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Research Article

Waste and hazardous material handling at green ship recycling facilities

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Abstract

The study aims to develop requirements for handling waste and hazardous materials at green ship recycling facilities in Indonesia. Since the implementation of the cabotage principle in 2005, the number of ships in Indonesia has increased significantly from 6,041 in 2005 to 37,722 in 2022, with 20 percent of them being over 30 years old. This creates a significant potential for ships that are no longer economically suitable for operation and need to be recycled. Additionally, there has been a continuous increase in domestic steel demand, for which raw materials could be supplied from the scrapped steel of old ships. Despite the abundance of old ships and the demand for steel, Indonesia has not been able to utilize the opportunity, because the ship recycling industry is far from compliant with the required international standards, in particular the Hong Kong Convention, and which compliance is urgently needed, especially in conjunction with the its upcoming entering into force on 26 June 2025. Ship recycling facilities in Indonesia are still behind concerning the handling of waste and hazardous materials, which is a crucial aspect in complying with international regulations. A literature study and in-depth discussions with experts in the field of ship recycling were carried out to compare the international regulations related to ship recycling with current Indonesian conditions and, based on the findings, the requirements for handling waste and hazardous materials were developed. It is concluded that the procedure would include planning for ship recycling process flow, identifying waste and hazardous materials, and deciding requirements for handling waste and hazardous materials. It is expected that the requirements would contribute to the development of Indonesia's ship recycling industry to comply with the international regulations and gain international recognition.

1. Introduction

Since the implementation of the cabotage principle, based on the Presidential Instruction Number 5 of 2005 on the Empowerment of the National Shipping Industry, and Law Number 17 of 2008 on Shipping, the size of the national flagged ships fleet has continued to increase, with an average growth of 9.24 percent per year. According to data from the Ministry of Transportation of the Republic of Indonesia, in 2022, the total merchant ships in Indonesia amounted to 37,722 vessels (Rizaty, 2022). This amount has increased sixfold compared to the number of national flagged ships when the cabotage principle was first implemented in 2005, which were 6,041 units. According to the Indonesian National Shipowners' Association (INSA), as quoted by Rahayu (2022), among all vessels, 40 percent of them are aged between 20 and 30 years, while 20 percent of them are over 30 years old. These data indicate the high number of old ships, which are reaching the end of their operational life.

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On the other hand, there is an increasing demand for steel in the international market. The Chairman of the South East Asia Iron & Steel Institute (Syahputra, 2023) projected that global steel demand is increasing at least 1.1 % in 2023, reaching around 1.8 billion tons, and according to Andi (2022), steel consumption is expected to grow by 5 percent to reach 16.3 million tons. Domestically, in 2022, based on the data published by the Indonesian Iron and Steel Industry Association (2022), imported steel raw materials, mostly in form of scraps, have increased by 4 percent, exceeding 6 million tons. The growing demand for steel can be met through the recycling of old ships, as most ships are 90 % made of high-quality steel, allowing it to be recycled in steel mills and reused for various purposes.

With regard to ship recycling activities, at the international level, since June 26, 2023, the required criteria for the International Maritime Organization's (IMO) treaty for safe and environmentally sound ship recycling, the Hong Kong Convention, to enter into force have been fulfilled. Therefore, the Hong Kong Convention will enter into force on 26 June 2025 (International Maritime Organization, 2023). It would be regrettable if Indonesia, as a country with increasing large number of old ships, and geographically located in a strategic maritime shipping route, does not prepare itself for the enforcement of the Hong Kong Convention, resulting in a potential loss of market opportunities in the ship recycling industry and the risk of sanction from the IMO. Therefore, the development of the ship recycling industry in Indonesia is urgently needed to enable the country to leverage the international market potential of ship recycling while meeting the domestic steel demands and increase its competitiveness. To do this, as Sunaryo et al. (2021) stated, the Indonesian government is preparing to ratify the Hong Kong Convention and to be included in the European Union's Ship Recycling Facility (EUSRF) List. This is challenging, considering the current condition of the ship recycling industry in Indonesia, which is still far from meeting the standards outlined in the Hong Kong Convention, especially with regard to the handling of waste and hazardous materials. Although the handling of waste and hazardous materials (HAZMAT) are crucial aspects to be considered for compliance with international regulations, unfortunately, there have been no sufficient studies on these subjects.

Considering the above argumentations, the research is aimed to develop requirements for the handling of waste and hazardous materials at green ship recycling facilities in Indonesia as an important aspect to comply with the international standards. It is expected that the requirements would contribute to the safety and health of the workers, and the cleanliness of the environment, and would make Indonesia's ship recycling industry gain international recognition and obtain an international market increase.

2. Materials and methods

This research was conducted using a literature study through reviewing publications on previous studies and reviewing international and national regulations, along with in-depth discussions with experts in the field of ship recycling, especially with regard to the handling of waste and hazardous materials

It was expected that, from the previous studies, references could be obtained on how far the issues of waste and hazardous materials handling in ship recycling industry have been studied, and therefore be used to support the research. The purpose of investigation of related international and national regulations is to gather all relevant requirements that should be fulfilled by ship recycling facilities to be qualified as "Green Ship Recycling Facilities", and to be used for conducting a gap analysis, as the base for developing the study. In-depth discussions with experts are needed to obtain information on how the challenges should be met, and an implantation strategy should be carried out.

The following aspects were identified, both from the literature study and the discussions, that should be included in this study:

- Categories of waste and hazardous materials in ship recycling processes.
- Specific waste and hazardous materials generated from ship recycling activities.
- Safety and health of workers, and environmental impacts of waste and hazardous materials

on workers in ship recycling activities.

- Requirements for waste and hazardous materials handling.

2.1 Green ship recycling

Based on the information obtained from the reviews on regulations, guidelines, and conventions related to ship recycling, the term "green ship recycling" is introduced by the Hong Kong Convention (International Maritime Organization, 2023) as the enhancement of its former definition on ship recycling, which stated that ship recycling is the activity of dismantling a ship wholly or partially at a ship recycling facility to retrieve components or materials for reuse. The process involves handling hazardous substances and other materials, including related operations such as storage and maintenance of components and materials on the ship, but does not involve further processing or disposal at the ship recycling facility. Referring to feedback from various international organizations such as the International Maritime Organization (IMO), the International Labour Organization (ILO), and the United Nations Environment Programme (UNEP), the term "green ship recycling" represents a modernization of previous conventional terms such as ship scrapping, ship breaking, ship decommissioning, ship deconstruction, and ship de-engineering, as stated by Akriananta and Suastika (2017). The difference between conventional ship recycling and green ship recycling lies in the implementation and adherence to more ideal standards compared to those previous terms. According to IMO Guidelines on Ship Recycling (International Maritime Organization, 2023), green ship recycling pays more attention to the safety and health of workers, as well as environmental cleanliness from pollution that arises during the ship recycling processes.

2.2 Condition of Indonesian ship recycling industry

Referring to the findings by Sunaryo et al. (2021), in general, there are two types of ship recycling facilities, i.e., conventional ship recycling, which mostly implements a beaching method for landing the ships, and employs manual workers to dismantle the ships, without any care for the safety and health of the workers, or consideration of the impact to the environment; and semi-modern ship recycling, which starts to attempt to comply with the existing national and international regulations, and gains status as a green ship recycling facility, among other things, by implementing a dry docking method for landing the ships, using more modern facilities, tools, and equipment, putting more attention on the safety and health of the workers and the cleanliness of the environment, mandating the workers wear proper personal protection equipment (PPE), and gathering the waste and HAZMAT in proper storage areas.

Based on the study by Fariya et al. (2023), there are five stages commonly applied in carrying out ship recycling in Indonesia, namely:

- The arrival and administrative process stage: Before sending the ship for recycling, several specific documents should be prepared.
- The preparation stage: After the documents are prepared, the end of life (EOL) ship will be transferred to the ship recycling facility. Once the ship arrives at the facility, the facility will prepare the docking procedures.
- The cleaning and primary cutting stage: After the ship is ready, workers will start the cutting process. They clean and cut the ship simultaneously. During this stage, the ship will be cleaned of easily combustible materials, equipment, and hazardous substances.
- The secondary cutting stage: After being cut in the primary cutting zone, ship sections will be sent to the secondary zone for further cutting into smaller pieces.
- The separation stage: The separation process is carried out for steel pieces, recyclable materials, reusable components, and waste.

During the cleaning and primary cutting stage, the ship will be cut into blocks, and all waste, especially hazardous materials, will be removed. The waste should be temporarily stored in specific storage areas to prevent any negative impacts on the environment and the workers. Unfortunately, as

highlighted in the study by Sunaryo et al. (2021), in Indonesia, there is still a significant lack of regulation concerning the handling and storing of waste and hazardous materials at ship recycling facilities, which therefore creates a challenge for the industry to comply with the international regulations, in order to gain international recognition and increased global market share.

2.3 Ship recycling facility

According to IMO Guidelines on Ship Recycling Resolution A.962(23), a Ship Recycling Facility (SRF) is a location, yard, or facility used for the recycling of ships, which is authorized or permitted for this purpose by the competent authority of the country where the location, yard, or facility is located. Based on the Basel Convention: Technical Guidelines for the Environmentally Sound Management of the Full and Partial Dismantling of Ships (United Nations Environment Programme, 2023), an SRF consists of several areas or zones, namely:

- Containment, for initial containment (docking area)
- Zone A or primary block breaking area or primary cutting, including activities for oil (sludge) and fluids removal, dismounting of re-useable equipment, cutting of large ship segments, removal of asbestos and batteries, emptying fire extinguishing systems, and removal of CFCs from cooling systems.
- Zone B or secondary block breaking area or secondary cutting, including activities for primary sorting of components and further cutting into suitable size for further transport.
- Zone C or assorting, finishing, and overhauling areas, including activities for definitive sorting of materials and equipment, segregation of composite materials, finishing of materials for re-sale, and overhauling.
- Zone D or storage areas including activities for stockpiling of assorted, finished materials.
- Zone E for office buildings and emergency facilities, including activities for administrative work and first aid help (if not dealt with on the spot).
- Zone F for waste disposal facilities which optional for the SRF and includes facilities of landfilling, incineration, and wastewater treatment.

3. Results and discussion

Results of the findings obtained from literature study and in-depth discussions with experts include: information regarding ship recycling procedure within a ship recycling facility; procedure on materials identification, both prior and during ship recycling process; and waste and hazardous materials handling requirements.

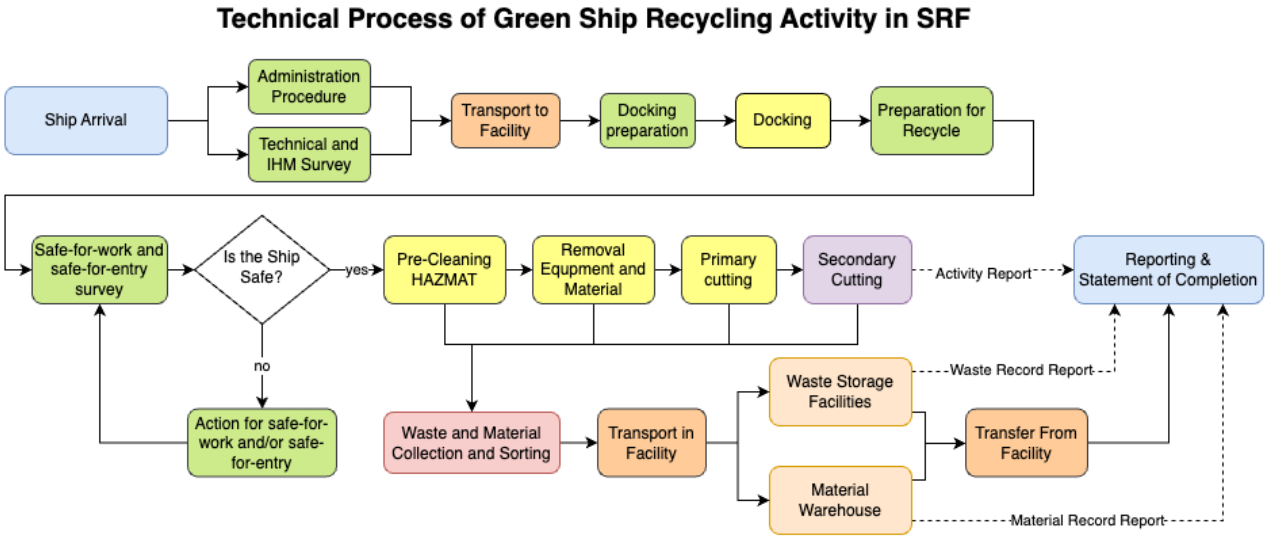

Figure 1 Green Ship Recycling Technical Process Flow at SRF (Self-Created).

3.1 Ship recycling procedure within green SRF

Figures 1 and **2** depict the design procedure of the green ship recycling process required by national regulations (Ministry of Transportation Republic of Indonesia, 2023) and international regulations (Hong Kong Convention), and previous research studies, such as by Irawati (2023); Hiremath et al. (2015); Hossain et al. (2011); Hossain (2019), and Sunaryo and Tjitrosoemarto (2021).

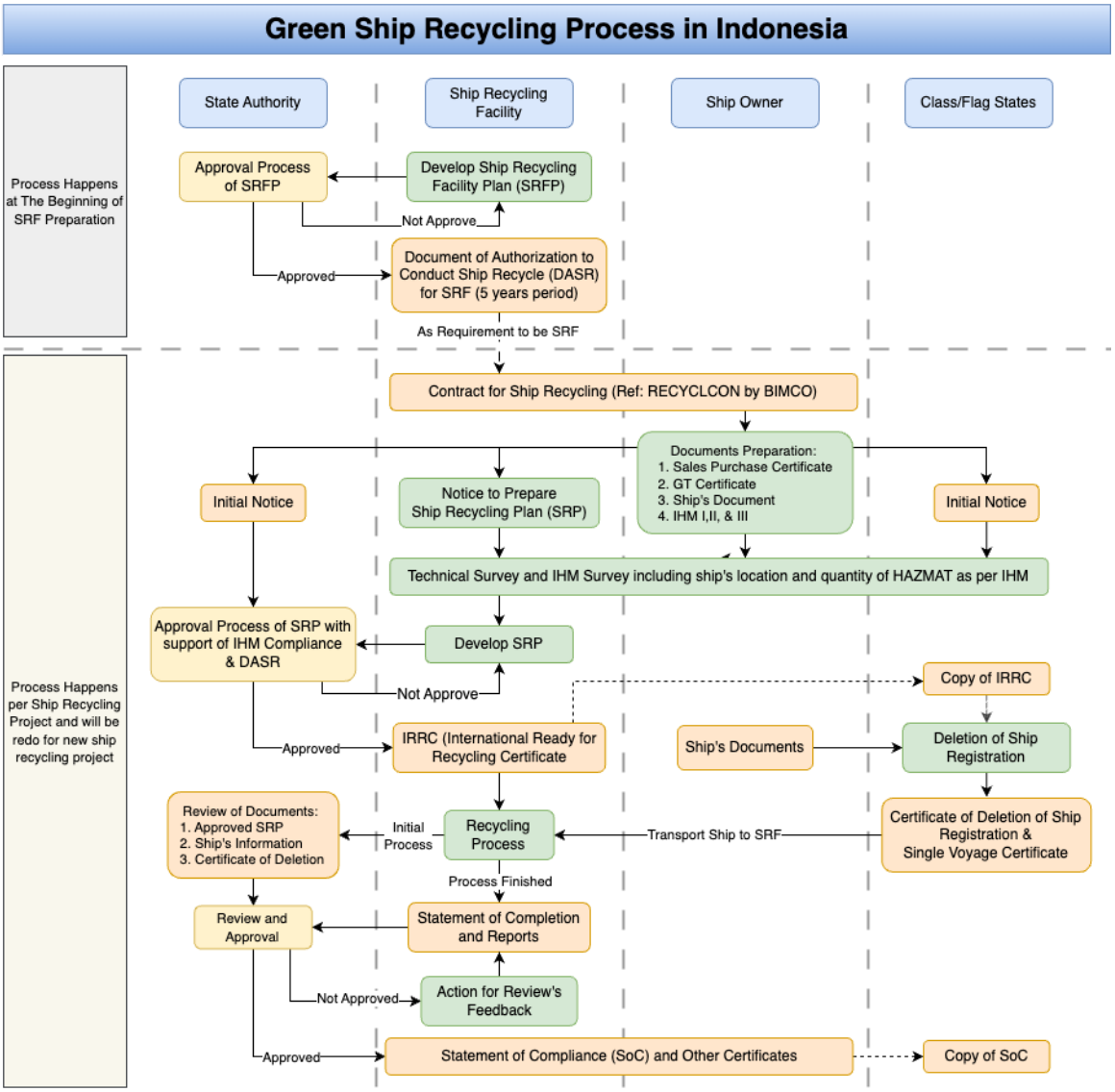

Figure 2 Green Ship Recycling Process Flow in Indonesia (Self-Created).

Figure 1 shows the technical process flow of green ship recycling within SRF, which includes 3 stages:

- Arrival, administrative, and preparation process, which includes ship arrival at the SRF to safe-for-work inspection, the administration process and preparation of all documents, technical survey, Inventory of Hazardous Material (IHM) survey, and Ship Recycling Plan (SRP) to obtain International Ready for Recycling Certificate from the Authority.
- Cleaning and cutting process, which include waste and HAZMAT removal, primary cutting, secondary cutting, and material sorting to temporary storage facility.
- Waste handling and reporting, which include sorting and transferring all materials and waste within the SRF into their respective storage areas, then record all the waste and HAZMAT collected and prepare reports for overall ship recycling activity.

Figure 2 shows the overall management process flow of green ship recycling in Indonesia, which includes roles of authority, ship recycling facility, ship's owner, and flag state. For a facility to be allowed to carry out a ship recycling project, it needs to develop a Ship Recycling Facility Plan (SRFP) and granted a Document of Authorization to Conduct Ship Recycle (DASR) from the authority as approval, requiring renewal every 5 years. For every ship recycling project, an SRP need to be developed by the SRF and approved by the authority along with ship's owner and flag state. Once an SRP is approved, the SRF will receive an International Ready for Recycling Certificate (IRRC) and will be permitted to start the ship recycling process, as shown in **Figure 1**. After all processes are completed, the SRF must submit statement of completion and reports, including a waste disposal record to be reviewed and approved by authority. The project will be completed once the SRF receives a Statement of Compliance (SoC) from the authority.

3.2 Procedure on materials identification

Figure 3 represents the material identification procedure, including waste and non-waste materials, and the material storage facilities based on previous research studies by Du et al. (2018); Jain et al. (2017), and the Indonesian National Research and Innovation Agency (2022).

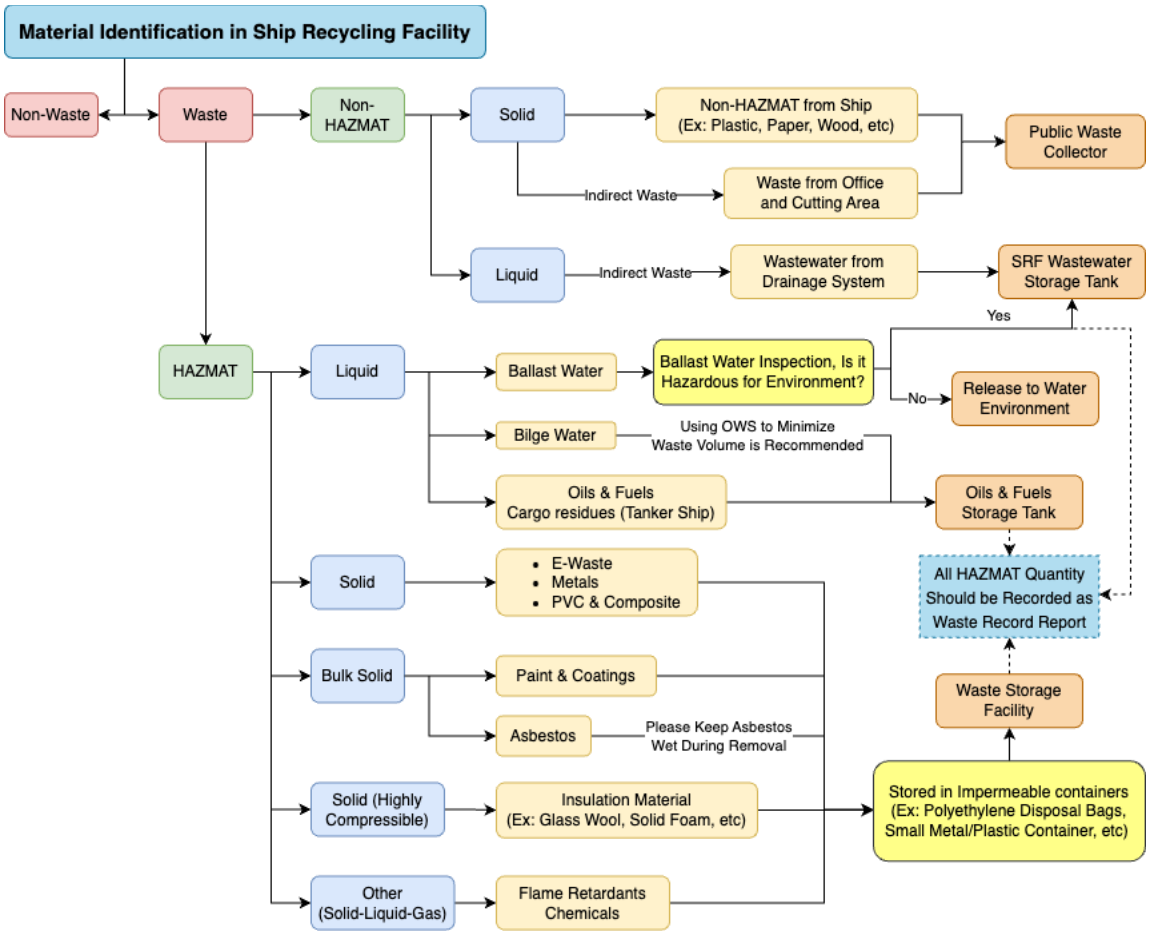

Figure 3 Waste Identification Flow at SRF (Self-Created).

The identification for waste is first categorized based on whether it is a hazardous material or not; then, it will be categorized based on its properties. Waste with the same properties can be placed in one storage area, due to their characteristics. In practice, waste identification within the SRF is not just limited to categorization of waste and its storage, but also includes the selection of handling method, handling equipment, and process of recording and reporting of waste disposal from the SRF

to the waste treatment facility. Even though the Hong Kong Convention does not require further processing or disposal at the ship recycling facility, such a process needs to be considered by stakeholders. Stakeholders have an obligation to supervise the process of disposal from the SRF until the waste treatment facility to make sure the amount of waste which is produced from the ship recycling activity in the SRF is the same amount as the waste received by the waste treatment facility. It should be ensured that all requirements for the ship recycling activity, especially waste handling, are fulfilled, and the safety, health of the workers, and cleanliness of environment are ensured.

Hazardous materials are classified into 3 categories: solid, liquid, and others. Each category of hazardous materials also needs specific handling requirements. Several aspects must be considered in HAZMAT handling, such as: potential hazardous material, hazardous components, source, safety and environmental effects, and handling requirement for specific waste.

Table 1 Solid HAZMAT handling requirements.

Potential Hazardous Material	Parts and Components	Health, Safety, and Environmental Effects	Handling Requirements
E-Waste	Cable insulation, transformers, capacitors, electric and electronics equipment.	PCBs can affect workers through dermal contact or inhalation or spread to the surrounding environment through soil and/or water; it can remain suspended for a long time and accumulate in the lungs, leading to lung cancer. Burning cables to recover copper wire can generate highly toxic fumes.	• Use adequate PPE and sufficient ventilation. • Provide water sprayer and fire extinguisher. • Use cable stripper to peel cable cover.
Heavy metal	Ship structural parts; piping system; machinery parts; anodes and batteries.	Potentially hazardous heavy metals can spread through soil and water. Exposure to heavy metals can damage the nervous system, hearing, vision, reproductive system, blood vessels, kidneys, and heart.	• Use adequate PPE. • Provide proper storage.
PVC and toxic materials	Piping system; floor coverings; parts made of composite materials; cable insulation.	Difficult to recycle. toxic when burned or inhaled, they can produce carbon monoxide, highly toxic dioxins, furans, etc. Burial can release chemicals into the groundwater.	• Adequate PPE and sufficient ventilation. • Provide water sprayer. • Provide proper storage.
Fine materials	Thermal and acoustic insulation system; superstructure partitions; and parts made of composite materials.	Toxic when inhaled or burned. When burned, they can produce carbon monoxide, highly toxic dioxins, furans, etc. Glass fiber dust can cause serious health problems.	• Provide water sprayer. • Use compactor to minimize the volume and provide proper storage. • Adequate PPE and sufficient ventilation.

3.3 Waste and HAZMAT handling requirements

With regard to each HAMZAT category, the handing requirements are proposed based on the type of materials, the components that may contain such materials, and the effects of these materials to safety, health, and environment.

Tables 1 - 3 present study results on the types of HAZMAT and the requirements for their handling.

Table 1 shows the handling requirements for solid HAMZAT. The potential hazardous materials include: E-waste; heavy metal waste; PVC and toxic materials; and fine materials. The components that may contain E-waste materials, such as PCB, are: cable insulation, transformers, capacitors, electric and electronics equipment, etc. Heavy metals might be found in paint and coating of ship structural parts; piping system; machinery parts; anodes and batteries. The components that may contain PVC and toxic materials include: piping system; floor coverings; parts made of composite materials, etc. Fine materials such as glass wool and asbestos could be found in thermal and acoustic insulation system; superstructure partitions; and parts made of composite materials. The effects of solid HAZMAT to safety, health, and the environment could be seen through dermal contact or inhalation; exposure to heat and toxic substances; and contaminated foods and drinks. The handling requirements for solid HAMZAT include: using adequate PPE and sufficient ventilation; providing sufficient fire extinguishing system and water sprayers to prevent fire; using cable strippers to peel cable insulation.

Table 2 Liquid HAZMAT handling requirements.

Potential Hazardous Material	Parts and Components	Health, Safety, and Environmental Effects	Handling Requirements
Oils & Lubricants	Fuel and lubricant tanks, machineries equipment, piping system; cargo tanks (oil and chemical tankers); engine room structural parts; bilge well structural parts; water ballast tanks.	Can contaminate the external environment. Toxic and fire hazards to workers. Oil waste makes work spaces slippery.	• Provide safe impermeable storage tanks. • Use adequate PPE and have sufficient ventilation.
Cargo residues (Tanker)	Cargo tanks / holds.	Can contaminate the external environment. Toxic and fire hazards to workers. Oil waste makes the work spaces slippery.	• Provide safe impermeable storage tanks. • Use adequate PPE and have sufficient ventilation.
Bilge Water	Engine room structural parts and bilge well structural parts.	Can contaminate the external environment.	• Stored in safe impermeable tanks. • Use oily water separator.
Ballast Water	Ballast water tanks.	Can contaminate the external environment and threatens the local biodiversity and human health.	• Inspect the ballast water to check itis safe to be released. • Provide safe impermeable storage tanks.

Table 2 shows the handling requirements for liquid HAMZAT. The potential hazardous materials include: oil and lubricants; cargo residues; bilge water; ballast water. The components that may contain liquid HAZMAT are: fuel and lubricant tanks, machineries equipment, piping system; cargo tanks (oil and chemical tankers); engine room structural parts; bilge well structural parts; ballast water tanks. Liquid HAZMAT and waste can easily contaminate the surrounding environment when leaked on to beaches, oil waste makes work spaces slippery, oil gas might create fire hazard, chemicals and toxic gas may threaten safety, health, and the environment. The handling requirements for liquid HAMZAT include: using adequate PPE and sufficient ventilation; providing sufficient fire extinguishing systems; providing safe impermeable storage tanks; oily-water separator is recommended to be used to minimize the volume of water from waste; inspecting the ballast water before it is released.

Table 3 shows the handling requirements for other HAZMAT. The potential hazardous materials include: antifreeze fluids and compounds, solvents/ thinners, battery electrolyte, evaporator dosing and de-scaling acids, corrosion inhibitor, compressed gases; plastics, ozone depleting substances, flame retardants, etc. Parts and components that may contain these HAZMAT are: machinery system parts, battery, cables, firefighting system equipment, insulation, piping system, compressed gas vessels, lifesaving equipment, etc. Effects of these HAZMAT to workers' safety and health, and the environment, are dependent on the characteristics of the individual HAZMAT; special identification is highly recommended before handling instructions are agreed. Some common requirements for handling this category of HAZMAT are: using adequate PPE and having sufficient ventilation, using proper handling tools, equipment, and procedures, and providing proper storage systems.

Table 3 Other HAZMAT handling requirements.

Potential Hazardous Material	Parts and Components	Health, Safety, and Environmental Effects	Handling Requirements
Antifreeze fluids and compounds, solvents/ thinners, battery electrolyte, evaporator dosing and de-scaling acids, corrosion inhibitor, compressed gases, plastics, ozone depleting substances, flame retardants.	Machinery system parts, battery, cables, firefighting system equipment, insulation, piping system, compressed gas vessels, lifesaving equipment, etc.	Dependent on the characteristics of the individual HAZMAT; may threaten workers' health and safety or pollute the environment.	• Use adequate PPE and have sufficient ventilation. • Use proper handling tools, equipment, and procedures. • Provide proper storage systems.

Based on the study of each potential HAZMAT, hazardous parts and components, and health, safety, and environment (HSE) effects based on their properties, specific requirements for handling the HAZMAT and waste are proposed. There are also suggested that some common waste and HAMZAT handling requirements which must be applied to all wastes and HAMZAT regardless of their types. Details of the common waste handling requirements are as follows:

- Adequate PPE (including whole body protection and respiratory equipment)
- Sufficient ventilation when material removal is performed in confined spaces or, if it is not feasible, workers must use air-line respirators
- Impermeable storage container (e.g., polyethylene disposal bags, metal/plastic containers, etc.)

- Water sprayer and fire extinguisher equipment for fire prevention
- Drainage systems for rainwater and area cleaning
- Impermeable floor to prevent water and soil pollution
- Provide proper lighting, especially in confined spaces

To ensure the safety and health of all workers, and the cleanliness of environment, the requirements for waste and HAZMAT handling at ship recycling facilities have been proposed based on their potential risks. It is expected that, by applying the proposed handling requirements, the ship recycling facilities would comply with the national and international standards and be categorized as green ship recycling facilities, and would gain international recognition and global market share.

3.4 Discussion

Due to the limitations in conducting the study, especially with regard to the gathering of real and up to date information, it is admitted that the proposed requirements for handling waste and HAZMAT at green ship recycling facilities are still general; therefore, deeper investigation into the existing facilities and practices of each individual ship recycling facility is recommended to be carried out to adjust the proposed requirements to the real conditions of each ship recycling facility.

Further study should be carried out on the economic aspects of the proposed requirements, so as to enable the industry to consider the costs and benefits of implementing them.

4. Conclusions

It is concluded that the proposed requirements for waste and HAZMAT handling at the green ship recycling facilities in Indonesia would include:

- Planning of proper ship recycling process flow.
- Identification of waste and hazardous materials.
- Deciding on requirements for waste and hazardous materials handling.

These results are expected to be used as means for covering the lack of references regarding waste and hazardous materials handling at the green ship recycling industry in Indonesia. Therefore, it is recommended that the findings should be further developed and adjusted when implemented at a specific green ship recycling facility in order to achieve their economic benefits.

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