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Remanufacturing: Trends and Issues

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The twenty-first century is a knowledge-based and increasingly environmental age. Many countries are introducing new policies and production concepts that are consistent with these trends. Recently, interest in recycle, reuse and remanufacturing technologies has been increasing, with the eco-friendly and energy-efficient production. One of these eco-friendly production methods, remanufacturing, is defined as a series of processes to re-commercialize end-of-life products and parts as new products. Various remanufacturing markets already exist throughout the world. However, the size and types of remanufacturing markets differ from country to country according to technological level and national policy. In this paper, a literature review of trends and issues related to the remanufacturing from the last five years was performed. Then, the global remanufacturing landscape, including the types of remanufactured goods, the scale of the markets and national policies in the major remanufacturing countries was summarized. Also, approaches in the design of disassembly and several remanufacturing technologies, including cleaning and repairing, are provided from the last three years.

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1. Introduction

Today, many companies are required to invest in environmental protection measures, due to increasing environmental regulations, decreasing resources and fossil fuels, etc. These environmental protections are considered by most companies to be an additional cost factor. However, such environmental protection measures are not necessarily added cost factors, but can also be opportunities to create new and eco-friendly manufacturing concepts.[1-13] Fig. 1 shows a conceptual diagram of the resource circulation that can be employed in eco-friendly manufacturing.[14]

Remanufacturing has been attracting attention as an emerging field because of its contribution to the growth in green manufacturing industries. Although there are significant differences between remanufacturing and manufacturing processes, as shown in Table 1, the two processes still have a lot in common, compared with other environmental processes.[15] Remanufacturing has already been applied to various products such as automobile parts, machinery, ink cartridges, medical devices and furniture. The concept of remanufacturing is clearly distinguished from simple recycling and reuse. Recycling is defined as the use of raw materials from new or older product that have been obtained by dissolving or disassembling the end-of-life products. Reuse means to use again after simple repairs and cleaning, without a special manufacturing process.[16] Remanufacturing is defined as a series of processes that allow end-of-life products and parts to be re-commercialized as new products, by disassembling, cleaning, inspecting, repairing, replacing, and reassembling, as shown in Fig. 2.

The remanufacturing industry contributes to the green economy, job creation and price stabilization. Production costs can be reduced by remanufacturing because most of the end-of-life product parts can be used again as parts in a remanufactured product. Generally, the production cost of a remanufactured product is 40 - 65% of the production cost of a new product. The energy required to produce the remanufactured product can be more than 85% less than the energy required for a new product. Moreover, the remanufacturing industry can have a great impact on job creation because it is a labor intensive industry. Remanufacturing creates new markets for remanufactured products that have the quality and performance of new product, but can be purchased at a cheaper price by consumers. This can have a positive effect on price stabilization.[17,18]

In this paper, a literature review of the trends and issues in the remanufacturing field over the last five years is performed in Chapter 2. In Chapter 3, the global remanufacturing landscape, including remanufactured goods and markets in the major countries of the world, is summarized. In Chapter 4, approaches of the design for disassembly and several remanufacturing technologies, including cleaning and

Table 1 Comparison of remanufacturing and manufacturing in 8 categories

Category		Costs	Competition	Automation	Design for remanufacturing (DFRem)	Inventory	Raw materials (returns)		
							Quality	Quantity	Timing
↑ Bad	Score 1	High	Low	Low	Low	High	Uncertain	Uncertain	Uncertain
↓ Good	Score 2	Low	High	High	High	Low	Stable	Stable	Stable
Remanufacturing score		2	1	1	1	1	1,2	1,2	1
Manufacturing score		1	2	2	2	2	2	2	2

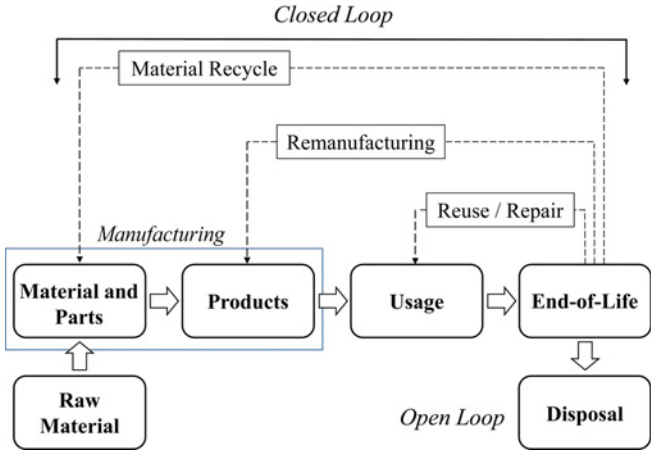

Fig. 1 Conceptual diagram of resource circulation

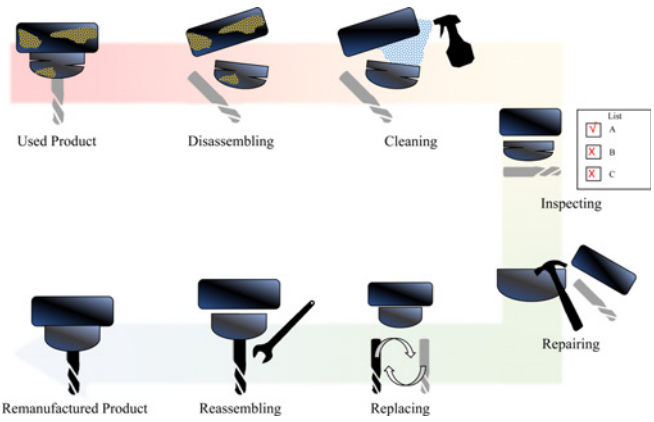

Fig. 2 Remanufacturing process

repair, are provided from the last three years. Also, several patents on remanufacturing methods for certain goods from the major countries are listed. The final part of this paper provides a summary and outlook.

2. Literature Review

The life cycle of existing products has been shortened by the increasingly rapid technological development of new products, along with the growing desire of consumers to acquire the latest technology. This has resulted in environmental pollution, because of the increase in the volume of discarded products.[19-28] This environmental problem represents an opportunity for remanufacturing and green manufacturing.[29-35] A number of studies on remanufacturing have accordingly been performed in the areas of production planning, business issues, management decisions and products.[36-38]

In the following review of the literature, trends and issues that have been reported over the past five years involving remanufacturing are listed, based on the various perspectives.

Table 2 List of literature on environmental and economic issues[40-45]

Environmental and economic issues	Author
Energy savings of remanufacturing	Gutowski et al. (2011)
Evaluation of acquisition price and quantity of used products	Pokharel and Liang (2012)
Evaluation of economic feasibility by using the graph theoretic approach	Sabharwal and Garg (2013)
Environmentally friendly approach for removal of contaminants by supercritical CO_2	Liu et al. (2014)
Economic and environmental assessment of remanufacturing strategies	Ovchinnikov et al. (2014)
Alleviation of environmental damage under emissions regulation	Yenipazarli (2016)

2.1 Managerial Perspective

2.1.1 Environmental and Economic Issues

In the last decade there has been growing concern around the world about environmental issues, sustainable development, resource shortages and mandatory controls. In light of these trends, interest in remanufacturing as a specific type of recycling has been growing globally. Not only can environmental pollution be mitigated, but energy consumption can be reduced by remanufacturing. Also, growth in remanufacturing should increase of the profits of manufacturing firms, and decrease their environmental impact.[39] Table 2 shows a list of recent literature on environmental and economic issues.

2.1.2 Marketing Issues

Marketing strategies differ depending on the type of sales (spare parts or complete remanufactured product) for a particular company. Those strategies also depend on the targeted users of the remanufactured product, such as the company itself, or other companies in the business chain, or other companies outside the business chain.[39]

Marketing strategies for remanufacturing can be determined by reviewing the important characteristics of the remanufactured product that affect profitability, such as whether:[46]

I. The remanufactured product has a lower cost than the new product;

Table 3 List of literature on marketing issues[47-50]

Marketing issues	Author
Key factors for remanufactured products in the market	Subramanian and Subramanyam (2012)
Market size and survey of various products in European remanufacturing	Parker et al. (2015)
Market competition between original manufacturer and remanufacturer	Shi et al. (2015)
Third-party competition and perceived value of consumer	Agrawal et al. (2015)

II. The remanufactured products have generally lower valuation and less demand from consumer segments;
III. The remanufactured products and production methods have a 'green image' because resources are recycled (this can attract the attention of environmentally conscious consumers);
IV. The remanufactured products have the level of functionality and quality of a new product (some manufacturers believe that the remanufactured product cannibalizes new product sales);
V. Supply of the remanufactured products is limited by the number of returns from previous sales (supply constraints).

Table 3 shows the list of literature on marketing issues.

2.1.3 Acquisition and Reverse Logistics Issues

The raw materials for remanufacturing are obtained by returns of used products. This acquisition of raw materials by return is a very unique characteristic of the remanufacturing process. In general manufacturing, the process of acquiring raw materials is fixed or obvious. However, the process of acquiring raw materials in remanufacturing is not fixed or uncertain. The uncertainty surrounding the return of the parts and used products complicates the remanufacturing process. The uncertainties of returns in remanufacturing are as follows:[39]

- Timing of the return
- Quality of the return
- Quantity of the return

These uncertainties are important to consider in the process of acquisition. If these factors are not considered, the remanufacturer may suffer huge losses.

Reverse logistics is a very important activity for the company. Reverse logistics is the series of processes used to acquire and transport the parts and used products. A well planned reverse logistics network is required to ensure the proper functioning of the remanufacturing operation. Reverse logistics networks can be classified into three types based on the role of the original equipment manufacturer (OEM) in the business activity, as follows:[39]

- All the remanufacturing activities are managed by the OEM (products are directly remanufactured by OEM);
- The acquisition and reverse logistics activities of a Third Party Logistics Provider (TPLPs) are managed by the OEM;
- Remanufacturing activities are only conducted by Third Party Remanufacturer (TPRs).

A reverse logistics network can be analyzed by examining the optimal return and distribution flows, locations and facilities, distribution network, etc. Table 4 shows the list of literature on acquisition and reverse logistics issues.

Table 4 List of literature on acquisition and reverse logistics issues[51-57]

Acquisition and Reverse logistics issues	
Acquisition issues	Author
Quality variation impact of returns	Korugan et al. (2013)
Optimum acquisition pricing in a closed-loop supply chain (CLSC)	He (2015)
Optimum acquisition of multiple used products	Yang et al. (2016)
Reverse logistics issues	Author
Remanufacturing logistics process based on closed-loop supply chain management	Xia et al. (2011)
Green supply chain model for product	Urvashi et al. (2013)
Reverse logistics challenges of automotive devices	Sundin and Dunback (2013)
A mixed model incorporating the reverse logistics network into the forward logistics network	Yi et al. (2016)

Table 5 List of literature on design and production planning issues[58-71]

Design and production planning issues	
Design issues	Author
Design content for new products' remanufacturability	Xiaoyan (2012)
Design for disassembly for remanufacturing	Soh et al. (2014, 2015)
Product and sales contract design	Yalabik et al. (2014)
Design for remanufacturing (DFRem)	Fegade et al. (2015)
Quality design of green consumerism	Gu et al. (2015)
Redesign of service modes for remanufactured products	Zhu et al. (2016)
Production planning issues	Author
Production planning and control for remanufacturing	Junior and Filho (2012)
Optimal remanufacturing quantities	Bulmus et al. (2013)
Determination of optimal reconditioning process	Kin et al. (2014)
Development of new remanufacturing production planning model	Wen et al. (2015)
Genetic algorithm approach for process planning and scheduling	Zhang et al. (2015) Jiang et al. (2016)
Development of holistic approach to improve remanufacturing processes	Butzer et al. (2016)

2.1.4 Design and Production Planning Issues

The uncertainties of returns can cause problems with attempts to analyze complications in the remanufacturing operation. For this reason, many management scientists have investigated production planning and control strategies, for effective production. The process of remanufacturing is complicated by uncertainties in timing, by the quality and quantity of return in terms of inventory control, the design of product, and production planning of the remanufactured product. Also, the uncertainties involved with returns make it is difficult to set the market sale price of remanufactured products.[39]

The design of the parts and products is very important because it materially affects the lifetime of the product. Consequently, design for remanufacturing (DFRem) and the materials used in the process have been studied by many researchers. Table 5 shows the list of literature on design and production planning issues.

Table 6 List of literature based on the types of product[72-84]

Research range	Author	Type of product
Remanufacturing for automotive electronics control parts	Mok et al. (2013)	Automotive
Designing automotive products from material selection perspective	Yang et al. (2015)	
Application of fuzzy analytic network process for barrier evaluation	Govindan et al. (2016)	
Potential benefits and opportunities of remanufacturing	Chen et al. (2014)	Dies and molds
Environmental benefits and remanufacturing through laser cladding	Liu et al. (2016)	Cylinder heads
Stochastic models and numerical solutions for remanufacturing systems	Francie et al. (2015)	Cartridge
Environmental impact and life evaluation	Shi et al. (2015)	Engines
Supply chain-based barriers for truck-engine remanufacturing	Zhu et al. (2015)	
Method for optimum remanufacturing point	Zhang et al. (2014)	Batteries
Remanufacturing processes	Busu et al. (2015)	Electrical and electronic equipment
Optimal strategy for remanufacturing	Ullah et al. (2016)	Machine tools
Remanufacturing by laser direct deposition and environmental impact analysis	Wilson et al. (2014)	Turbine blades
Remanufacturing processes and improvement of fatigue life	Darisuren et al. (2014)	Bearings

2.2 Types of Product

The literature is categorized based on the types of product being remanufactured, as shown in Table 6.

3. Global Remanufacturing

This chapter provides a summary of the global remanufacturing landscape, including types of remanufactured goods and markets in the major countries of the world. Global Industry Analysis (GIA Inc.) reported on the global business prospects of the remanufactured automobile parts market. According to GIA Inc., the global market for remanufactured automobile parts will reach about US$ 139.8 billion by 2020.[85]

3.1 United States (US)

An overview of the US remanufacturing industries was provided by the United States International Trade Commission (USITC), published in 2012. The USITC review is focused on international trade and remanufactured goods and markets. According to this review, the world's largest remanufacturer is working in the US. Remanufacturing in the US involves a widely diverse range of industrial fields. Also, in the US, policy and legal system are well established, and the use and sale of remanufactured goods are recommended. For example, when remanufactured goods are purchased by consumers, in the states of New York and Connecticut, advantages including tax benefits are provided.[86]

The major sectors involved in remanufacturing in the US are aerospace, heavy-duty and off-road (HDOR) equipment and automobile parts. These three sectors account for 63 percent of all remanufactured goods in the US.

Table 7 shows statistics for the US remanufacturing market for different sectors. The market size for remanufactured products differs based on the type of remanufactured goods. It is worth noting that remanufacturing investment in the US nearly doubled during 2009 - 2011. The percentage of remanufactured goods as a fraction of total sales (of new and remanufactured products) was 2 percent in 2011. Remanufacturing industries employed more than 180,000 workers (full-time jobs) in 2011. About 87,000 workers were employed in the major sectors.[86]

Fig. 3 shows a schematic of the US trade in remanufactured goods.

3.2 European Union (EU)

The remanufacturing industrial fields in the EU are similar to those in the US. The major remanufacturing sectors are aerospace, automobile parts, HDOR equipment and machinery. Remanufacturing activities are being actively conducted throughout the EU, and Germany is estimated to account for the largest scale. European populations tend to have excellent environmental awareness and therefore view remanufacturing as a method of cost reduction and protecting the environment. Also, the European Commission (EC) under the EU government has implemented several mandatory controls for the growth of remanufacturing.[48,86]

Table 8 shows the market size of the EU's remanufacturing sector in 2015. This information also provides the relative proportion of the each sector. The production value of all manufactured goods is calculated to be €1.5 trillion, based on remanufacturing intensity value. Remanufacturing makes up a small proportion (1.9%) of the total value of EU production. However, remanufacturing has unlimited potential because of the growth in market share and increasing profitability being brought about by changing perceptions on environmental problems.[48,86]

The cumulative production in aerospace (42%), automobile parts (25%) and HDOR (14%) accounts for about 80 % of the EU's total remanufacturing output. Also, the major countries involved in EU remanufacturing are Germany, France and Italy. These three countries account for 64 % of all remanufacturing value in the EU.[48,86]

3.3 China

Before 2008 the remanufacturing sector of China had not been established. In 2008, two government-led pilot programs (in the automobile parts remanufacturing sector and the industrial machinery and electrical equipment remanufacturing sector) were allowed to engage in limited remanufacturing by China's National Development and Reform Commission (NDRC) and the Ministry of Industry and Information Technology (MIIT). Only the companies 'approved' by the

Table 7 Statistics of remanufacturing market based on the remanufactured goods in US[86]

Sector	Production (US$ million)		Investment (US$ million)		Employment ('000 Full time equivalent)		Exports (US$ million)		Imports (US$ million)		Intensity (%)[c]
	2009	2011	2009	2011	2009	2011	2011	2011	2009	2011	2011
Aerospace	11,691	13,046	95.7	90	35.8	35.2	2,546	2,590	484	1,870	2.6
HDOR equipment	5,152	7,771	80.1	163	18.0	20.8	1,695	2,452	1,042	1,489	3.8
Automobile parts	7,018	6,212	76.1	106	30.0	30.7	430	582	1,219	1,482	1.1
Machinery	4,059	5,795	206.5	711	24.8	26.8	858	1,349	136	268	1.0
IT products	2,709	2,682	14.8	18	11.4	15.4	219	260	1,931	2,756	0.4
Medical devices	1,307	1,463	21.0	31	3.7	4.1	453	488	109	111	0.5
Retreaded tires	1,038	1,399	19.8	24	3.9	4.9	15	19	6	11	2.9
Consumer products	557	659	34.0	5	8.2	7.6	13	21	325	360	0.1
All other[a]	3,745	3,974	84.0	68	21.4	23.0	128	225	39	41	1.3
Wholesalers[b]			6.5	8	8.1	10.9	1,139	3,752	960	1,874	
Total	37,276	43,000 (+15.3%)	638.5	1,223 (+91.5%)	165.3	179.5 (+8.5%)	7,496	11,736 (+56.5%)	6,251	10,263 (+64.1%)	2.0

(a) Includes remanufactured electrical devices, locomotives, office furniture, and restaurant equipment

(b) Total value of shipments of remanufactured goods as a % of total sales of all products

(c) Wholesalers do not produce remanufactured goods

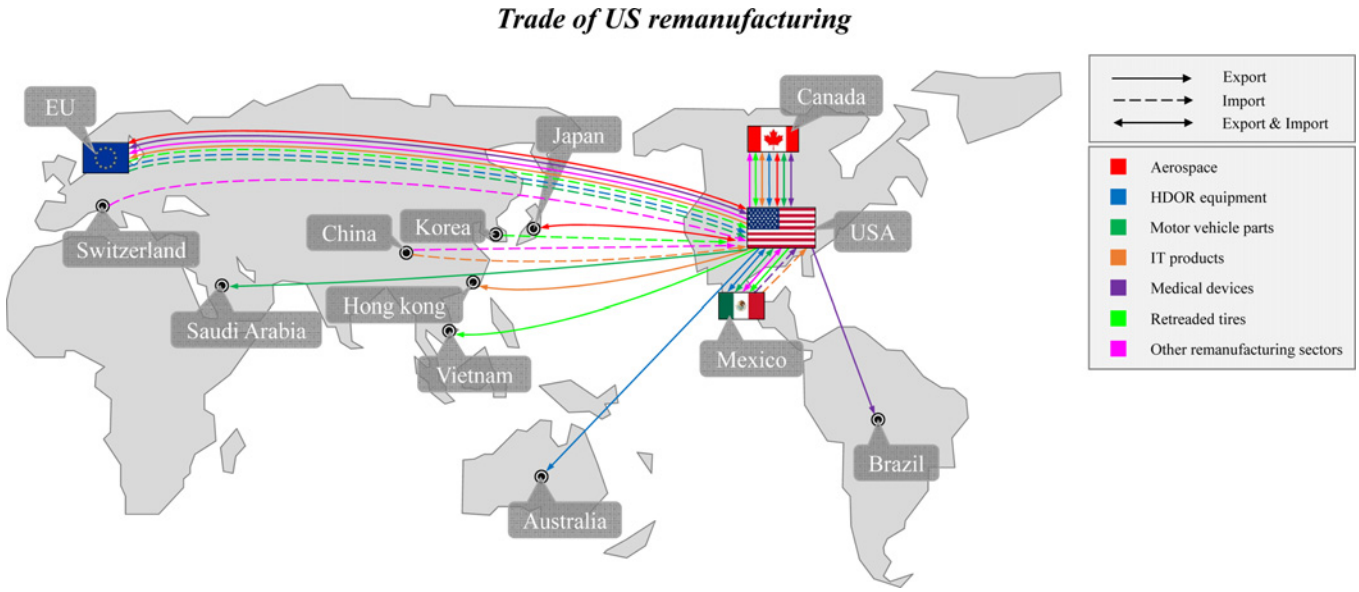

Fig. 3 Schematic diagram of US remanufacturing trade

government can participate in these programs. In the automobile parts sector, only 15 companies are approved for remanufacturing. In 2009, 110,000 engines, 60,000 transmissions and a million starter motors were remanufactured by the approved companies. In the industrial machinery and electrical equipment sector, approximately 60 companies are approved for remanufacturing.[48,86,87]

In 2010, a guidance document was issued by the key ministries including the NDRC, in an effort to develop the remanufacturing industry. Then, in 2011, the number of industries in the guidance for remanufacturing was expanded.[48,87]

Although tire retreading is not included in the pilot programs, it is well established with over 1,000 remanufacturers. Total production of retreaded tires is estimated to be 11.5 million tires in 2008, and is predicted to reach 19 million tires in 2010.[86]

3.4 Other Countries

3.4.1 Brazil

Although the remanufacturing market in Brazil is small, remanufacturing activity is being aggressively developed. The major remanufacturing sectors in Brazil are aerospace, automobile parts, HDOR equipment and IT products. The remanufacturing industry in the country mainly consists of thousands of small companies and, and a relatively small number of people are working in the remanufacturing industry. More than 2,000 engine remanufacturing companies located in Brazil employ fewer than six workers. However, a number of large multinational companies account for most of the remanufacturing output.[48,86]

The automobile parts remanufacturing industry includes engine remanufacturing, and the repair of automobile parts. In 2010, the automobile parts remanufacturing industry was estimated to be US$ 1.4

Table 8 Market size of EU's remanufacturing activities based on sector in 2015[48,86]

Sector	Production (€ billion)	Companies	Employment ('000 Full time equivalent)	Intensity (%)
Aerospace	12.4	1,000	71	11.5
Automobile parts	7.4	2,363	43	1.1
HDOR	4.1	581	31	2.9
Machinery	1.0	513	6	0.7
Furniture	0.3	147	4	0.4
Electrical and electronic equipment	3.1	2,502	28	1.1
Marine	0.1	7	1	0.3
Medical devices	1.0	60	7	2.8
Rail	0.3	30	3	1.1
Total	29.8	7,204	192	1.9

billion in size, with half of the companies concentrated in Sao Paulo state. The remanufacturing of IT products in Brazil is mainly focused on printer cartridges. There are an estimated 18,000 printer cartridge remanufacturing companies. The annual market for remanufactured printer cartridges is US$ 260 million and more than 12 million printer cartridges are consumed. OEM producers and remanufacturers account for 50% of the market, respectively. A series of restrictions on imports of remanufactured goods has been imposed by the government of Brazil, and imports of cores are specifically prohibited. Therefore, Brazil's remanufacturing industry trade is negligible, and remanufactured products are mainly sold to the domestic market.[48,86]

3.4.2 India

The remanufacturing industry in India is relatively underdeveloped. The major sectors of remanufacturing are IT products (printer cartridges) and HDOR equipment. In the IT products sector, refilling or remanufacturing is performed by 30,000 companies. The annual market size of printer cartridges remanufacturing is estimated to be US$ 250 million.[48,86,88]

The import of used goods (cores) to be remanufactured in India and sold in the domestic market is prohibited by the government of India. However, imports of cores that are intended to be remanufactured domestically and subsequently exported are allowed.[48,86,88]

3.4.3 Japan

The remanufacturing sector in Japan is well relatively established. The total remanufacturing market size of Japan is estimated to be 500 billion Yen. The automobile sector, toner cartridges, retread tires and photocopiers are estimated to be 109 billion Yen, 30 billion Yen, 20 billion Yen and 15 billion Yen, respectively. In the automobile and toner cartridges sector, the remanufacturing industry is led by remanufacturing companies rather than OEMs.[48,86]

3.4.4 Singapore

The major remanufacturing sectors in Singapore are HDOR equipment, automobile parts, medical devices, electrical devices and marine equipment. There are no government regulations for remanufactured goods, such as distinctions between new and remanufactured cores or specific marking requirements. Cores for remanufacturing can be freely imported and exported to ASEAN and Australia. In 2011, the Advanced Remanufacturing and Technology Center (ARTC) was formed to enhance remanufacturing technologies for the aerospace, automobile parts, marine, and HDOR equipment sectors.[48,86]

3.4.5 Korea

Korea's remanufacturing industry is focused in the automobile parts and printer cartridge, IT products, medical devices and defense sectors, with some activity in heavy duty equipment. In 2005, the legal basis for the development of a remanufacturing industry was secured, and the foundation for developing remanufacturing was comprehensively established. In 2011, remanufacturing growth was encouraged by the Korean government through the Ministry of Trade, Industry and Energy (MOTIE).[48,86,89]

The automobile parts sector accounts for 80% of the Korean domestic remanufacturing industry and the printer cartridge sector accounts for 17%. The remanufacturing industry has grown by 11 % during the last five years. However, the number of companies and workers has been reduced from about 1,500 companies down to 1,100, and from 11,000 workers down to 7,300. The HDOR equipment remanufacturing market is small, and remanufacturing or repair activities are led by OEMs rather than independent remanufacturing companies.[48,86]

4. Remanufacturing Technologies

This chapter introduces the approaches used in the design of disassembly processes in the last three years, and discusses several remanufacturing technologies, including cleaning and repairing. Also, the remanufacturing processes of certain products are summarized. Table 9 shows a list of several patents (application and publication) on the remanufacturing methods of certain goods based on the country over the last five years.

4.1 Design for Disassembly

To remanufacture used goods, disassembly of the original product is required. Most disassembly processes are manually performed because of the high capital cost of automation, lack of flexibility given the number of different types of goods, and the need for human intervention to determine the appropriate tools. However, manual disassembly may not be cost effective, because of the increase in

Table 9 International patent list based on the country[90-113]

Country	Patent name	Application date (Publication date)	Applicants	Application No. (Publication No.)
US	Remanufacturing hydraulic pumps	Apr 11, 2011	Caterpillar Inc.	13084282
	Technique for remanufacturing a BIS sensor	Sep 26, 2011 (Dec 29, 2015)	Donald R. Sandmore Covidien LP David P. Besko	13245040 (09220436)
	Method of remanufacturing hydraulic cylinders, and remanufactured hydraulic cylinders	Apr 02, 2012 (Apr 19, 2016)	Zbigniew Robert Paul	13437080 (09314884)
	Polystyrene product remanufacturing apparatus and methods of use	Mar 15, 2013 (Aug 23, 2016)	Jason Womack	13837057 (09421696)
	Method of remanufacturing a sealing surface	Jun 10, 2013	Caterpillar Inc.	13913702
	Remanufactured hydraulic device, housing and remanufacturing method	Jun 11, 2013	Caterpillar, Inc.	13915104
	Methods and devices for remanufacturing printer cartridge components	Jul 25, 2013 (May 05, 2015)	Mitsubishi Kagaku Imaging Corporation	13987441 (09025996)
	Remanufacturing method for battery module	Jul 30, 2013	Johnson Controls Technology Company	13954932
	Method of remanufacturing a wheel housing	Oct 21, 2013	Caterpillar Inc.	14058462
	Method for remanufacturing toner cartridges	Jul 07, 2014	Flo-Tech, LLC	14324483
	Method for remanufacturing flywheel	Jan 05, 2015	Caterpillar Inc.	14589060
	Technique for remanufacturing a medical sensor	Oct 07, 2015	Covidien LP	14877671
EU	Remanufacturing of bearings using isotropic finishing and thin film coatings	Jun 20, 2013	Caterpillar Inc.	13830576.8
	Remanufacturing method for battery module	Mar 12, 2014	Johnson Controls Technology Company	14719435.1
	Method for remanufacturing toner cartridges	Jul 01, 2015	Flo-Tech, LLC	15174713.6
	Remanufacturing method of developer accommodating unit	Oct 26, 2015	Canon Kabushiki Kaisha	15191485.0
	Cleaning device, cartridge, method for remanufacturing cleaning device, and method for remanufacturing cartridge	Nov 05, 2015	Canon Kabushiki Kaisha	15193114.4
JP & KR	Method for remanufacturing inelastic developing roller of process cartridge	Feb 18, 2011 (Nov 07, 2012)	J. H. Choi	1020110014562 (1012008900000)
	Consumable part, cleaning blade, elastic roller, manufacturing method thereof, and remanufacturing method thereof	Aug 10, 2011	Canon Inc.	23175187
	Method for remanufacturing of bearing	Feb 08, 2012 (Dec 06, 2013)	SunMoon University	1020120012863 (1013411000000)
	Device for remanufacturing SF6 with high efficiency and mobility and method for remanufacturing SF6 using the same	Jul 10, 2012 (Jun 03, 2014)	Kocat Inc.	1020120074986 (1014061970000)
	Remanufactured SCR aged catalyst by in-situ technology	Oct 12, 2012 (Dec 19, 2013)	Hanseo University	1020120113672 (1013454440000)
	Method of remanufacturing toner cartridge and remanufactured toner cartridge	Apr 22, 2014	Xerox CORP	26087840
	Remanufacturing apparatus for shock absorber	Oct 23, 2014 (Jan 27, 2015)	Wooriengineering Inc.	1020140144475 (1014888370000)

disassembly time and the resulting high labor cost, and the inefficient disassembly designs for many goods.

Goods that are intentionally designed to be later disassembled and remanufactured can save both energy and cost compared with goods that are not designed with this intention. In this respect, design for disassembly is very important for economically remanufacturing used products.

Various approaches (methodologies, technologies and human factors) have been proposed for this purpose. Methodologies (such as the and/or graph and the petri-net approach) have been proposed to establish optimal methods of disassembly in terms of sequence planning and hierarchical modular modelling. New technologies (one-to-many disassembly) have improved disassembly efficiency by enabling fasteners to be removed at the same time. Human factors must be considered in the design of a product and the disassembly process because disassembly is conducted by the manual operations. If these factors are not considered, it could cause various problems. Therefore, three factors are considered necessary for effective and complete disassembly design.[59]

4.2 Cleaning

Cleaning is an important technology in the remanufacturing process. The remanufacturing cleaning process should be eco-friendly, and developing new cleaning technologies is essential to reduce environmental pollution. Currently, high temperature decomposition and shot blasting cleaning are used as conventional cleaning technologies for

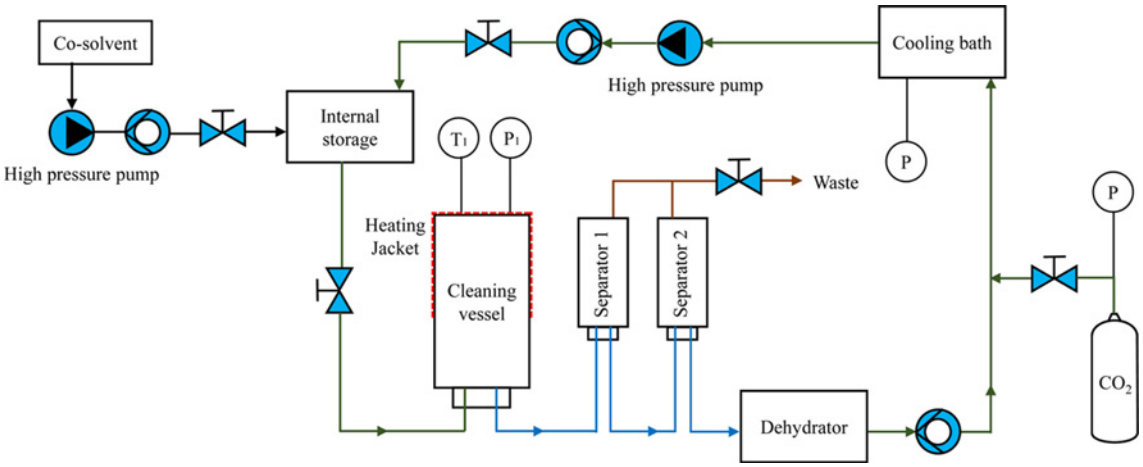

Fig. 4 Schematic diagram of the SC-CO_2 cleaning device[116]

Table 10 Main input based on the remanufacturing cleaning method

Cleaning method	Main input (Amount)
Supercritical carbon dioxide (SC-CO_2)	Electricity (3.36 kWh)
Liquid blasting	Electricity (0.67 kWh)
	Abrasive (15 g)
	Water (0.4 kg)
High temperature decomposition	Diesel (5.6 kg)
Shot blasting	Electricity (0.995 kWh)
	Steel shot (15 g)

remanufacturing. Supercritical carbon dioxide (SC-CO_2) cleaning and liquid blasting cleaning are relatively new methods. Fig. 4 shows a schematic diagram of a SC-CO_2 cleaning device. Table 10 shows the main systematic input based on the remanufacturing cleaning method.[114]

Liu et al. investigated the feasibility and effect of cleaning using SC-CO_2. The experiments were performed with different parameters, including cleaning temperature, pressure, flow rate, time and with or without dehydrated ethyl alcohol. Also, optimum process parameters are determined by design of experiment (DOE). As a result, cleaning performance was calculated to be 89.3% effective.[115]

Li et al. proposed a novel and eco-friendly method for remanufacturing cleaning using SC-CO_2 to remove oily contamination from used engine components. Experiments were conducted by comparing various cleaning methods, including thermal cleaning, water-jet cleaning and ultrasonic cleaning. The experimental results showed that the proposed method was an ideal alternative to cleaning in the remanufacturing of aluminum components.[116]

4.3 Repairing

Repairing is one of the remanufacturing processes used to make high quality products after cleaning. Repair technologies differ, based on the types and shapes of products, the materials and the purpose of remanufacturing.

Qin et al. studied the honing process for remanufacturing hydraulic cylinder bores. The remanufacturing honing process was divided into five steps, as follows.[117]

- Step 1. Initialization and clamping
- Step 2. Rough honing
- Step 3. Fine honing
- Step 4. Polishing
- Step 5. Detection and removal of workpiece

Experiments were performed for selected parameters, such as machining diameter range, spindle speed, stroke rate and adjustment time. The experimental results proved that the application of hydraulic cylinder bore honing was suitable for remanufacturing, and reduced remanufacturing costs.

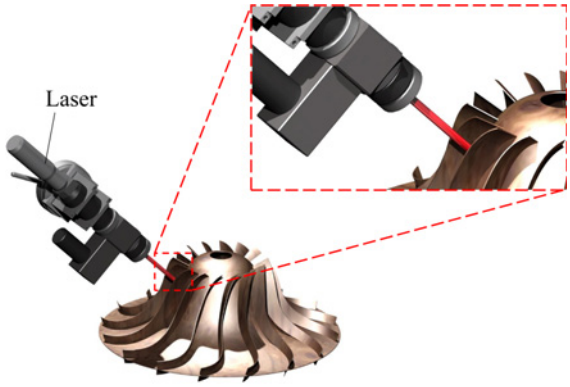

Fig. 5 Schematic diagram of impeller blade remanufacturing by laser cladding

Lei et al. studied the an impeller blade remanufacturing process using laser cladding with an FeCrNiCu alloy powder, as shown in Fig. 5. The microstructure, microhardness, and tensile properties of the cladding layers were analyzed, and the average microhardness and tensile strength were found to be 361 HV and 860 MPa, respectively. Also, safety tests of the remanufactured impeller blade were performed by dynamic balance test, and the unbalanced quantity was less than 0.3 g.[118]

Jhavar et al. studied die and mold surface remanufacturing using micro-plasma transferred arc (μPTA) additive manufacturing. Experiments were carried out with three parameters (plasma power, machine travel feed and wire feed). As a result, μPTA was determined to be an excellent alternative for surface remanufacturing.[119]

Kawasaki et al. proposed a method for remanufacturing the pinion member of large-sized skew bevel gears using a CNC machining center. The bevel gear remanufacturing process used in this study was as follows:[120]

(1) Development of mathematical model for tooth surface forms

(2) Measurement of real tooth surfaces of existing gear member
(3) Analysis of tooth contact pattern and transmission errors
(4) Remanufacturing of the pinion and gear member by swarf milling
(5) Measurement and analysis of remanufactured pinion and gear member

As a result, the validity of the proposed remanufacturing method was confirmed by analysis of the tooth surface form deviations. Also, the mathematical model was in good agreement with the experimental tooth contact patterns.

5. Summary and Outlook

This paper has reviewed remanufacturing trends and issues from the last five years. Remanufacturing is an economical and eco-friendly activity because it recycles resources and saves energy. The remanufacturing industry has a significant effect on job creation because it is a labor intensive industry, and remanufacturing provides opportunities to create new markets. Recently, because of changing environmental awareness, many countries have strengthened their environmental regulations and are encouraging remanufacturing activity.[1,2,15,17,18]

The global remanufacturing industry market is still small, and relatively few companies are engaged in remanufacturing activities, but the types of products suitable for remanufacturing and their markets are increasing every year. Also, studies on remanufacturing technologies are being actively conducted by many researchers.[4,8,86,121]

Interest in remanufacturing is expected to continue to increase. Therefore, cooperation between various organizations and stakeholders, including companies, governments, consumers, and researchers are required. Also, each country should develop an institutional strategy, such as a tax benefits for remanufacturers who participate in remanufacturing activities.[37]

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