

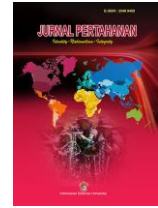


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APPLICATION OF INCONEL 718 (IN718) FOR ADVANCED ARMOR MATERIAL AND ITS POTENTIAL IN INDONESIA DEFENSE INDUSTRY

Nyimas Aljaniah Zahra

Sriwijaya University

Palembang, South Sumatera, Indonesia 30128

nyimasaljaniahzahra@gmail.com

Sovian Aritonang

Republic of Indonesia Defense University

IPSC Area Sentul, Bogor, West Java, Indonesia 16810

sovian.aritonang@idu.ac.id

Nugroho Adi Sasongko

Agency for The Assessment and Application of Technology (BPPT), National Research and Innovation Agency (BRIN)

Gedung BJ Habibie, Central Jakarta, Indonesia 10340

nugroho.sasongko@idu.ac.id

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Abstract

Indonesia is the world's largest source of nickel ore, controlling 27 percent of the global nickel market. Because of its unique physicochemical properties, such as malleability, high-temperature stability, strength, corrosion resistance, ductility, heat conductivity, and electrical conductivity, nickel is one of the most important metals in the industry. Nickel-based superalloys are commonly utilized to build hot-end components for aviation engines and gas turbines. The purpose of this study is to examine the use of Inconel 718 (IN718) for armor and its prospective development in Indonesia's military industry. The outcome demonstrates IN718's potential in the Indonesian defense industry, with the manufacturing of military aircraft gas turbines, submarines, military electric engines, and high-protection armor vehicles among its most prominent applications. Nickel may be recycled by using a nickel extraction technique like the liquid metal extraction-vacuum distillation (LME-VD), which produces no waste gas or solid and is environmentally beneficial. IN718's development is also by the government's goal of increasing the value-added of Indonesia's nickel production while minimizing environmental impact.

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INTRODUCTION

Indonesia is the world's largest source of nickel ore, controlling 27 percent of the global nickel market. Nickel comes in two different forms, sulfide and laterite. Indonesia contains the world's third-largest laterite deposit, behind New Caledonia and the Philippines. This is because the environment at the ore location influences the nickel content in nickel laterite. Indonesia has 1,600 million tons of laterite out of a total of 3,900 million tons of resources. The largest is in Pomalaa, in Southeast Sulawesi.

Because of its unique physicochemical properties, such as malleability, high-temperature stability, strength, corrosion resistance, ductility, heat conductivity, and electrical conductivity, nickel is one of the most important metals in the industry. Even though nickel laterite ore only contains 1-1.5% nickel, the high production of nickel sulfide causes the depletion of sulfide resources, nickel laterite has a bright future (Supriyatna, Sihotang, & Sudiby, 2019). Nickel is a critical resource that has evolved into a key material in the modern defense industry, particularly in aerospace. Nickel-based alloys, alloy steel, stainless steel, electroplating, and battery manufacturing all use it (Zhang et al., 2020). Indonesia has the potential to build a nickel-based economy in the future, and the government has said unequivocally that the country would not export raw nickel since its focus is on the added value of nickel, which is more lucrative (Voi.id, 2020). In the downstream industry plan in Indonesia, hydrometallurgy processing had a great opportunity to produce the main material for nickel-based alloy and could be indicated that the hydrometallurgy process has high competitiveness in the international market (Arifianto, 2021).

As previously stated, nickel is used in alloys such as nickel-based superalloys. Because of their outstanding strength, excellent fatigue property, high corrosion resistance, and strong heat stability at high temperatures, nickel-based superalloys are

commonly utilized to build hot-end components for gas turbines and aviation engines (Wang et al., 2020). Inconel 718 (IN718) is a superalloy made mostly of Nickel, Chromium, and Iron that can withstand temperatures below 10,000°C. The IN718 has a lot of potential in the military industry; one of its most well-known applications is military aircraft manufacturing (Garay et al., 2020). As a result, demand for turbine and jet engines is predicted to rise in the future, and demand for Ni-based superalloys is expected to rise as well. Because of the severe environment in which superalloys operate, impurities will accumulate over time as serving time increases, posing the challenge that a large number of scrap superalloys cannot be reused directly (Cui et al., 2020). Currently, numerous ways are being used to develop a more effective and environmentally friendly recycling method that produces no trash. The purpose of this research is to see how IN718 can be utilized for armor and how it can be developed for the Indonesian defense sector without affecting the environment. Theoretically, the findings of this research are expected to add to the theory or concept of IN718 development in the Indonesian defense industry.

METHODS

This study employs qualitative methodology and is structured around data gathering procedures in the form of a literature review with a descriptive-analytic approach, which aims to describe, summarize various conditions, situations, or phenomena of reality that are the object of research, and draw these realities as characteristics, characters, traits, models, or descriptions of certain conditions. This paper was created by a careful and thorough assessment of the literature, which included previous and published related articles, e-books, magazines, news, and policies.

Indonesia Nickel Industry

The nickel industry's value chain is separated into the following groups: the

upstream industry chain, which includes mining, and the mining products, which are nickel ores. NPI (Nickel Pig Iron), ferronickel, and nickel mattes are examples of processing and refining goods, which are then processed into downstream products such as batteries, Ni Alloy, Ni Plating, and numerous stainless-steel products. Finally, domestic appliances, ships, buildings, agriculture, electronic casing, defense, oil and gas transportation, automobiles, and trains are provided to end consumers (Suherman & Saleh, 2018).

Some of the industries existed in Indonesia, while others did not, as shown in Figure 1. Many connections in the industry chain have yet to be connected, implying that the backward and forward links for the nickel industry have yet to be constructed. Despite being the world's greatest nickel producer, Indonesia's goods are exported as raw materials, therefore it does not rank among the top countries for processed nickel output. The value-added of this commodity belongs to other nations due to a lack of nickel-based industrialization (intermediate/ downstream industries).

Indonesian Ministry of Energy and Mineral Resources (ESDM) announced that nickel ores below 1.7% nickel content are no longer to be exported from January 1, 2020. According to ESDM, 11 nickel smelters had been built and another 25 were in the works, requiring 94 million tons of nickel ore and a proven resource of 698 million tons that can only last 7.3 years. The export embargo is intended to stimulate greater downstream investments and early operations, as well as the export of more value-added intermediate products outside (Young, 2019).

Nickel prices have fluctuated dramatically in response to news from Indonesia, including an earthquake that wreaked havoc on mines and affected nickel ore supplies. Because Indonesia produces more than 60% of the world's nickel ore, natural disasters like typhoons and earthquakes, as well as government

regulations, have had an impact on LME nickel prices.

On January 4, 2021, a recent case occurred. Nickel prices on the London Metal Exchange (LME) increased by 4.8 percent, owing to news from Indonesia that an earthquake was occurring near the Morowali Industrial Park. Because of the increased financialization of commodities, Spot nickel prices were shown to be skewed by LME nickel pricing forecasts (Lim, Kim, & Park, 2021).

Indonesia possesses large Ni laterite deposits, which it has been using in recent decades to become a major worldwide producer. In 2016, Indonesia ranked among the top ten nickel-producing countries in the world, with 5.74 percent of total world reserves and 7% of overall nickel output. Indonesia's mining industry contributed roughly 9% of the country's overall gross domestic product in 2014. However, the industry accounts for a substantially bigger portion of many provinces' regional economies, including Sulawesi, West Nusa Tenggara, and Papua. As a result, nickel mining and processing play a significant part in the economy of the country (Kurniawan, Murayama, & Nishikizawa, 2021).

Distribution of nickel ore reserves in Indonesia, 90% spread over Central Sulawesi, South Sulawesi, and North Maluku, with a total resource of 11.7 billion tons and reserves of 4.5 billion tons (Kementerian Energi dan Sumber Daya Mineral Republik Indonesia, 2020). Nickel 1.99 wt% and iron 17.55 wt% are found in Ni Laterite from Southeast Sulawesi, Indonesia. The mass ratios of Ni-Fe and SiO₂-MgO are 0.11 and 1.97, respectively. It's a form of laterite known as garnierite, with a high nickel concentration and low iron content. The primary minerals are olivine, serpentine, clay, hematite, chlorite, and magnetite, while the minor minerals include actinolite, pyroxene, chromite, and limonite as determined by XRD (X-Ray Diffraction), OM (Optical Microscopy),

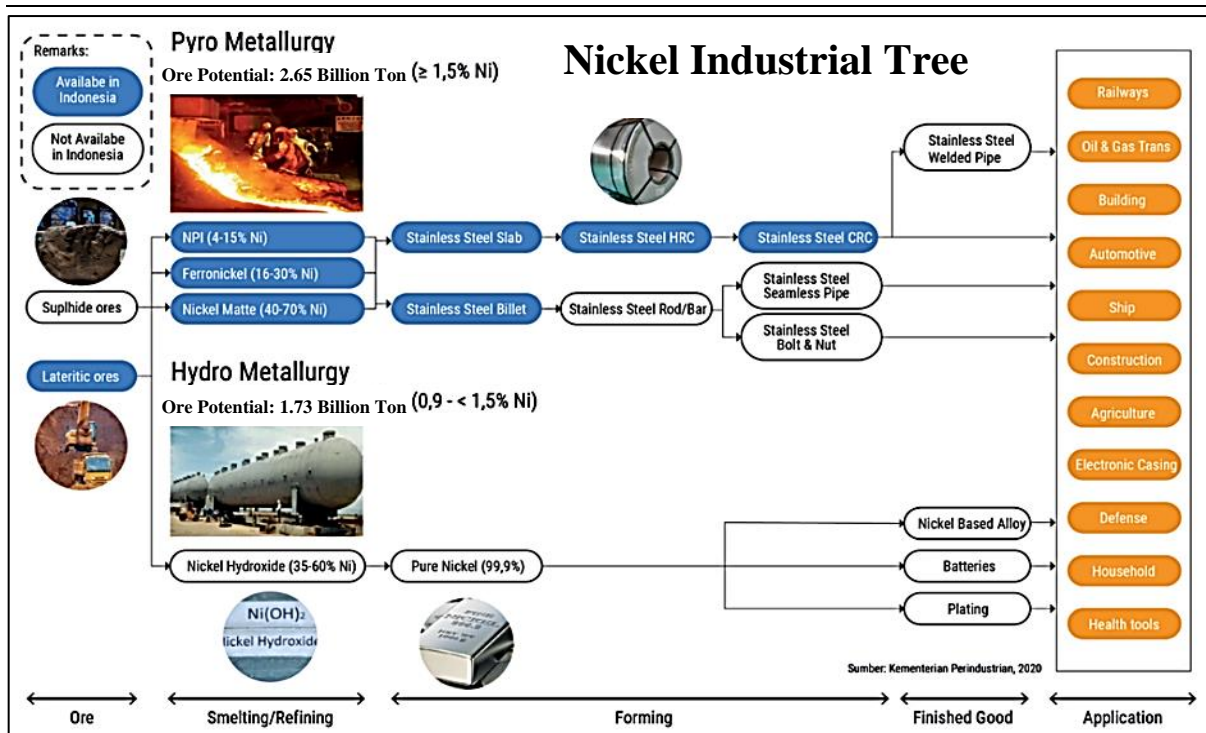


Figure 1. Industrial Chain of Indonesian Nickel

Source: Kementerian Energi dan Sumber Daya Mineral Republik Indonesia, 2020

Spectrometry). The principal nickel minerals are serpentine and olivine, which has typical nickel concentrations of 3.65 and 1.73 wt percent, respectively. Ni and Fe exhibit homogeneity and symbiosis in serpentine and olivine, and when the peak value of Fe rises, so does the peak value of Ni. Fe and Ni concentrations are frequently found to be positively linked (Zhang et al., 2020).

PEFINDO (PT. Pemingkat Efek Indonesia) expects the nickel industry in Indonesia would stay steady in the near to medium term, owing to the rising demand for nickel products to fulfil global demands for stainless steel and electric vehicle (EV) batteries. The government's implementation of legislation aimed at establishing a downstream nickel sector confirms their belief that the nickel industry is one of the government's top goals for boosting economic growth (Pandingan, 2021). Indonesia is on track to become the world's nickel capital, with new projects underway. The pace of expansion in the nickel sector is best assessed by an investment bank prediction

that the country may increase its share of global nickel production from 27% to 60% in the next eight years (Treadgold, 2021).

IN718 (Nickel-Based Superalloys)

Nickel, iron-nickel, and cobalt-based alloys used at temperatures above 5400 degrees Celsius are known as superalloys. Superalloys with the right compositions can be forged, rolled to sheets, or shaped in a variety of ways. When the highest temperatures (about 1,204 to 1,371 C) are necessary and strength is a factor, nickel-base superalloys are the material of choice. It has a melting point fraction that is greater than almost any other commercially available material. High-temperature uses for superalloys include aviation components, chemical plant equipment, and petrochemical equipment. Figure 2 depicts the F119 engine, which is used by the military to power high-performance aircraft.

In 1959, the International Nickel Company developed Inconel 718 (IN718), a popular nickel-based superalloy. IN718 is commonly used to 3D print things for a

wide range of purposes. According to Doug Hedges, president and COO of metal 3D printing service provider Sintavia LLC, the material is tough to process, but 3D printing allows for the fabrication of complex inner channels within constructions, which saves time. Because of its strong tensile, yield, and creep-rupture capabilities at higher temperatures, this superalloy is ideal for 3D printing aircraft and jet engine parts. It's ideal for 3D printing since it can make things lighter and reduce the amount of machining required by fabricating pieces in near-net shape. Because of its exceptional strength and aqueous corrosion resistance at ambient and low temperatures, IN718 is also utilized as a general alloy in the nuclear, oil, and gas sectors, and cryogenic structures.

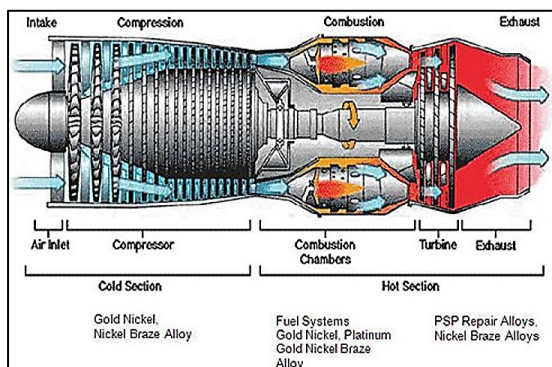


Figure 2. Typical turbofan engine shows the most common locations for use of alloys
Source: SP Airbus, 2020

Annealing and precipitation hardening are two techniques that may be utilized to create IN718. During annealing, the metal is heated and then progressively cooled to a lower temperature. This is what gives the materials their toughness and resistance to stress. The metal components are thoroughly dissolved so that they can properly precipitate and give IN718 its

intended strength. Precipitation strengthening, also known as age hardening, increases the strength of an alloy by introducing impurities before heating (Matmatch, n.d.). Figure 3 shows the process from raw material (nickel ore) to nickel-based superalloys.

In a hot turning operation, Parida and Maity compared the machinability of Inconel 718, Inconel 625, and Monel 400, and found that Inconel 718 had a better surface finish than the other two materials under the same cutting conditions (Parida & Maity, 2018). Because of its good mechanical qualities at extreme temperatures, IN718 is the most often used nickel-based alloy in the aerospace industry, and it has been widely employed in the turbine component of the aero-engine. It can withstand loading at temperatures as low as $1,336^{\circ}\text{C}$ (106°F), which is close to its melting point. The face-centered-cubic (FCC) nickel matrix has high phase stability and may be supplemented with additional alloys like chromium and/or aluminum.

Aeroengine manufacturers are currently investigating the use of additive manufacturing (AM) components in their manufacturing process since it offers great processing flexibility and potential cost savings. IN718 is one of those metal alloys that are best suited to the AM process route since it allows manufacturers to process it in a simple and basic manner while maintaining the material's qualities. When producing components layer by layer, up to 5% of the raw material is wasted, which is much less than when manufacturing them conventionally for aero-engine components (Yong, Gibbons, Wong, & West, 2020).

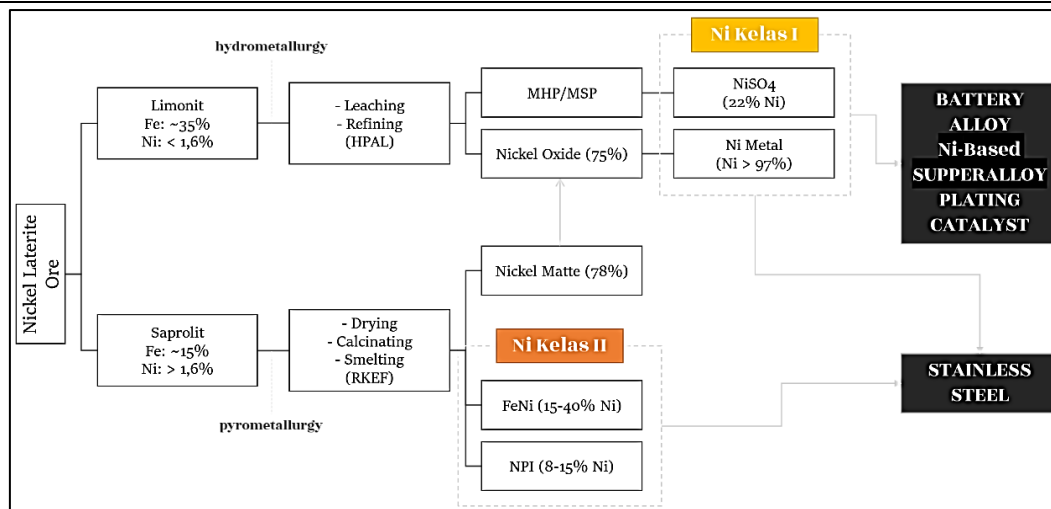


Figure 3. Processing of Nickel Ore to Ni-based Superalloy
Source: Processed by Researcher, 2021

Ni-based superalloys are used in many parts of gas turbine engines, high-pressure compressor blades, including discs, and combustion chambers, because of their ability to function at high temperatures (close to 80% of the melting point) and resist creep, corrosion, and oxidation. Weight reduction and adaptability to complex designs. These parts benefit from additive manufacturing because of the blade integrated disk (BLISK), a higher build-to-fly ratio, and the elimination of unwanted joints, which helps to prevent corrosion. Despite its reputation for passive layer formation, the IN718 alloy is prone to pitting corrosion. Chen et al. studied the effect of corrosive conditions on this alloy, discovering that it behaved passively in a 3.5 wt % NaCl solution at ambient temperature, 50°C, and 80°C. However, in a 21 wt % NaCl solution, the material showed active deterioration. According to Dempster et al., different heat treatments had little effect on the corrosion resistance of the IN718 alloy in a 3.5 wt % NaCl solution (Mythreyi, Raja, Nagesha, & Jayaganthan, 2020).

RESULT AND DISCUSSION

Because of its superior mechanical qualities at high temperatures and low cost, the IN718 accounts for more than half of all superalloy production globally (Rafiei,

Mirzadeh, Malekan, & Sohrabi, 2019). It's one of the most extensively used alloys in the aerospace industry, including gas turbine blades, vanes, compressor blades, diffusers, support cases, shafts, and other components used in rocket thrusters and aircraft (Widłaszewski, Nowak, & Kurp, 2021). Because of its superior machinability and welding capacity when compared to other superalloys, IN718 is the most extensively utilized nickel-based alloy in the aerospace sector. Nickel-based alloys are classified as difficult to cut due to their unique properties, a tendency to work harden, such as high strength at high temperatures, poor thermal conductivity, high chemical reactivity with tool material and coatings, and the presence of hard abrasive carbides on their microstructure (Iturbe et al., 2017). But still, it is not excluded from its potential in the defense industry.

Other research has looked at the effects of heat treatment on ballistic impact and failure mechanisms in this superalloy; for this, penetration rates and velocities with Ti-6-4 projectiles with a cylinder diameter of 12.5 mm and a length of 25.4 mm impacting flat plates at 150–300 m/s were used; an annealed IN718 absorb more than 25% of the energy in compaction as a result of this.

Some armory firms, such as Altemp

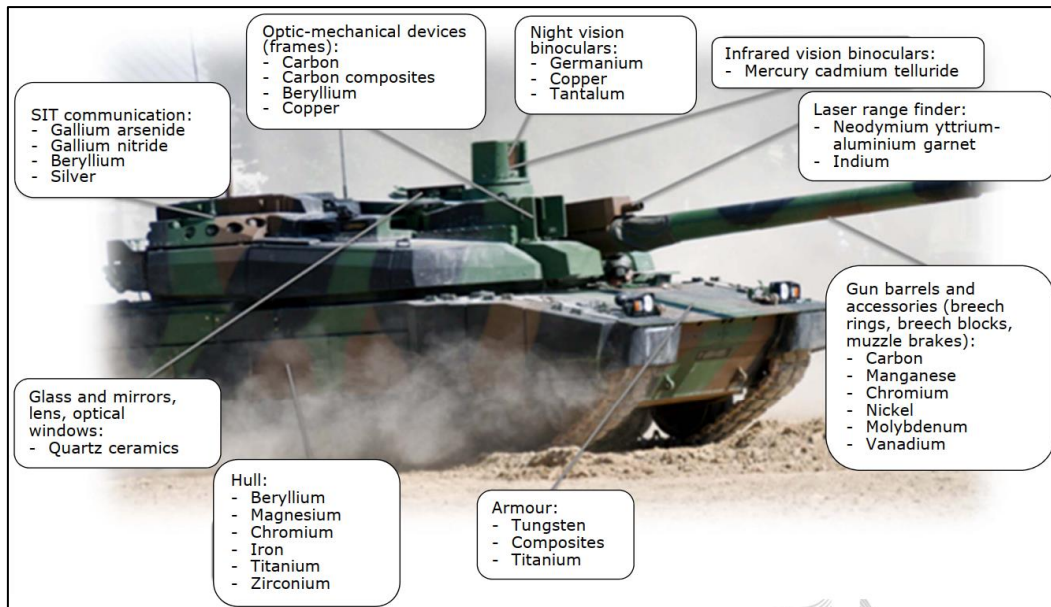


Figure 4. In a military vehicle with caterpillar traction, superalloy was used

Source: Garay et al., 2020

Alloys Inc, create high-performance alloy products that can withstand high temperatures for reaction engines, structures, vehicles, and vessels that protect the armed forces, emphasizing their high resistance and durability, as well as corrosion resistance, creep, and high wear out levels. The superalloy IN718 was used to produce the caterpillar traction system on a military platform (see Figure 4).

Given the strategic importance of nickel, and given the tremendous potential for nickel reserves in Indonesia to meet local needs, global demand for downstream processed products is expected to rise by 5-10 percent (Basuki, 2013). It is very possible that independence in various sectors that have been highly dependent on imports, such as the fulfilment of materials in the development of the defense industry, can be achieved if policies on energy management and other metals, including rare earth metals and refractories, are integrated. And, because of the features indicated above, IN718 is one of the nickel products that are extremely likely to be produced in the Indonesian military sector, particularly for use as high protection in armor vehicles.

To recycle to close the sustainability

gap, Ni reclamation should be viewed as a limited non-renewable resource. During the production and usage of nickel-based superalloys, a substantial amount of alloy scrap is generated. As a result of the breakdown of vast volumes of superalloy residues, many critical metal materials are thrown away. Because they contain rare and valuable metals like ruthenium, rhenium, hafnium, iridium, and other rare and valuable metals, nickel-based superalloy leftovers have a high recycling value. As a result, large-scale treatment procedures and recycling technology for recovering precious metals from garbage superalloys are required immediately (Tian, Gan, Cui, Yu, & Guo, 2021).

The recovery of Ni from molten metal has been extensively researched. Cui et al. devised a technique for extracting nickel (Ni) from superalloy residues using molten magnesium (Mg), which has a strong chemical affinity for Ni as well as high Ni solubility at high temperatures. After vacuum treatment, Mg was distilled out of the magnesium alloy, yielding Ni with a purity of 95.5 wt percent. To develop a more profitable and ecologically sound recycling technique that creates no waste, Yagi and Okabe researched direct Ni extraction from wastes using molten Zn as

a selective collector for Ni in superalloys. Figure 5 depicts the overall notion of this procedure. This approach involves directly extracting Ni from the superalloy into molten Zn and isolating it from the superalloy's other components, such as refractory metals. Selective distillation of Zn from the resultant Zn-Ni alloy can be used to separate and recover concentrated Ni and Zn metals. Furthermore, the Zn used for Ni extraction can be reused as an extraction medium. This is because pure Zn metal can be recovered in this method (Yagi & Okabe, 2017).

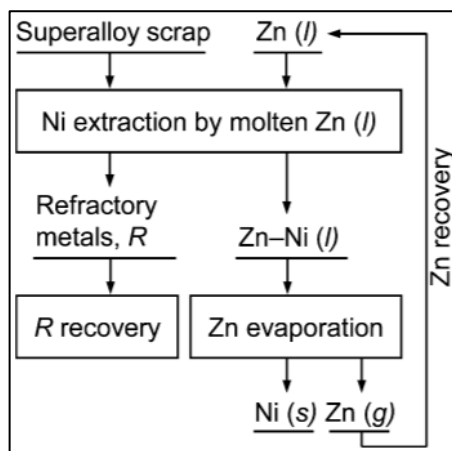


Figure 5. Ni Separation Process from Ni-based Superalloy Scrap (Molten Zinc)
 Source: Yagi & Okabe, 2017

Tian et al. looked into a new nickel extraction approach from superalloy scraps that used molten Mg-Zn as an extractant and found it to be very efficient and selective. Figure 6 depicts the basic flowsheet for the liquid metal extraction-vacuum distillation (LME-VD) process. In comparison to previous methods, the suggested method, LME-VD is an extraordinarily successful method for extracting Ni from Ni-based superalloys. The technique generates no waste gases or solids, making it environmentally benign. In addition, the liquid metal extraction medium may be recovered and reused in the LME-VD Process, significantly reducing material costs.

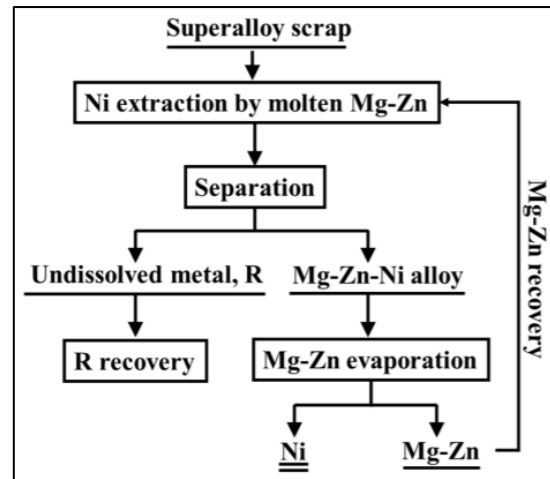


Figure 6. LME-VD Process
 Source: Tian et al., 2021

IN718 which can absorb more than 25% of energy in compaction, as well as its ability to function at high temperatures (close to 80% of the melting point), resist creep, corrosion, and oxidation, make IN718 very advantageous when used in armor, especially to develop the military industry in Indonesia. IN718 itself is very likely to be produced in Indonesia, considering that Indonesia has abundant nickel resources and reserves. So that if IN718 can be produced on its own, it will increase independence in the fulfillment of the defense industry in Indonesia. In addition, the production of IN718 is also in line with the Indonesian government's goal to make the nickel industry one of the drivers of economic growth, because processed nickel-based superalloys themselves have a high recycling value. After all, they contain rare earth elements of high economic value. So that this added value will no longer belong to other countries as has been the case because of the lack of nickel industrialization in Indonesia. The choice of nickel extraction with the LME-VD method can also answer environmental problems in Nickel industrialization because the extraction process does not produce gas or solid waste.

CONCLUSIONS

Inconel 718 (IN718) is a superalloy that can withstand temperatures of up to 5,400°C. Due to its superior strength and aqueous corrosion resistance at ambient and low temperatures, it is frequently used alloy in the aerospace industry. It is also used as a generic alloy in nuclear, oil and gas industries, and cryogenic structures. IN718 has a lot of promise in the Indonesian defense industry; among its most prominent applications in this sector are military aircraft gas turbines, submarines, military electric engines, and high-protection armor vehicles. Nickel can be recycled by environmentally-friendly nickel extraction processes such as LME-VD, which produces no waste gas or solid. IN718's development is also by the government's goal of increasing the value-added of Indonesia's nickel production while minimizing environmental impact.

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