Circular Manufacturing | Organized Session：OS: Circular Manufacutirng (4)

Thu. Nov 13, 2025 4:55 PM - 6:15 PM JST | Thu. Nov 13, 2025 7:55 AM - 9:15 AM UTC Room C (Crystal (3F))

[C-7] OS: Circular Manufacutirng (4)

Chair: Venkata Reddy Nallagundla (Indian Institute of Technology, Hyderabad, India)

Proceedings paper

5:27 PM - 5:43 PM JST | 8:27 AM - 8:43 AM UTC

[C-7-03] Estimation of GHG Emission Reduction Effect by Utilizing Remanufactured Parts of Automobile Engine Auxiliaries

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To achieve a sustainable society, it is important to reduce negative impacts on the global environment. To achieve this, it is necessary to reduce GHG emissions, resource use, and waste. Therefore, it is important to use existing products repeatedly and for long periods of time. In the automotive industry, the use of recycled parts can contribute to the realization of a sustainable society. Previous studies have investigated the GHG reduction effects of using reused parts for 90 parts with high sales, and have proposed estimation models based on these studies. On the other hand, studies on remanufactured parts have been limited to cases of reduction effects for individual parts such as engines and engine auxiliaries, and no estimation models have been proposed. In this study, we investigated and analyzed the remanufacturing process for three types of parts (starter, alternator, and compressor), and obtained a detailed understanding of energy consumption and material usage in each process. In addition, a disassembling investigation of each component was conducted to obtain information on the materials and weight of the constituent parts. Based on this information, GHG emissions during the manufacture of new parts, the remanufacturing process, and replacement parts production were calculated, and the effect of GHG emissions reduction through the use of remanufactured parts is clarified by comparing the emissions during the manufacture of new parts with those during the manufacture of remanufactured parts, which are the sum of the emissions during the remanufacturing process and replacement parts. The results showed that an average reduction of 58.5% was achieved for starters, 75.7% for alternators, and 42.1% for compressors. It was also confirmed that emissions from the manufacture of replacement parts accounted for a large proportion of the GHG emissions from the manufacture of remanufactured parts. Furthermore, two types of estimation equations based on the calculated reduction effect and the vehicle specifications (displacement and weight) are constructed using a single regression analysis. As a result, the estimation of the reduction effect for the alternator was possible with an error of 7.9% or less at maximum by using the estimation equation based on the vehicle weight. In the future, it will be necessary to improve the accuracy of the estimation for starters and compressors, since the average error is still about 40%. The system should be expanded to other automotive parts such as engines, and data should be accumulated so that it can be used regularly for a wider variety of parts.

Estimation of GHG Emission Reduction Effect by Utilizing Remanufactured Parts of Automobile Engine Auxiliaries

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Abstract
Achieving a sustainable society requires the prolonged use of products, and using recycled parts in the automotive industry can contribute to this goal. However, the environmental impact reduction from recycled parts, especially remanufactured parts, is not well understood. This study investigates and models the remanufacturing process of automotive parts, calculates the environmental impact reduction effect, and derives an estimation formula. This study also confirmed that the majority of the environmental impact of remanufactured parts production is due to the production of replacement parts, and the impact of the reduction was assessed. The results showed that the effect of process improvements was limited, suggesting that promoting the use of remanufactured parts is effective in reducing GHG emissions.

Keywords:
Sustainable society, Climate change, GHG emissions, Remanufactured parts, Life Cycle Assessment

1. INTRODUCTION

For the attainment of a sustainable society, the reduction of greenhouse gas (GHG) emissions, resource consumption, and waste is essential, and the reuse and long-term utilization of products are required. In the automotive industry, the utilization of recycled parts is effective. Recycled parts are components removed from end-of-life vehicles, appropriately processed, and reintroduced into the market. Recycled parts are classified into two categories: reused parts and remanufactured parts. Reused parts are components that, once removed from vehicles, are not subjected to disassembly or additional processing, but are inspected through visual checks and testing devices, then cleaned and reintroduced into the market. Remanufactured parts are components that, once removed from vehicles, are disassembled, with worn or deteriorated parts replaced by new ones. After reassembly, they undergo quality inspection and are reintroduced into the market [1].
Previous studies have proposed estimation models of GHG reduction effects based on investigations of the top 90 reused parts in terms of sales [2] [3]. On the other hand, investigations of remanufactured parts have been limited to case studies of individual components, such as engines [4] and auxiliary equipment [5], and no estimation model for reduction effects has been proposed. Therefore, in this study, investigations and analyses of the remanufacturing processes of starters, alternators, and compressors are conducted, the GHG reduction effects are evaluated through comparison with new parts, and a model to estimate these effects is proposed. Furthermore, since it was confirmed that GHG emissions from the production of replacement components account for a large proportion of the total in the remanufacturing process, a sensitivity analysis is conducted to evaluate the impact on the overall reduction effect when this proportion is reduced. In this paper, nine starter components and ten components each of alternators and compressors are evaluated, and the proposed estimation model as well as the results of the sensitivity analysis are reported.

2. CONCEPT AND ESTIMATION METHOD OF GHG REDUCTION EFFECTS

In this study, the GHG reduction effects from the utilization of remanufactured parts are defined as the reduction effects in terms of CO_2-equivalent emissions. Fig. 1 illustrates the concept of GHG reduction effects. The GHG reduction effect, E_R, is calculated based on equation *(1)* by subtracting the sum of GHG emissions from the production of replacement components, E_m, and GHG emissions from each process in the remanufacturing of parts, E_p, from the

GHG emissions during the production of new parts, E_n. In addition, it is assumed that the GHG emissions during transportation and use are equivalent for new and remanufactured parts, and therefore these stages are excluded from the analysis. Accordingly, the LCA is conducted for the scope from material procurement to product manufacturing.

$$E_R = E_n - (E_p + E_m) \qquad (1)$$

The activity data required for calculating GHG emissions are obtained through investigations of the remanufacturing processes, identifying the energy input to the equipment used and the amounts of liquids and other materials consumed. GHG emissions from the production of replacement and new parts are calculated by disassembling the actual components into single materials as much as possible and investigating the materials, weights, and manufacturing methods. The emission factors used are those for greenhouse gases listed in the environmental impact database IDEA v3.1.0 [6].

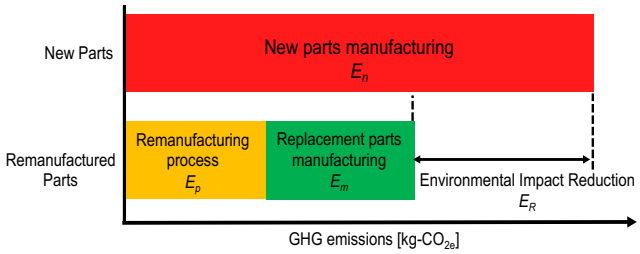

Fig. 1: Conceptual diagram of ghg emission reduction

3. INVESTIGATION AND MODELING OF REMANUFACTURED PARTS PRODUCTION PROCESSES

3.1 Factory Investigation and Inventory Data Collection

In order to collect information on the remanufacturing of starters, alternators, and compressors, investigations of the production factories were conducted. In these investigations, activity data such as the manufacturing processes, the equipment used in each process, their operating times, and the materials consumed were collected. The activity data for remanufacturing one starter unit are shown in Table 1.

3.2 Modeling of Remanufactured Parts Production Processes

Based on the investigations of the remanufacturing factories, a model of the production processes was created, and the equipment used in each process, the resources consumed, and the operational and work standards were visualized. The modeling of remanufactured parts production processes was performed using IDEF0 (Integration DEFinition 0) [7]. Fig. 2 shows the basic unit of IDEF0. Each function in IDEF0 is composed of four elements: Input, Output, Control, and Mechanism. In the model developed in this study, function names were defined as work processes, Inputs as resources consumed and power used, Mechanisms as the personnel and equipment required for the work, Controls as the work standards for each process, and Outputs as the outputs generated from the processes. As an example, part of the model of the remanufacturing process for alternators is shown in Fig. 3. In this way, the manufacturing processes are modeled, and based on this model, GHG emissions generated in each process of remanufactured parts production are calculated.

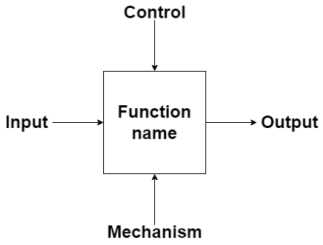

Fig. 2: IDEF0 base unit

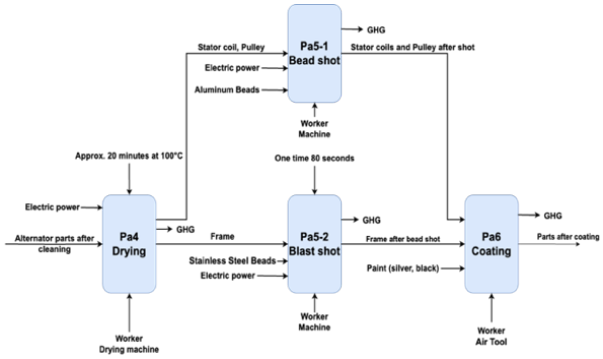

Fig. 3: Part of the remanufacturing process of an alternator

3.3 Obtaining Component Information through Disassembly Investigation

Next, disassembly investigations of each part were conducted to examine the weight, material, and manufacturing method of the constituent components. In addition, although worn components in remanufactured parts are replaced with new ones, some replacement components require substitution every time, while for others, the necessity of replacement is determined based on the condition of the component. Therefore, a survey was conducted to collect information on the replacement rates of constituent components, which is used to calculate the GHG emissions from the production of replacement parts. An excerpt of the information on the weight, material, and manufacturing method of the components is shown in Table 2. Through the disassembly investigation, it was confirmed that there are three types of compression mechanisms in compressors.

Table 1: Materials used for remanufacturing one starter

Process	Material	Amount of material used	Unit	GHG emissions [kg-CO_2e]
Cleaning	Ultrasonic Cleaning Fluid	0.0038	kg	0.0022
Cleaning	Trent Cleaning Fluid	0.0486	kg	0.0279
Paint	Paint (Thinner)	0.0018	kg	0.0032
Paint	Paint (silver)	0.0093	kg	0.0351

Table 2: Component information for a kei car starter

Component name	Weight [kg]	Material	Machining method	CO_2 emissions [kg-CO_2e]
F housing	0.03392	Aluminum	Casting	0.081
R cover	0.07865	Steel	Press	0.094
Armature parts 1	0.00102	Steel	Press	0.003
Armature parts 2	0.00242	Steel	Press	0.006
Armature parts 3	0.18865	Steel	Press	0.464
Armature parts 4	0.04255	Steel	Machining	0.058
Yoke magnet	0.10382	Magnet	Ceramic Processing	0.547
Yoke parts	0.00706	Steel	Press	0.017
Brush holder part 1	0.02040	Steel	Press	0.050
Brush holder part 2	0.00874	Plastic	Injection Molding	0.028
Brush holder part 3	0.00197	Steel	Press	0.005
Brush holder part 4	0.00557	Silicone rubber	Injection Molding	0.045

4. GHG EMISSION REDUCTION EFFECTS FROM THE UTILIZATION OF REMANUFACTURED PARTS

The GHG emissions of each part during the production of new parts and the remanufacturing processes (corresponding to E_n and E_p in Fig. 1) were calculated using the activity data obtained from disassembly and factory investigations. The GHG emissions from the production of replacement components (corresponding to E_m in Fig. 1) were calculated by combining the aforementioned activity data with the replacement rates of each part obtained through surveys. Based on these data, the GHG reduction effects were calculated. As an example, Fig. 4 shows the breakdown of GHG emissions during the remanufacturing of an alternator for a wagon-type vehicle. The analysis confirmed that, for all parts, the GHG emissions generated during the production of replacement components used for worn parts accounted for the largest proportion. While the types of parts replaced were generally similar across components, it was confirmed that the replacement rates varied depending on the part. For alternators, the replacement rate tended to be higher for those used in trucks than for those in kei cars or similar vehicles. Furthermore, focusing on the manufacturing processes of alternators other than the production of replacement components, it was found that the GHG emissions from polishing processes using blast or bead shot were particularly high. This is because many alternator components require polishing, and the unit emission factor for the metal beads used in polishing is high. In addition, as an example of the calculated GHG reduction effects, those for alternators are shown in Fig. 5. The results of the investigation revealed that using remanufactured alternators can reduce GHG emissions by 51.0% to 94.8%.

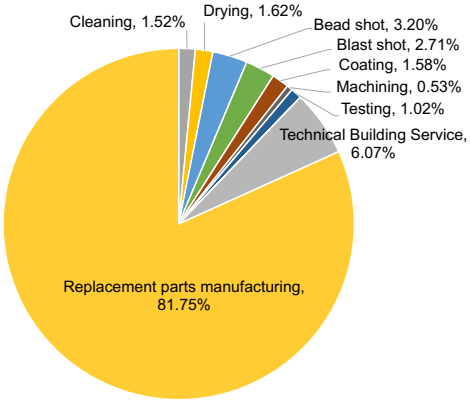

Fig. 4: Breakdown of GHG emissions by process for a remanufactured alternator for a van

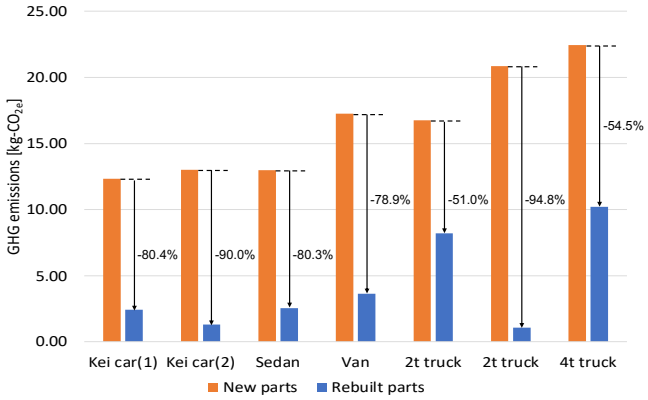

Fig. 5: GHG emission reduction through the use of remanufactured alternators

5. SENSITIVITY ANALYSIS

From the breakdown of GHG emissions during remanufactured parts production, it was confirmed that the majority of emissions come from the production of replacement components. Therefore, we conducted a sensitivity analysis to evaluate the GHG emission reduction effects of using remanufactured parts when the GHG emissions from replacement parts production were reduced by 10% to 50% compared to the current levels. The results for alternators are shown in Fig. 6. The analysis confirmed that even if the GHG emissions from the production of replacement components were reduced by 50%, the reduction effect would improve by merely an average of 10%. This suggests that simply improving the manufacturing process alone is insufficient for achieving substantial GHG emission reductions. To realize more effective reductions, approaches beyond process improvement are required. One such approach is to promote the use of remanufactured parts while suppressing the use of new parts, thereby effectively reducing emissions associated with the production of new parts.

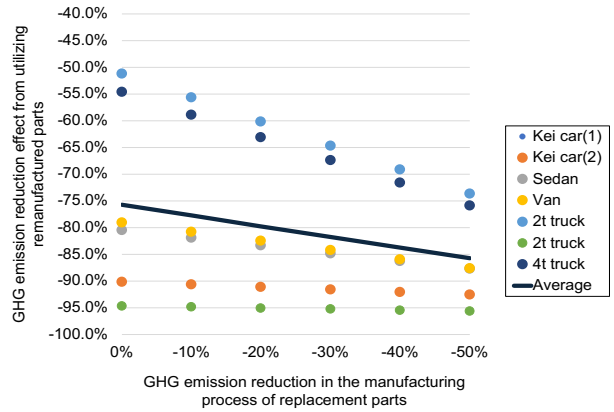

Fig. 6: Impact of GHG emissions from replacement parts on remanufactured alternator production

6. GHG REDUCTION EFFECTS FROM THE USE OF REMANUFACTURED PARTS AND THEIR ESTIMATION

Based on the calculated GHG reduction effects from the use of remanufactured parts and the specifications of the vehicles, we created estimation formulas for the GHG reduction effects. Since the target components were engine auxiliaries, we conducted two types of simple regression analyses using engine displacement and vehicle weight as explanatory variables. Furthermore, we added variables according to the characteristics of each component. Specifically, for starters and alternators, we conducted simple regression analyses using the engine's maximum output and rotational speed as explanatory variables, while for compressors, we used the cabin volume. In addition, since the operating voltage of components differs between commercial trucks and passenger vehicles, we analyzed them separately. Fig. 7–9 show the relationships between vehicle weight and the GHG reduction effects of alternators for passenger vehicles, engine rotational speed and the reduction effects of starters, and vehicle weight and the reduction effects of compressors, respectively. The estimation equations are provided in each figure. For alternators, the difference from measured values averaged 4.6%, with a maximum of 7.8%. For starters, the average error was 18.0%, although a large error of up to 47.1% was observed in some data points. In contrast, for compressors, the errors were large regardless of the variable used, with an average exceeding 35% and a maximum surpassing 100%. Therefore, for alternators used in passenger vehicles, it was found that the GHG emission reduction effects can be estimated within an error margin of 20%, similar to the case of reused parts [3]. On the other hand, for starters, large errors in some data indicate that stable estimation is difficult. This is because, even within the same vehicle category, differences in replacement rates can lead to substantial variation in reduction effects. Likewise, for compressors, large errors were observed regardless of the variables used, and stable estimation is difficult. This is mainly due to the presence of certain components that show extremely low reduction effects compared with others.

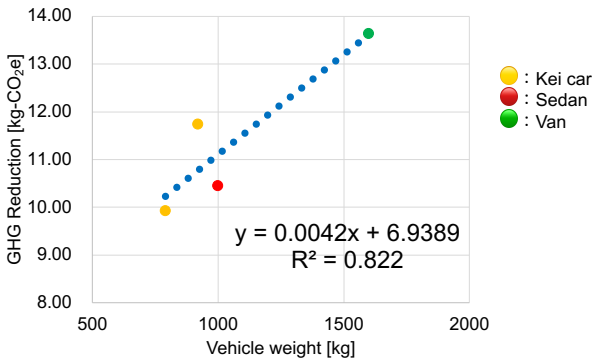

Fig. 7: Relationship between vehicle weight (excluding trucks) and GHG reduction effects of alternators

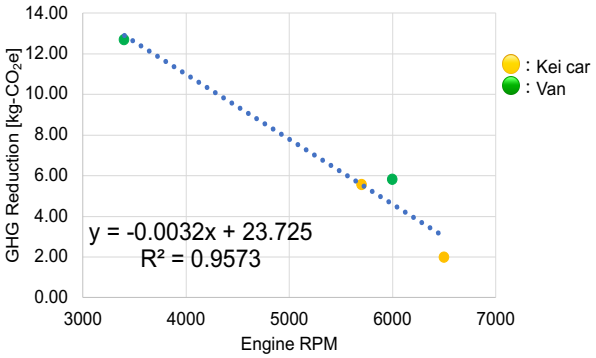

Fig. 8: Relationship between engine RPM (excluding trucks) and GHG reduction effects of starters

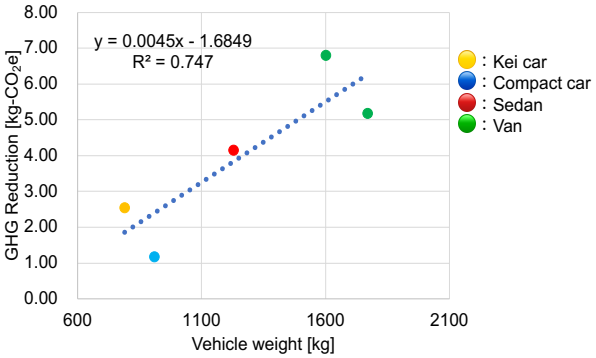

Fig. 9: Relationship between vehicle weight (excluding trucks) and GHG reduction effects of compressors

7. CONCLUSION

In this study, it was confirmed that the use of remanufactured parts resulted in GHG emission reduction effects of 58.5% on average for starters, 75.7% for alternators, and 42.1% for compressors. Furthermore, since it was confirmed that GHG emissions from the production of replacement parts account for the majority of emissions in remanufactured part production, a sensitivity analysis was conducted. The results showed that even if the emissions from replacement part production were reduced by half, the overall reduction effect would not improve significantly. Even when improvements are made to the manufacturing process, the enhancement of the reduction effect remains limited. Therefore, increasing the use of remanufactured parts themselves and suppressing the use of new parts is more effective in reducing GHG emissions. Furthermore, we conducted an estimation of the reduction effect and confirmed that estimation is possible for some parts.

As future work, it is necessary to increase the number of samples for parts with low estimation accuracy in order to improve precision. In addition, improving the estimation of the GHG emission reduction effects of remanufactured parts for components other than engine auxiliaries is also required.

ACKNOWLEDGEMENTS

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