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# CURRENT TREND, CONCEPTS AND CHALLENGES IN REMANUFACTURING OF THE INDUSTRIAL PRODUCTS

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***Abstract:*** *The depletion of raw materials and the escalation of environmental degradation have been the main driving forces for the development of an industrial process that is environmentally and consumer-friendly. The main environmental advantages of remanufacturing are reduced energy use and a minimal carbon dioxide production, while consumers are drawn to the practice since it makes cutting-edge products available at much reduced costs. This study investigates, based on the literature, the main concepts behind the remanufacturing process, the benefits and drawbacks of operating a company based on the remanufacturing process, and the most recent developments that are brought on by innovative manufacturing technology.*
***Key words:*** *remanufacturing, additive technologies, green manufacturing, reverse engineering, 3d printing,*

## 1. INTRODUCTION

Nowadays the concept of sustainability and the principles of circular economy have received significant attention and have emerged as crucial areas of focus. The constantly evolving nature of the world we live in has propelled these concepts to the forefront of discussions and debates. The need to ensure that our planet's resources are utilized in a sustainable manner that does not jeopardize future generations' ability to meet their own requirements has become increasingly apparent. A multitude of industries spanning various sectors have taken part in the exploration and implementation of innovative approaches aimed at reducing waste generation, conserving valuable resources, and minimizing their overall environmental footprint. In today's economic surroundings, there is a particular industry that is directing the movement towards sustainable and environmentally friendly practices, and that industry is none other than the remanufacturing sector.

In essence, remanufacturing embodies industrial practices aimed to achieve environmentally sustainable outcomes.

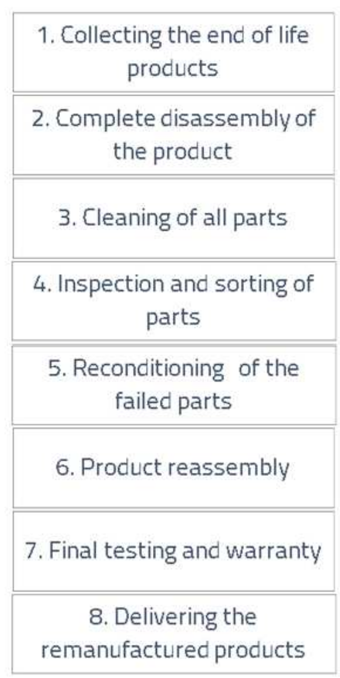


**Fig.1** Steps of the remanufacturing process [1]

As shown in Fig. 1, remanufacturing has eight steps, from collecting used products through disassembly, cleaning, inspection, refurbishing/repairing, reassembly (potentially with new components included), testing until delivery with warranties [1],[2]. This process proves crucial for resource conservation while significantly minimizing waste production. Through material recovery (reusing/recycling), remanufacturing allows drastically reduce landfill requirements. Extending product life cycles offers to companies an ideal option for reducing relentless rolling out of new products onto markets; further research proves outstanding resource gain thereof [2]. In present times, where sustainability bears immense power over businesses and consumers, investing in such a beneficial approach would prove optimal. Multiple industries, from transportation to electronics and manufacturing, benefit from remanufacturing processes due to resource conservation and environmental benefits above discussed. The aim of the paper is to present a literature review of the remanufacturing process highlighting the benefits and future research directions for using this process in the industrial environment.

Remanufacturing has become popular in the recent two decades due to its benefits: reduced energy and material consumption, reuse of a product, access to cutting-edge technology at a lower cost, and new employment and business prospects. Remanufacturability is now considered in product design due to environmental awareness. Considering remanufacturability in product design promotes sustainable production and consumption [3]. The remanufacturing concept should be introduced into a part or product early in the design phase to maximize the process [4]. Remanufacturing has hurdles despite its environmental and economic benefits. Developing a remanufacturing factory requires expensive equipment and trained people, which is the main drawback [5]. On top of that, the limited diversity of products poses a major challenge, as remanufacturing is best suited for standard, high-volume products. The remanufacturing process of a product whose composition is not based on modular components nor on standardized components is a difficult one, and in order to produce a business based on this product or to implement it in a production line, it is necessary to experimentally research remanufacturing modes and choose the best solution. The technical challenges in remanufacturing products from used components and the market's perception of remanufactured goods as inferior add to the disadvantages [6], [7]. In addition, legal and regulatory considerations, such as environmental regulations and product safety standards, increase complexity and cost. Despite these obstacles, ongoing research and development efforts, technological advancements, and policy support seek to increase the economic viability and environmental responsibility of remanufacturing, making it an important component of the circular economy.

## 2. CONCEPTS USED IN REMANUFACTURING

Several major factors in the manufacturing industry have contributed to the rapid evolution of the remanufacturing process in recent years. First, there is a shift toward eco-friendliness and circular economy practices. By reusing old parts, remanufacturing helps cut down on waste and save natural materials. Remanufacturing is becoming more widely used as an alternative to traditional manufacturing by businesses across all sectors due to rising environmental concerns [8],[9]. Remanufacturing is not limited to certain industries; rather, it is being adopted by businesses in a wide variety of fields, including among them: automotive industry, electronic industry, aerospace industry, mining industry, healthcare industry, energy industry, manufacturing industry, and the supply chain industry [10],[11],[12]. The impact of technology on advanced remanufacturing technologies has been a significant area of research. In research is investigated electro-brush plating, hypersonic velocity plasma spraying, scratch-fast fill and high-speed arc spraying in the context of automotive remanufacturing [13]. From the depths of electroplating technology, electro-brush plating, also called selective plating or swab coating, is gaining popularity, providing a quick and portable way to modify gear steels [14] and other materials. It has the ability to coat precisely, enabling changes in coating thickness. Single- and multi-phase coatings applied on the surface are the result of this technique. Nickel, chromium, tungsten, and copper can all be called forth by its enchanted touch. Electro-brush plating has been called upon to bestow durability, usability, and the gift of corrosion resistance upon the inner walls of metal pipes. It is a portable and flexible technology with excellent coating quality, low power consumption, high plating rate, and less environmental pollution [15].

High-speed arc spraying offers secure construction, fast lamination, and a variety of coatings. Surface engineering applies coatings using electric arcs [16]. To cover a substrate, molten metal particles are atomized and driven at high speeds. Automotive, aerospace, and manufacturing use high-speed arc spraying for corrosion protection, wear resistance, and thermal barrier coatings [17]. This technology offers fast deposition, robust adhesion, and complex shapes. These procedures allow for more accurate and effective remanufacturing, resulting in higher-quality products. Laser remanufacturing is another technology that has changed the field. Laser remanufacturing, a cutting-edge repair method, uses laser cladding, a surface modification technology, to revive old or damaged parts. A high-energy-density laser beam melts and deposits coating ingredients onto the surfaces, improving performance. Laser remanufacturing technology is considered a green and efficient one. [18], [19].

Laser remanufacturing provides numerous advantages by delivering high-quality repairs, reduced porosity, and a stronger link between the coating and the substrate. From rotors and gears to shafts, turbine blades, and mold steel, this inventive approach has brought back machinery and equipment [20]. Laser remanufacturing can increase hardness, wear resistance, and return components to like-new condition [21]. While traditional methods such as welding and thermal spraying remain useful, laser remanufacturing technology offers a number of advantages such as a smaller heat-affected zone, stronger bonding, and easier automation. Of course, there are still obstacles to overcome on the path to improving this technology, such as the requirement for high-power laser systems, the continuous development of laser remanufacturing processes, and government and industry backing. Despite these challenges, the potential for economic and societal gains is significant, particularly with the introduction of on-site laser remanufacturing, intelligent laser surface modification, and the preparation of specialized alloy materials.

The future of laser remanufacturing technology is bright, with enormous potential for the creation of new markets and the fulfillment of its promise [22]. It has been demonstrated that this technology is effective in resolving complex issues that arise throughout the process of equipment repair and remanufacturing. The process that is deeply involved in the remanufacturing industry, is additive manufacturing (AM). The production of replacement components for remanufactured items through the usage of 3D printing is an example of additive technology that may be seen in the remanufacturing industry [23].

Additive manufacturing allows on-demand part production, lowering costs and increasing the availability of replacement parts for remanufactured items. Traditional production methods demand costly tooling and longer lead times [24]. Directed energy deposition, micro-PTA additive manufacturing, plunge milling, cold spray, and dynamic cold gas spraying are presented in the different research. These are in addition to fused deposition molding, selective laser sintering (SLS), selective laser melting (SLM) and electron beam melting (EBM).

The capability of various additive manufacturing processes in remanufacturing to repair or remanufacture parts with high geometric complexity, good mechanical performance, and complex 3D geometries are among the advantages of using additive manufacturing in this context. The capabilities of additive technologies have been demonstrated in numerous case studies and the results have always been encouraging.

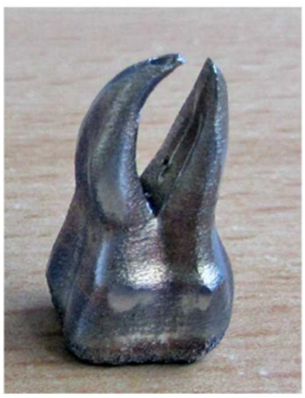

**Fig.2** Molar manufactured with SLM process [25]

The realization of a complete molar structure (Fig. 2) using SLM additive technology [25] demonstrates that this technology can be used to fabricate complex dental structures, such as teeth. This demonstrates possibilities for manufacturing different custom parts, and it can be used in any field for most products. They provide production that is more environmentally friendly, customizable, locally produced, and able to manufacture spare parts for repairs, in addition to reducing waste. Certain procedures can boost remanufacturing flexibility, productivity, and capability. The literature discusses additive-subtractive hybrid technology, additive laser and subtractive milling for composite refabrication, directed energy deposition, micro-PTA additive manufacturing, plunge milling, cold spray, and dynamic cold gas spraying [50]. The industry seems to focus most on Direct Energy Deposition (DED) is an additive manufacturing (AM) technique that deposits metal particles using a laser beam as the primary source of energy [26]. This allows the production of fully dense and functional metal parts; it is a versatile form of additive manufacturing that is especially well-suited for the maintenance and remanufacturing of components used in automobiles and aerospace. The deposition of energy in DED is accomplished by melting and fusing metal powders layer by layer, which makes it possible to create complicated shapes and repair damaged components. When it comes to the deposition of energy, DED has a number of benefits to offer, including the capacity to process huge build volumes and rapid deposition rates [27],[28]. Many applications of DED process in the remanufacturing industry were in the aerospace area: turbine blades, centrifugal compressor impeller, gas turbine bearing housing [29],[30],[31]. A problem of DED-based repair is the strength of metallurgical bond between, deposited layer and substrate, as well as the bond between the layers. The weak bond is caused by the bonding area porosity, microstructure, and residual strain. The tensile strength is determined by anisotropic microstructures and fracture propagation due to porosity. To prevent the emergence of pores and master the microstructures, one must govern the thermal gradient and cooling pace. This can be accomplished by meticulously picking the laser potency, scanning velocity, and particle provision rate [31],[32]. These parameters affect additive manufacturing solidification, particle size, and defect creation. Microstructure and porosity are affected by beam size, distance between holes, and gas pressure. Bonding strength must be evaluated for deposited materials, substrate geometries, and deposition-rate ranges. DED-based restoration requires exact form restoration and process parameters like laser spot diameter to build a product with a precise thickness [33].

Design for remanufacturing (DFR) is responsible for making remanufacturing a commonly utilized process. Without it, in most cases, remanufacturing would not be possible. Design for Core Collection (DFCC), Design for Disassembly (DFD), Design for Environment (DFE), and Design for Upgrade (DFUp) are the design rules for different stages of the remanufacturing process [34], [35]. Design for remanufacturing highlights developing items to make remanufacturing easier at the end of life [36]. The objective is to make it possible to disassemble, clean, repair, and reassemble things in an efficient and cost-effective manner so that they can be reused or sold again [37], table 1 provides a convincing illustration of this set of principles. Products can be constructed in a way that makes disassembly simple, the identification of parts that can be reused, and the procedures of remanufacturing more effective if the remanufacturability of the product is taken into consideration throughout the design phase [38], [39].

*Table 1*

**DFR guideline example**

| | |
|---|---|
| Design for functionality and upgradability [40] | Products should be designed with a focus on their core functionality and the ability to be easily upgraded |
| Modularization [41] | Modular components that can be easily disassembled and replaced |
| Platform design [41] | Platforms that allow for the reuse of common components across different product variants |
| Active disassembly [41] | Standardized fasteners and clear labeling of parts |
| Failure mode analysis [42] | Consider potential failure modes and design products to minimize the likelihood of failures |

Design for Environment (DFE) is a way to create products that tries to make them less harmful to the environment over their whole lives [43]. It involves incorporating environmental considerations into the design of a product, such as material selection, energy consumption, waste generation, and end-of-life (EOL) products disposal. DFD is the process of designing products with easily detachable components, standard fasteners, and plain labeling or marking of parts to facilitate their identification and sorting during disassembly. DFD aims to facilitate efficient and cost-effective disassembly processes, thereby decreasing the time and effort required to extract valuable components or materials from a product [43].

## 3. REMANUFACTURING CHALLENGES

Remanufacturing depends on consumer acceptance and perception. Studies [7, 45, 46] show that buyers may be wary of remanufactured products and require large reductions before buying them. Thus, longer warranties and acceptable price [45], [46] can encourage customers to buy refurbished products.

*Table 2*

**Challenges faced by remanufacturing [47]**

| |
|---|
| 1. Product complexity |
| 2. Technological advancements |
| 3. Legal framework |
| 4. Consumer perception |
| 5. Quality control |
| 6. Reverse logistics |
| 7. Component variation |
| 8. Economic viability |

Analyzing the remanufacturing challenges presented in Table 2, is easy to mention that remanufacturing can also succeed by evaluating and optimizing processes based on ecological efficiency, comprehensive benefits, and low-carbon design [47],[48],[49].

Modern items include complicated architectures, materials, and interconnected parts, making disassembly and reassembly harder. Remanufacturers have trouble accessing and dismantling components, and OEMs may use complicated procedures like ultrasonic welding to prevent disassembly, which increases time and labor costs [50].

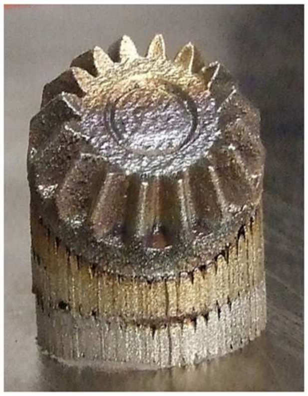

**Fig. 3** Sewing machine gear manufactured using SLM process [51]

Product quality can vary when remanufacturing used or returned products and, for example, using the proper manufacturing process good parts could be obtained (Fig. 3) [51]. The remanufactured products' quality and function depend on the components' condition. End-of-life products require a strong reverse logistics network. Collecting discarded products, organizing component migration, and engaging customers, manufacturers, and suppliers is logistically demanding [52]. Remanufacturing needs costly equipment, expert labor, and process optimization. A business plan that balances remanufacturing costs, market demand, and competitive price is tough. Overcoming these obstacles will promote sustainable remanufacturing.

## 4. FUTURE RESEARCH DIRECTIONS

Sustainable and green manufacturing requires remanufacturing, a future manufacturing trend. The worldwide remanufacturing business will increase demand for automotive industry, aerospace industry, parts, computer peripherals, and technology. Based on the literature, remanufacturing has several research and development priorities: Autonomous remanufacturing automates the process using advanced technology and robotics, this improves remanufacturing efficiency, affordability, and sustainability. The design of remanufacturing reverse logistics networks optimizes the collection, transportation, and processing of used products for remanufacturing. Research is also needed on the uncertainty of demand, supply, and product pricing models. Remanufacturing depends on technological advancements. Industry 4.0 technologies like IoT, VR, and AR can improve remanufacturing efficiency. These technologies increase remanufacturing decision-making, quality grading, and sorting. The remanufacturing sector faces both obstacles and possibilities as electric vehicles become more popular. Electric car components require the remanufacturing sector to adapt and create new capabilities.

## 5. CONCLUSIONS

Based on the studied references, the benefits of using remanufacturing process in different industries can be summarized as follows:

1. Remanufacturing has a big impact on the sustainability of the environment because it can reduce waste, save resources, and cut down on energy use and emissions. It is included in the circular economy strategy by making goods last longer and stopping the demand for new products.
2. By engaging in the process of remanufacturing, one can use components and substances from products that seem to reach their end of life. This practice reduces the necessity of extracting materials and manufacturing new items, thereby is save precious natural resources. It serves as a potent means to diminish the demand for landfill space and reduce the impact of waste on the environment.
3. Remanufacturing opens the door to wealth and happiness. This lets society reuse old parts

and materials, avoiding new output and its expenses. Remanufacturing might also create new skilled jobs and profitable economic opportunities by selling refurbished goods.

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**Tendințele actuale, concepte și provocări ale refabricării produselor industriale**

Epuizarea materiilor prime alături de creșterea poluării mediului înconjurător au fost principalii factori în dezvoltarea unui proces industrial benefic atât mediului înconjurător, cât și consumatorului. Reducerea consumului de energie și generarea unei cantități mici de dioxid de carbon reprezintă beneficiile cheie ale refabricării pentru mediul înconjurător, iar consumatorii sunt atrași de acest procedeu datorită accesibilității acestora la produse de ultimă tehnologie la un preț mult mai mic. Acest studiu evidențiază conceptele de bază ale procedeului de refabricare, oportunitățile și barierele unei afaceri bazate pe procesul de refabricare și tendințele actuale datorate tehnologiilor inovative de fabricare dezvoltate.

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