CLOSED CIRCUITS FOR POWERTRAIN COMPONENTS – RESOURCE EFFICIENCY THROUGH THE EXTRACTION AND PROCESSING OF SECONDARY SEMI-FINISHED PRODUCTS INTO NEW PRODUCTS IN FORMING PROCESS CHAINS

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Abstract

In order to be able to react to disruptions in global supply chains in a targeted manner, the development of process chains aimed at the repurposing of components in the powertrain of passenger cars is presented in this paper. Semi-finished products are obtained directly from end-of-life vehicles as secondary semi-finished products. After that, they are processed using bulk metal forming processes. For example, it shows how drive shafts can be reworked into connecting elements such as screws or gear racks in tie rods. Aspects to be considered are disassembling, separation and specific heat treatment if necessary to guarantee identical mechanical properties of the original product. On the one hand, this strategy contributes to significantly higher utilization. On the other hand, it demonstrates solutions for closing material cycles for automotive components.

Keywords: *power train, circular economy, repurpose, connectors, vehicle rod*

1. INTRODUCTION

The recycling of vehicles and the reuse of their components is becoming increasingly important in the context of global sustainability endeavours. The automotive industry is faced with the task of developing efficient vehicles while at the same time offering sustainable solutions for the end of their life cycle. Creating the conditions for vehicle components to be reused, either by reconditioning them for their original purpose or by processing them for other applications, offers the potential to significantly influence the use of resources, reduce the environmental impact and increase economic efficiency. The relevance of the topic of the high-quality circulation of components and materials also increases, taking into account the current political situation. Due to the changing global framework conditions, the following continuous trends can be observed with increasing importance in almost all economic sectors [1]:

- Scarcity of resources
- Increasing price of raw materials
- Limited availability of raw materials and components
- Stochastically interrupted supply chains
- Disposal, waste and contamination problems
- CO_2 emissions from production facilities
- Energy shortages and non-linear price increases
- Global population growth with increasing demand for consumer goods

State of the art

The aviation industry plays a pioneering role in the introduction of recycling and the further processing of high-quality components. Aircraft consist of a variety of materials and components that are not only costly but also resource-intensive to manufacture. Recycling can promote sustainable practices that offer both economic and environmental benefits.

a) https://jacobmetal/de/recycling/services/flugzeugturbinen b) https://gbsalvage.com c) https://www.aeroexpo.online/de/prod/pratt-whitney/product-170325-49701.html

Fig. 1. a) aircraft engine, b) turbine, c) landing gear

At the beginning of this recycling process, high-quality assemblies such as engines, landing gear or fan blades (Fig. 1) are specifically dismantled from end-of-life aircraft in order to be re-used or re-manufactured. Thus, they are transformed from old components and structures into new products [2]. This concept plays a key role in reducing waste and improving resource efficiency. Increasing the use of recycling in aviation can help reduce resource consumption and waste production. This strategy also means that new products can be manufactured with a smaller environmental footprint. Mastering recycling and further processing will play a key role in determining how the aviation industry can meet future challenges. The reduction of environmental pollution and the realisation of economic potential must also be seen in this context.

In contrast, the recycling of end-of-life vehicles is based almost entirely on the recovery of secondary raw materials, based on the separation of the type of the material (e.g. steel, aluminium). Until now, the reuse of components from end-of-life vehicles has mainly consisted of utilising these components for vehicle types that correspond to the original. Examples of this are complete engines or engine components, drivetrain and exhaust system components, equipment components and wheels. The main motivation here is to save costs for the user compared to new spare parts. However, these components are currently only used in the aftermarket and are not used in the industrial production of new vehicles.

Own preliminary work

Various technologies have been developed and tested at the Fraunhofer IWU to reduce energy consumption and the emission of environmentally harmful greenhouse gases based on innovative concepts for the release of thermal and mechanical joints: In collaboration with the Mercedes-Benz Group AG, a technology was developed that allows welded joints, preferably of powertrain components, to be separated without damaging the active surfaces of the gears and then re-welded after regeneration [3]. Furthermore, a technology for the non-destructive disassembly of laser-brazed car bodies was developed as part of an EU project [4, 5]. Using a temperature-controlled laser processing process, the brazed seam is liquefied in a temperature range of approximately 950 – 1000 °C and blown out of the joining zone using a specially developed gas nozzle. The patent for this innovative technology has been published [6]. An integration of the technologies into building blocks of production systems (“dismantling cells”), robot-based automation modules or the consideration of the impacts or acceptance of remanufacturing in car supply chains are completely missing in these approaches.

In his dissertation [7], Choudry developed a selection methodology for optimized decision-making regarding joining technologies in car body construction. The goal was to enable optimized decision-making in car body development through a multidimensional evaluation matrix. This principle is to be transferred to remanufacturing processes. Disassembly strategies for mechanical joints were investigated in concept studies, among others, focusing on the following key topics. As part of internal preliminary work, prototype functional models for rivet elements were created using generative manufacturing technology. These prototypes combine the process-related advantages of self-piercing riveting processes (short process time) with a detachability function. Thread-like geometries, for example, can enable the rivet elements to be unscrewed with minimal damage. The setting process for such elements, however, is not performed by screwing in, as with screwing, but by pressing in using joining pliers. Other concepts envisage a split structure of connectors that can be unlocked during disassembly. This can be achieved, for example, through bayonet-like locking systems or push-button-like mechanisms. For example, as part of a diploma thesis, a functional model for a plastic clip was developed that can be triggered using an SMA wire [8] [9]. In terms of remanufacturing, special boundary conditions arise, particularly in mechanical, forming and joining. The reason is that knowledge of the technological-mechanical properties of the recovered components is subject to uncertainty. In these cases, it is necessary that the joining processes used for reuse are robust against fluctuations in strength, ductility, and sheet thickness. This is not the case for most processes, such as self-piercing riveting and clinching. As part of an IGF research project 132015 [10], self-piercing riveting was developed. This process exhibits high flexibility with regard to the aforementioned adherend properties and its potential for joining recovered components needs to be investigated. Increasing the remanufacturing potential through forming technologies for the reprocessing of metal components/assemblies was investigated within the reProd® approach, which describes the direct return of products to new production and usage cycles [11], and the "CarE-Service" project [2]. The use of secondary raw materials as semi-finished products for the manufacture of new products with high utility or added value was investigated in a reprocessing concept for automotive sheet metal parts. The implementation of these strategies was successfully demonstrated using demonstrators, e.g., the production of a seat component or a brake shield from a car roof [12]. Another development focus in forming technology is the development and qualification of resilient process chains for formed components. Within the framework of this project, the conception of forming process chains based on alternative semi-finished products was applied. The demonstrator was used to implement the forming technology for the production of a screw (in the example ISO 4017 M24) from a car drive shaft within the innovation program, RESYST, topic cluster 3: "Resource-efficient production processes to increase resilience" [13].

2. METHODS AND APPLICATIONS

2.1. Resource-efficient production processes to increase resilience

In order to be able to fulfil short-term and temporary requirements as quickly and cost-effectively as possible in terms of resilience, it is necessary that alternative materials, semi-finished products and any necessary process modifications are already sufficiently known. Consequently, alternative production can begin as quickly as possible. In addition to know-how about the manufacturing process and any modifications, this requires a comprehensive database of the materials and semi-finished products that can be used.

The following global project objectives were formulated based on the state of the art:

- Identification of components that can be recycled with or without reprocessing
- Securing the properties of such components (service life) [14]
- Processes, technologies and methods required to manufacture and guarantee the component properties
- Overall evaluation of the concepts

Based on these project objectives, the demonstrator 'screw' ISO 4017 M24x180, material 42CrMo4 was selected. This is a classic representative, produced by process stages of a forming process chain (hot/cold) supplemented by machining and heat treatment.

The basic process chain (Fig. 2a) consists of the following production steps: cutting to size, upsetting the head (hot forming), heat treatment, followed by calibrating the diameter (machining) and the final thread rolling, a cold forming process.

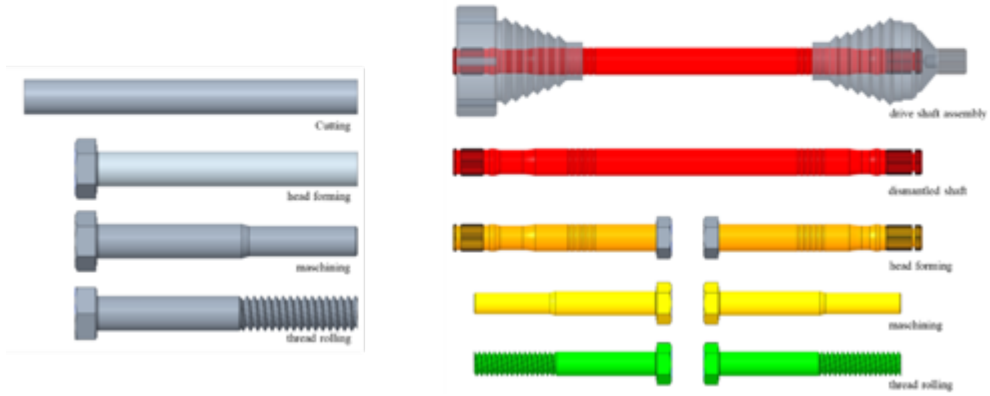

Fig. 2. a) Process chain screw manufacturing schematically, b) from secondary semi-finished product

Focus of the research project was the investigation of concepts for alternative forming process chains in order to respond to potential disruptions to global supply chains. One promising alternative is a process chain based on secondary semi-finished products (Fig. 2b). Semi-finished products are obtained directly from used parts and processed further. A car drive shaft (Fig. 3), from which high-strength screws could be obtained, is used to demonstrate such a realisation. The disassembly process is followed by a cutting process as well as hot forming and heat treatment processes. With subsequent machining and the use of a cold forming process for thread production, high-strength screws with identical mechanical properties to the original product could be produced.

Fig. 3. Process chain reProd® screw manufacturing – real parts

The challenge here was the complex interaction of mutually influencing factors, such as material composition, material structure, mechanical properties, forming behaviour, thermal process control and the final component properties. Knowledge of the material properties of the semi-finished product and finished part serves to adapt the manufacturing process to the new semi-finished product. It also provides evidence of the desired final product properties of the screw. For this purpose, material parameters were determined by means of tensile and hardness tests. The material flow behaviour was determined by means of compression tests and the microstructure was analysed. The tests were carried out comparatively on 4 gear shafts (1xnew, 3xold). Figure 4 summarises the tests carried out, their results and the sampling from the drive shaft. On the basis of these investigations, it was possible to show that all production and application-relevant properties of various drive shafts at the end of their component life do not differ significantly from those of new drive shafts. Their material can be reused without restriction in the sense of a circular economy after suitable heat treatment.

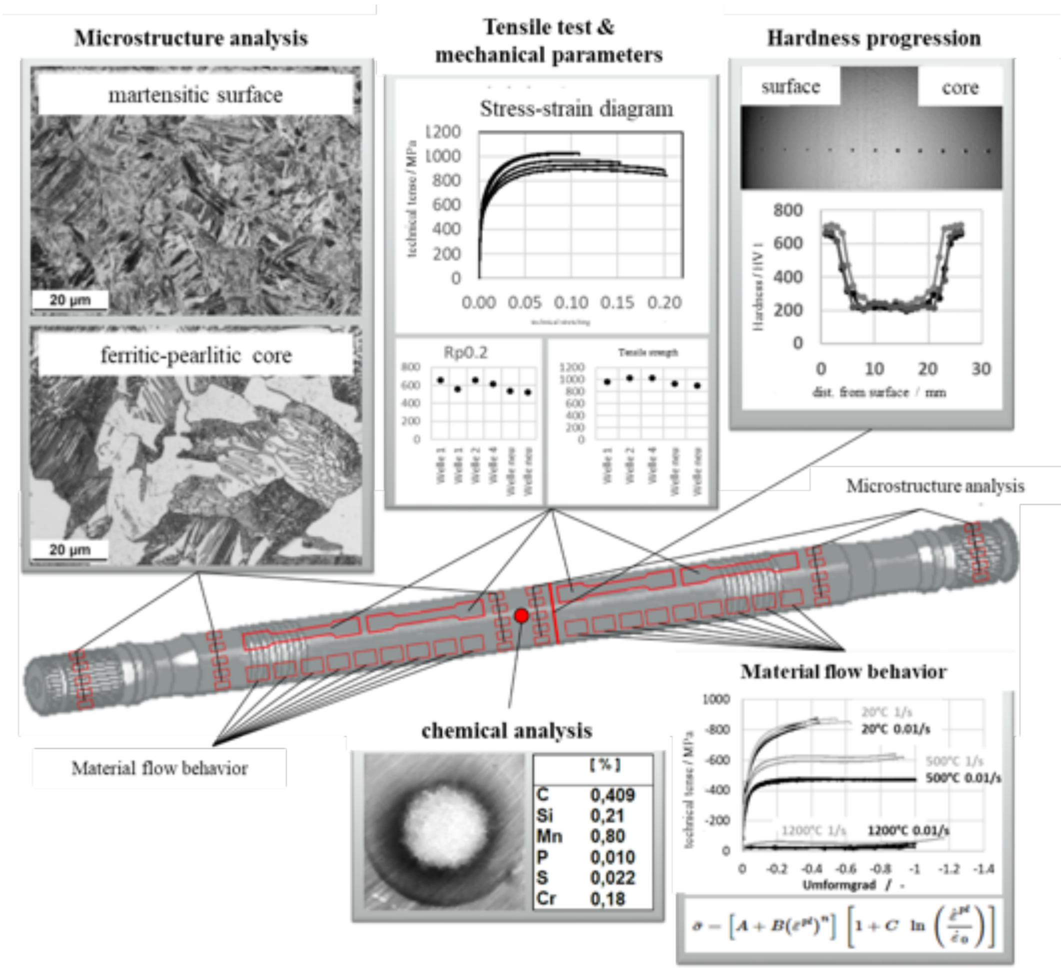

Fig. 4. Schematic representation of the sampling procedure from one of the four drive shafts tested and an overview of the tests conducted and their results

The local microstructure and property distribution of the resulting screw was also analysed. Fig. 5 shows the spatially resolved hardness distribution in a longitudinal section through the screw as well as two of the microstructure images. The hardness and microstructure in the screw core are comparable with the core material of the drive shaft. The local microstructure and property distribution results from a large number of parameters during the manufacturing process and the unknown as well as possibly highly scattering properties of the secondary semi-finished product. For this reason, the spatially resolved property description in a suitable data form (product and material twin) is of central importance for continuous further processing in the product cycle.

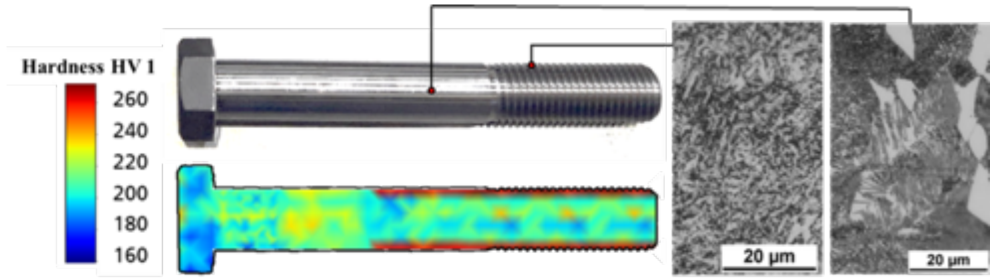

Fig. 5. Left: Spatially resolved hardness distribution in a longitudinal section through a screw made from a drive shaft; Right: Microstructure in the thread land and in the screw core

By producing a demonstrator screw from an old car drive shaft, which has identical mechanical properties to the original product, it was possible to show that car drivetrain components do not necessarily have to be recycled via the blast furnace. The high potential for CO_2 savings through direct recycling compared to a process chain with primary forming process was also clearly demonstrated. However, in order to realise this in an ecologically and economically sensible way, the processes must be considered holistically, i.e. both technology and possible business models. The recycling of components must also be geared towards real needs in order to establish a circular economy in automotive production in the future. A research project should start here to make this process economical and to make a significant contribution to transferring such an exemplary process into a series application.

2.2. Efficient and economical cycle-orientated dismantling and reconditioning

As part of the EKODA [15] research project, technologies and business models were developed that are understood as high-quality recycling of components and materials in the production environment of motor vehicles. This is intended to contribute to a significantly higher utilisation of resources and an increase in resilience through alternatives in supply chains. Taking into account the objectives of the EKODA project, one focus is on closing material cycles through efficient and economical dismantling and industrial reprocessing (re-manufacturing) of automotive components.

Two use cases were considered to demonstrate the methods and technologies developed. Use case I was focussed on the automated dismantling of a typical car battery storage system, while use case II contained the dismantling of a powertrain component.

Use case II was also used to demonstrate component recycling. Here, both direct recycling in analogue performance and local reworking as the simplest manufacturing approach through to reworking were considered theoretically. A process chain for recycling a steering gear component was implemented using a forming process chain. Using the example of the steering rack component (see Fig. 6), the potential for closing material cycles to establish a circular economy in automotive production was demonstrated.

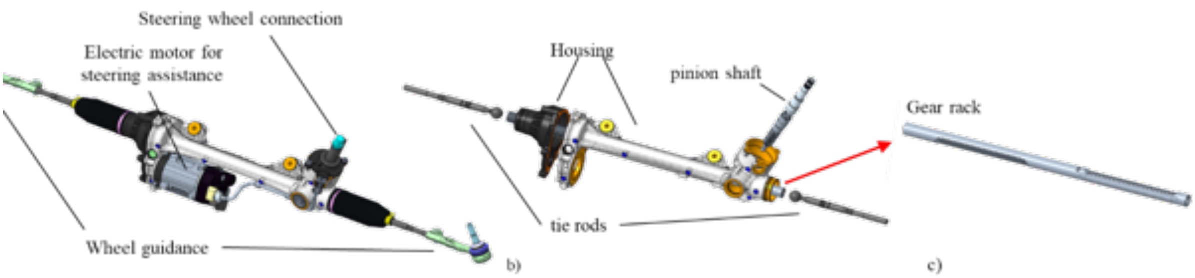

Fig. 6. a) steering gear, b) steering gear main components, c) gear rack

After selecting a specific component, in this example the gear rack, the condition was determined and assessed, focussing on wear (e.g. dimensional deviation), damage (e.g. cracks) and corrosion. Based on this result and the expected future demand, the question arose as to the utilisation strategy to be applied (refurbish, remanufacture, repurpose, recycle). The aim was to identify a preferred scenario (process chain) with the help of a comparison of variants based on criteria such as CO_2 savings potential, technological feasibility and economic effects. The result of this comparison was a process chain for repurposing the racks into two steering racks for a next-generation steering system (Fig. 7).

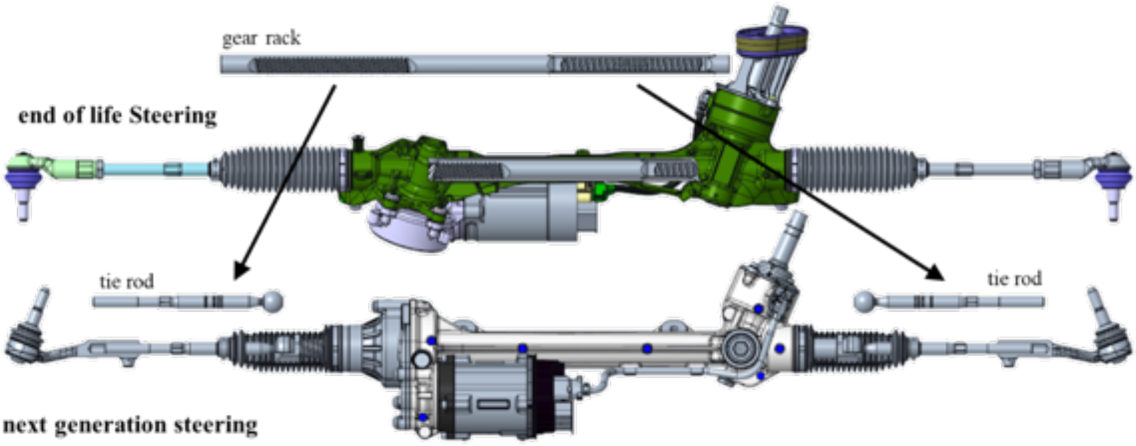

Fig. 7. Repurpose process

A process chain (Fig. 8a) consisting of established forming and machining processes was developed to manufacture the demonstrator. Simulations (Fig. 8b) were used for process design, process optimisation and feasibility assessment. In the area of forming technology, further emphasis was placed on the design of tools and the identification of suitable forming units. Based on the simulation results, guidelines for designing the tool engravings were created. Once the tool had been produced, the forging tests could be carried out.

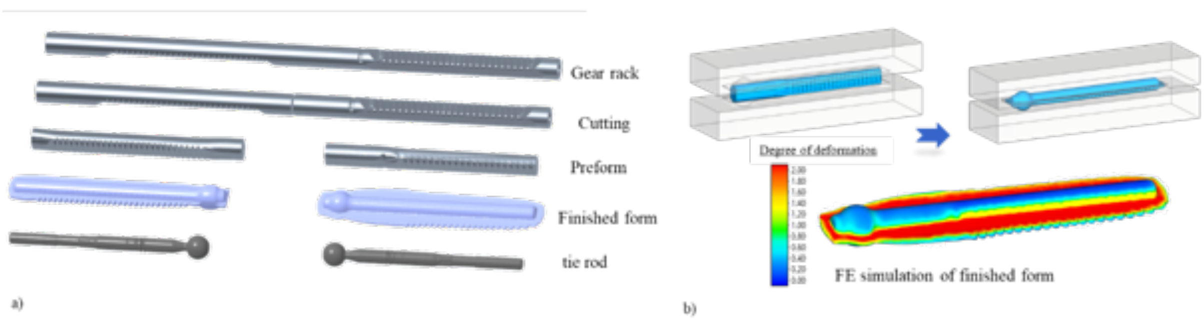

Fig. 8. Process chain and forming simulation

For this purpose, the rack sections were heated to 1100 °C in a rotary hearth furnace and inserted into the forging tool. This was followed by the two forming stages and the removal of the forged part. This was followed by deburring and machining of the forged parts to produce the steering racks (Fig. 9).

Fig. 9. Demonstrator EKODA, repurposing of one gear rack to two tie rods

3. DISCUSSION AND CONCLUSIONS

The demonstrated process chain for the reutilisation of powertrain components showed how the product life cycle/cycle can be closed in the future and how high-quality parts or components of an assembly can be reused directly or after reprocessing. With this approach, a contribution can be made to solving many of today's central problems (resources, availability, energy, CO_2). A basic concept has been developed which generates systematic, high-quality recycling for mass-produced automotive products. The product cycle consists of the recovery of part of the raw material (steel), which is not recycled via the blast furnace route. It will no longer represent a waste of resources in the future, but can be directly reutilised.

To summarise, the aim of future work is to work out the potential of the selected strategy with regard to closing product life cycles. Using the example of the selected demonstrators, which were also subjected to the corresponding component tests, the effects on reducing the use of resources and CO_2 emissions could finally be demonstrated and further optimisation potential identified.

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