RESEARCH ON SUSTAINABLE RECYCLING AND APPLICATIONS ON METALLIC PRODUCTS

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ABSTRACT: Recycling waste from various processes has been an important strategy for increasing material efficiency. There is highlighted a series of relevant elements concerning product recycling, such as material efficiency, material cycle, end-of-life items, circular economy, etc. Theoretical development on recycling a certain product, as a hook assembly, is structured and presented, evidencing important influencing factors, such as constructive characteristics of the product components as well as technological elements on recycling through casting, forging, and refining for recovering rare and valuable metals. In perspective, it is to determine all important technical and economic data in order to achieve optimal recycling.

KEYWORDS: recycling, product cycle, circular economy, end-of-life products, hook assembly

1. Introduction

Promoting sustainability and decreasing waste in industrial systems requires a strong focus on material efficiency. Although it has its limitations, recycling waste from various processes has been a popular strategy for increasing material efficiency. Instead, it is preferable to approach material recycling from a product-centric perspective. This method encourages closed-loop recycling and a circular economy by considering all systemic factors and material combinations used in any given product. A recycling development on an effective metallic product, such as hook assembly, reveals potential benefits.

2. Generalities

Material efficiency

Material efficiency refers to using natural resources efficiently and reusing waste and by-products. Recycling waste from other processes has been a common approach for improving material efficiency, but this approach has some limitations as it does not consider the complexity of recycling in industrial systems. A better approach is to look at material recycling from a product-centric perspective that incorporates all the systemic aspects, having at its core the material combinations present in any product [1].

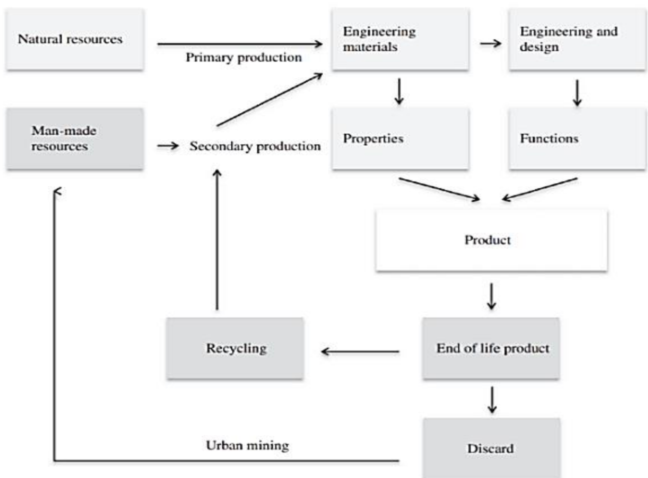


Fig. 2.1. Product-oriented material cycle including primary and secondary sources [1]

Material cycle

Material cycles are complex. Ore mining produces most metals for use. Ores are concentrated into metals and alloys with specified characteristics. Metallurgical operations can recycle most base metals after separation. Complex metal-containing recyclable streams from man-made sources must be prepared, e.g., shredded, and separated into generic categories. The metal-containing fractions can be recycled into metals (Fig. 2.1) [1].

End-of-life products

End-of-Life (EoL), also known as waste, is the state in which a product is no longer usable. Rare and valuable metals are necessary for modern technology and infrastructure, but their supply is limited, and their mining and refining can have negative environmental effects. End-of-life items are collected, sorted, dismantled, and processed to extract precious metals for recycling to reduce these problems. With existing technology, not all end-of-life items can be recycled, and metal losses may occur along the cycle [2].

The life cycle of metals, beginning with the first time that metals were utilized in goods and continuing all the way up to the point where metals are considered waste and may or may not be recycled, as presented in Fig. 2.2, where the arrows are used to show the many stages of this cycle and to indicate how metals move through the system [3].

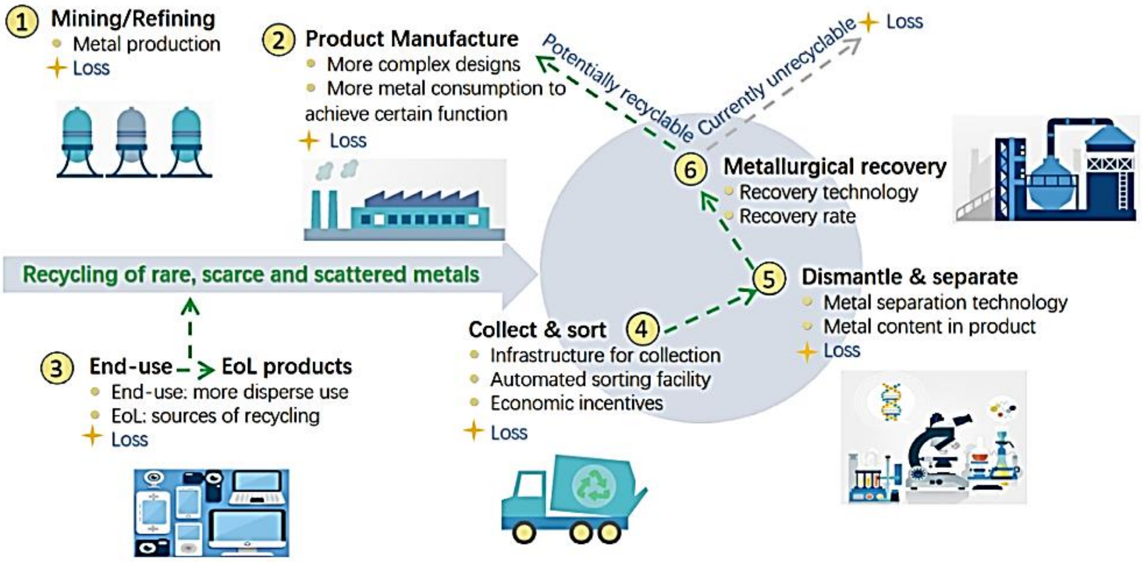


Fig. 2.2. Framework of the recyclability of rare and valuable metals in their life cycle [3]

Circular economy

The use of closed-loop recycling in the metal-mechanical sector is essential for advancing the circular economy (CE) and lowering emissions of pollutants and waste disposal. Even though businesses frequently put profit first, in this case, the environmental impact is more important. Industry managers can be motivated to adopt critical eco-friendly actions by doing research on closed-loop recycling. By monitoring the economic and environmental performance of recycling activities, they may assess the relationship between environmental and economic indicators, highlight CE initiatives, and gain a competitive edge. Adopting a micro-level approach not only promotes significant social-technical collaboration in decisions concerning industrial waste management but also supports sustainable solutions [4].

3. Case study

The present study case is concentrated on the recyclability of a particular product, the Hook H.100.00, which is a hook assembly utilized in a variety of applications.

The Hook H.100.00 assembly consists of identical or distinct components, as presented in Fig. 3.1 and Table 3.1.

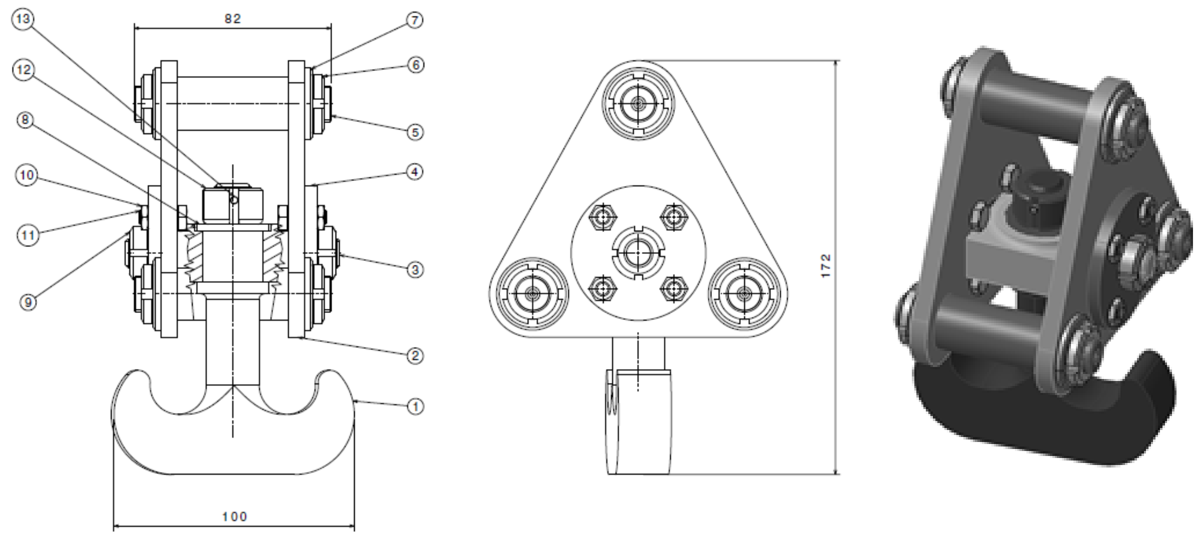


Fig. 3.1. Hook H.100.00 [5, 6, 7]

Table. 3.1. Data on components of the Hook H.100.00

Position no.	Designation	Qty	Reference (Standard or Drawing no.)	Material	Mass, kg
1	Hook	1	H.100.01	G20Mo5	0.744
2	Plate	2	H.100.02	C45	0.448
3	Hook support	1	H.100.03	S355JR	0.307
4	Flange	2	H.100.04	C45	0.112
5	Spacer shaft	3	H.100.05	C45U	0.193
6	Lock nut M15	6	ISO 2982	X5CrNi18-10	0.001
7	Washer	6	ISO 7089	25CrM04	0.001
8	Bush	1	H.100.08	C45	0,038
9	Lock nut M12	2	ISO 2982	X5CrNi18-10	0.002
10	Bolt M6x6	8	ISO 4017	S355GP	0.004
11	Nut M6	8	ISO 4035	X5CrNi18-10	0.002
12	Lock nut	1	H.100.12	G26CrMo4	0.032
13	Pin 3x26	1	ISO 2338	S355GP	0.001

It is to be noted that the materials prescribed for the Hook H 100.00 product components are all types of steel.

Some relevant general characteristics of the materials prescribed for the components of Hook H.100.00 are presented in Table 3.2.

Table 3.2. Relevant general characteristics of the materials prescribed to the Hook H.100.00 components [8, …]

Material	Chemical composition, %	Steel category
G20Mo5	0.20 C, max. 0.6 Si, 0.75 Mn, 0.50 Mo, max. 0.3 Cr	Medium-alloy steel (Cr-Mo) for casting, normalizing and tempering
G26CrMo4	0.26 C, max. 0.6 Si, 0.65 Mn, 0.23 Mo, 1Cr	
S355JR	max.0.24 C, max. 0.55 Si, max.1.6 Mn, max. 0.47 CE	Non-alloy steel (C-Mn) for: die forging; normalizing/quenching and tempering
S355GP	max.0.27 C, max. 0.60 Si, max.1.7 Mn	
C45	0.45 C, max. 0.4 Si, 0.65 Mn, max. 0.63 (Cr+Mo+Ni)	
C45U	0.45 C, 0.28 Si, 0.7 Mn	
25CrMo4	0.25 C, max. 0.4 Si, 0.75 Mn, 0.23 Mo, 1.05 Cr	Medium-alloy steel (Cr-Mo) for: die forging; quenching and tempering
X5CrNi18-10	max. 0.07 C, max. 1 Si, max.2 Mn, 18.5 Cr, 9.2 Ni	Austenitic stainless steel (18-10) for: casting

In the recycling perspective, the symbols, standards, and main possible technological uses of the considered materials are as presented in Table 3.3.

Table 3.3. The symbols, standards and main possible technological use of the materials prescribed to the Hook H.100.00 components [8, …]

Material		Main possible technological use				
		Part of mixes for *casting*	Manufacturing		Heat treatment	Refining
Symbol	Code		*Casting*	*Forging*	*Normalising/ Quenching* and *tempering*	
M1	G20Mo5 (1.5419) EN 10213:2007	x	x			
M2	G26CrMo4 (1.7221) SR EN 10293:2015	x	x			
M3	S355JR (1.0045) SR EN 10025-2:2019	x		x	x	
M4	S355GP (1.0083) SR EN 10248-1:1996	x		x	x	
M5	C45 (1.0503) SR EN ISO 683-1:2018	x		x	x	
M6	C45U (1.1730) SR EN ISO 4957:2018	x		x	x	
M7	25CrMo4 (1.7218) EN 10083-3: 2007	x		x	x	
M8	X5CrNi18-10 (1.4301) SR EN 10088-1:2015	x (for stainless steel casting)	x			x

A typical recycling technology applicable to the hook assembly is represented by the sequence of collecting, sorting, and shredding operated by a specialized recycling company. However, the case study focuses on a close-loop recycle technology, and from this perspective, we are interested in defining a close-loop technological way of recycling resulting in a specific series of material types. That is, by not involving a specialized recycling company, we pursue increasing the sustainability index.

Let's consider that, in general, at the end of the product cycle, the companies that can recycle Hook H.100.00, totally or partially, are:

- the company that has used the Hook H.100.00, i.e., CH,
- one or more external companies, i.e., EC.

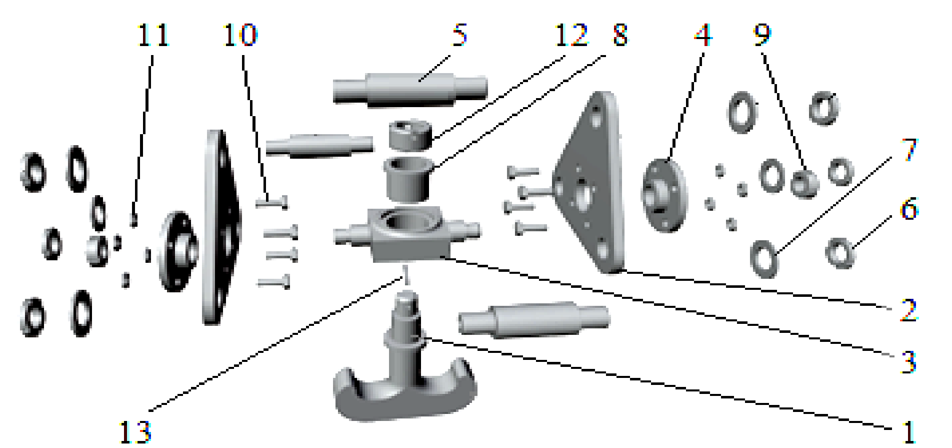
In the context of the actual data, it is assumed that, within the recycling of *components* from one or more Hook H.100.00, the technological actions or transformation processes that can be taken into consideration are the followings:

- adding components as part of mixes for casting, PMC,
- casting of similar or different components, using scrap hook components as raw material, i.e., CSC,
- forging of similar or different products, i.e., FSDP,
- stainless steel re-melting to recover Cr and Ni, i.e., RRCN.

Taking into account the material and the specific sizes/ mass of the Hook H.100.00 components, the possible companies, CH, CE, and, implicitly, the possible technological actions or transformation processes, PMC, CSC, FSDP, RRCN, and the recycling variants, RV_i, $i = \overline{1, r}$, are considered as presented in Fig. 3.2.

The recycling variants group, RVG, can be written [9] as:

$$RVG = \{RV_i \mid i = \overline{1, r}\} \Leftrightarrow RVG = \{RV_1, RV_2, \ldots, RV_i, \ldots, RV_r\} \tag{3.1}$$



Recycling	EC	RRCN											○	○	○
		FSDP			●			●	●		●				
		CSC	○												
		PMC	●	●	●	●	●	●	●	●	●	●			
	CH	RRCN											○	○	○
		FSDP			●			●	●		●				
		CSC	○												
		PMC	●	●	●	●	●	●	●	●	●	●			
Components of Hook H.100.00		Mass, kg/pc	0.744	0.023	0.307	0.004	0.001	0.448	0.112	0,038	0.193	0.001	0.001	0.002	0.002
		Material	M1	M2	M3	M4		M5			M6	M7	M8		
		Qty	1	1	3	8	1	2	2	1	3	6	6	2	8
		Designation	Hook	Lock nut	Hook support	Bolt M6x6	Pin 3x26	Plate	Flange	Bush	Spacer shaft	Washer	Lock nut M15	Lock nut M12	Nut M6
		No.	1	12	3	10	13	2	4	8	5	7	6	9	11

Fig. 3.2. Recycling variants on Hook H.100.00 components

Each recycling variant RV_i will be evaluated based on the *profit* obtained by the CH company interested in recycling the considered product, Hook H.100.00. Thus, the profit, P_i, $i = \overline{1, r}$, will be calculated for each recycling variant as being in direct relation to the sustainability index, not only as a financial term.

Among the group RVG of recycling variants (see eq. 3.2), the *optimal recycling variant*, ORV, is the variant RV_0 for which the correspondent profit is the maximum, i.e.,

$$P_0 = \max\{P_1, P_2, \ldots, P_i, \ldots, P_r\} \Rightarrow ORV = RV_0 \quad (3.2)$$

In perspective, it is necessary to determine the influencing technical factors as well as the calculus data associated with costs, revenues, profits, etc. concerning the recycling of the considered product, Hook H.100.00, but also, in general, for products recycling, in order to achieve the optimal recycling variant.

4. Conclusions

The result of this research suggests a sustainable approach to industrial waste management and material efficiency in order to build a circular economy and reduce waste's environmental impact. Recycling waste in various ways has its limits, so a better way to support closed-loop recycling and a circular economy is to focus on what is being recycled.

For sustainable recycling of metallic products, it is necessary to analyze various influencing elements. The Hook H.100.00 assembly can be challenging to recycle since it is made up of different types of steel.

The theoretical approach to recycling an effective product as a hook assembly, reveals important influencing factors such as material and geometrical characteristics prescribed to the product components, as well as main technological uses, actions, or transformations.

Further research and development should determine all important technical factors, as well as the economical calculus data concerning the products recycling in order to achieve the optimal recycling solution in each particular case.

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