of the manufacturing industry in Malaysia especially in the automotive field [12].

Additive manufacturing (AM) is a process of building an object layer by layer of material directly based on model data from a CAD system. To date, AM technology has been deployed in the reparation of damaged aerospace components however its application in the automotive industry is rather limited. Based on the National Policy for Industry 4.0, it is highly potential for AM to be deployed in the growing remanufacturing industry in Malaysia.

Remanufacturing is the most preferable strategies to manage the end-of-life components for industry such as automotive, aerospace, furniture, electronic equipment and others [13]. This is due to its ability to contribute to the sustainable policy as it can reduce the amount of waste generated and is more energy efficient compared to recycling [14]. In order to ensure that the design of a product is suitable for remanufacturing, several aspects need to be considered such as the value added, product life, recover value, remanufacturing capability and environmental impacts [9]. The design enablers of each aspect are shown in Table 1 [9]. Other design considerations to ensure efficient remanufacturing are presented in Table 2 [15].

Table 1 - Design enablers for remanufacturing

Aspect	Design enablers
Value added	Quality
Product life	Durability, design viability
Recover value	Disassembly; condition accessibility; restorability; material value recovery
Remanufacturing capability	Core availability; required knowledge
Environmental impact	Reduction in environmental release; reduction in resource use; life-cycle benefits

Table 2 - Design considerations for remanufacturing ability

	Material	Joining method	Structure
Disassembly and reassembly		• Disassembly without damage (include or exclude fasteners) • Ease of reassembly	• Ease of separation • Accessibility to valuable and reusable components
Cleaning	• Ease of removing deposits and impurities • Resistance to cleaning		• Avoid intricate or unnecessary concealed design
Restoring	• Ease of machining • Ease of restoration using additive processes		• Accessibility to failed parts • Tolerance design for multiple life cycle • Modularity for replacement

Remanufacturing is able to save approximately 80-90% of raw material and energy consumption compared to newly produced components or parts. In addition the price is about 35-40% lower than a new product [16]. Currently, most companies conduct reparation of damaged parts manually perhaps due to limitations in technology and skills. It is therefore necessary to deploy advanced technology such as AM to ensure efficient repair and restoration of damaged parts during remanufacturing.

3. Methodology

For the purpose of this study, it is necessary to understand how manual repair and restoration process are carried out. It is also important to understand the failure modes that typically occur on the ELV components. Next, the design of the cores must be analysed from the aspects of geometry complexity, features and architecture in order to ascertain any difficulties in repair and restoration using potential AM technologies.

It is also necessary to ascertain the difficulties in repairing complex geometry of products with many separate parts and using different joining methods and also fasteners. AM technology such as Direct energy deposition (DED) which includes cold spray, LENS and laser cladding have been identified as not only capable of fabricating new components but also to repair worn metal parts [17]. The technology involved the use of laser as an energy source to fuse the powdered metal. As for automotive cores, alternator, engine block, turbocharger or starters are some examples of products commonly remanufactured today. In order to identify the suitability and applicability of AM to be used in repairing components, this study has focused on three different components namely alternator, piston of an engine block and turbocharger.

3.1 Industrial Visit to Automotive Component Service Workshop

An industrial visit to an automotive repair service company was conducted in order to observe the process of manual repair to the components. The study focuses on disassembly and repair process of alternator, piston of an engine block and turbocharger. An in-depth interview with the owner of the workshop and mechanic was also conducted. From the study, information pertaining to parts that are frequently damaged, difficulties in disassembly and processes involved in a typical repair process were obtained. Fig. 2 shows the components of an alternator and parts that are commonly damaged which are chipping of the pulley and wear of the rotor. Fig. 3 shows parts of a piston in an engine block and the location of a typical damage on the base of the compression ring. Meanwhile, Fig. 4 shows parts of a turbocharger with broken turbine blades.

According to the respondent, the manual disassembly process for all the components involved are time consuming as it is carried out manually using conventional tools. After the components are fully disassembled, the type and severity of damage are identified. For reparable components, welding is the most common process used in the company. The type of welding process selected for repair will depend on the type of damage on the components. Common modes of failure that typically occurred to the components are crack, break and wear, and also dysfunctioning of electronic parts. These electronic parts will be replaced with new ones.

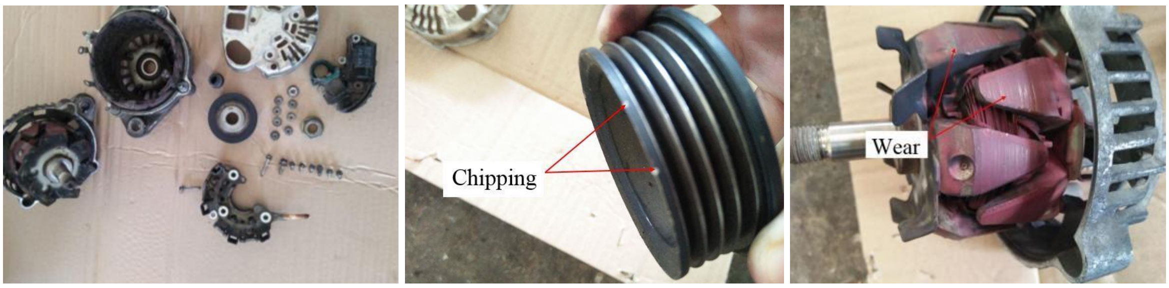

Fig. 2 - Alternator and its typical damaged parts

Fig. 3 - Piston and its typical damaged parts

Fig. 4 - Turbocharger and its typical damaged parts

4. Results and Discussion

There are several important processes involved in remanufacturing which are disassembly, cleaning, inspection, repair, quality testing and reassembly [18]. The most critical process to be considered is disassembly, cleaning and repair. Typically, the type of damage that occurred on the parts or components are fracture or crack of crankshaft in diesel engine, rust, and wear of metal parts and others [19], [20]. All of these damages are commonly repaired manually. Current manual repair for restoring the damaged components is time and labor intensive and also inconsistency in the quality of repaired components [21]. Based on the industrial visit to the service center for automotive components, the difficulties in repairing components manually have been identified. According to the respondent, in order to repair the damaged parts, manual disassembly of the whole component is necessary using conventional tools such as screwdriver, wrench and socket set. The process is time consuming and disassembly of parts is difficult especially when permanent joining was used on the components. Besides, to repair damages on these parts, the conventional method used is welding and this leads to a much longer time to conduct the operation. Other than that, the respondent has also mentioned that by using only welding process, there is a limitation to the type of damage that can be repaired. The industrial visit shows that advanced technologies are needed to automated repair and restoration in view of reducing barriers in the remanufacturing of the automotive components.

4.1 Applicability of Additive Manufacturing in Core Restoration

Additive manufacturing is a process of fabrication of parts or components layer by layer directly under the control of computer in terms of 3D model data [22], [23], [24]. This process is highly flexible and efficient in producing either simple or complex geometry of the parts. AM is needed to be applied in the industrial sector due to its benefits such as optimization of raw material usage, and solving environmental problems in terms of resources, energy, disposal waste and others. Besides, AM can reduce the time taken for parts producing compared to the conventional process. It does not require difficult molds and it has less operation.

Up till now, AM application has been focused more on part fabrication rather than reparation. Recently it has been reported that AM technology such as direct energy deposition (DED), coldspray, laser cladding and laser engineered net shaping (LENS) are capable of repair and restoration. All of these technologies are capable of repairing damaged parts such as turbine, transmission, gearbox and others [17], [18], [25], [26]. Nowadays, AM has become the key method to repair worn-out parts in order to reduce the needs for re-machining that lead to higher cost of remanufacturing process. This method is an effective way of reducing the metal cutting process [26]. For purposes of discussion on the applicability of AM for repair and restoration, two components namely a pulley of an alternator and piston is selected as the examples. Typically, the damages on pulleys are crack or wear and the repair process is welding. Reparation using welding normally took a long time. The design structure of a pulley as shown in Fig. 5 is quite simple and suitable to be repaired using AM technology such as Coldspray. The process of repairing the damaged area involved surface cleaning, spraying new material and final finishing. Laser cladding is also a suitable AM technology for repairing the damaged areas. The process involved scanning the damaged surface and depositing a coating of suitable material to build up the missing parts on the pulley. Damages on a pulley typically occurred on the outer surface. Therefore, there is a high possibility for the damages to be repaired using AM technology.

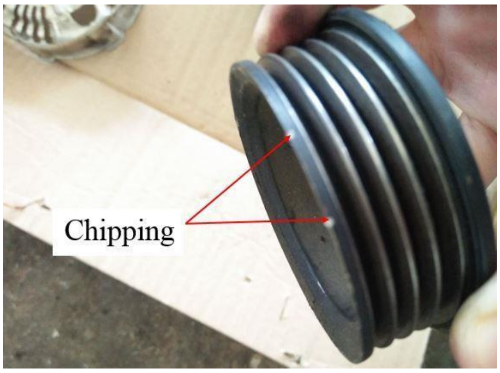

Fig. 5 - Chipping on pulley

Fig.6 shows the damage area of a piston ring groove. It can be seen that wear occurred on the ring groove of the piston due to frequent engine operations. The suitable AM process to repair the damages on piston is laser cladding. Despite the groove and narrow structure of the piston, it can be repaired using laser cladding technology since the laser is able to reach the damaged spot. The laser will be pointed to the groove and the feeder will be activated and depositions will occur with minimal heat distortion. Once the cladding process is completed, machining will be carried out to achieve the tolerance of the groove.

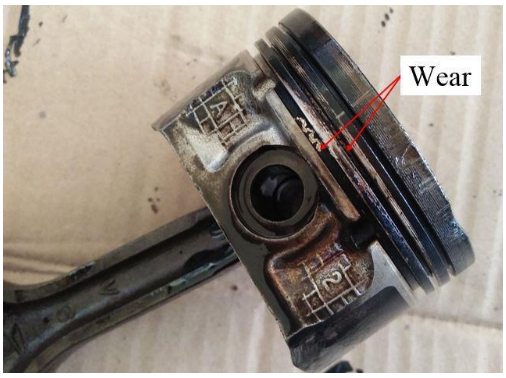

Fig. 6 - Wear on piston

Despite its advantages in repair and restoration of damaged components, there are some barriers and challenges in applying AM technology. For example, based on the experiment that has been carried out by Pinkerton et al. [27], it is stated that geometry is the main problem in repairing process using AM technology such as vertical side walls of square slots is shielding the powder. This is because the geometry does not have direct laser irradiation for the purpose of fusion bonding formation with the incoming powder. Besides, on V-slot, the sharp angle within the slot also is a problem for AM repair due to the structure is prone to porosity [27]. Laser cladding has been used for repairing damaged component especially in the aerospace industry but there is several limitation of the process such as difficulty in repairing the complex shape job other than difficulty in controlling the particle size, shape and distribution of deposition [28]. Flat and wide geometry is advantageous to be repaired using AM but not for tip structures such as on the blades of airplane [29]. According to Yin et al. [17], in coldspray repair, the material cannot be deposited directly on damaged surface due to its complex surface topography which needs pre-machining process and Li et al. [21] stated that the dimensional accuracy of repaired components using AM is poor and required to be machined after the spraying process.

5. Conclusion

Additive manufacturing technology has potential to be used for repair and restoration in remanufacturing. It is able to enhance efficiency besides lowering the cost of overall processing. AM has the capability to fabricate complex geometries and today with advancement in its technology, AM is capable of conducting repair and restoration on damaged components. Besides, AM technology should be able to overcome challenges in remanufacturing such as lack of skilled and experienced workers for repair and restoration. Moreover, limitations in high technology machines can be resolved by applying AM in repair and restoration. The application of AM in the aerospace remanufacturing industry has been widely reported but not in the automotive industry. Therefore, the benefits of AM in reparation of automotive components need to be realized so that it can be applied widely in the future. This paper has discussed and analyzed the design of some automotive components for reparation using AM. Further, the analysis should enable design improvements and design guidelines to be identified and in so doing, reparation in the remanufacturing industry will be more efficient and contributing significantly towards a more sustainable environment.

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