Chapter 1

Sustainable Solid Waste Recycling

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Additional information is available at the end of the chapter

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Abstract

Nowadays, overpopulation and rapid development of industries and lifestyle lead to an increase in the consumption of natural resources and reduction of their resource. On the other hand, humans have always produced waste and disposed it in some way, which influence the environment. Therefore, the increase in waste that was generated by the industrial factories and the human activities needs to be managed. For this reason, scientists have discovered new types of engineering that include sustainable engineering and green engineering to reduce energy and natural resource consumptions. The main goal of this chapter is to explain the main advantages of sustainable manufacturing process and their effects in minimizing or eliminating production and processing wastes through eco-efficient practices, and it encourages adopting new environmental technologies. Therefore, this chapter offers a short introduction about sustainability, sustainable manufacturing process, solid-state management, and two case studies that include experimental works for recycling plastic waste and nonferrous waste materials by using sustainable solid waste recycling process to reduce waste and eliminate its influence on the environment.

Keywords: sustainability, waste, recycling, solid state, environment, plastic

1. Introduction

Nowadays, overpopulation and rapid development of industries and lifestyle lead to an increase in the consumption of natural resources and reduction of their resource. On the other hand, humans have always produced waste and disposed it in some way, which influence the environment. Therefore, the increase in waste that was generated by the industrial factories and the human activities needs to be managed. For this reason, scientists have discovered new types of engineering that include sustainable engineering and green engineering to reduce energy and natural resources consumptions. The idea of sustainability has a quantifiable unit, which refers to three pillars of social, environmental, and economic. They focus on the environmental policies, which increasingly require the reduction, reuse, and recycling of waste for contributing to closing the loop of material use throughout economy by providing waste-derived materials as inputs for production.

Sustainable manufacturing process and solid waste management are used for conserving valuable natural resources, preventing the unnecessary emission of gas and protecting public health. The main goals include reducing environmental impacts and offering economic opportunities. Solid-state recycling process becomes an effective and powerful methodology to realize the green state forming from recyclable waste to useful parts. The developed process can be considered as a typical green forming or environmentally manufactured process. It has many benefits including simple, cost-effective, and energy saving and can be clean recycled as it does not harm the environment.

The application of plastic materials and their composites continues to grow rapidly due to their low cost and ease of manufacturing. Therefore, a high amount of waste plastic is being accumulated, which creates a big challenge for their disposal. Disposal the sustainability of plastic for a wide variety of application, organizations are faced with the growing problem of finding alternative methods for disposing a large volume of waste packages. Disposal of plastic waste in environment is considered to be a big problem due to its very low biodegradability and presence of large quantity. Moreover, different types and sizes of metal chips are produced during manufacturing process of metal products. The generated chips had been recycled by traditional methods that include remelting and casting processes, which lead to loss of parts of chips due to their oxidation because of their size and weight. The traditional recycling process becomes an expensive method because it consumed high energy and generated high pollution. Furthermore, energy conservation and environment preservation are a challenging task worldwide. Therefore, sustainable manufacturing process is a promising technology to reduce the waste and cost as well as reducing the usage of primary natural resource by developing and improving lightweight materials. Solid-state metal conversion is one of the most important processes that can be used to eliminate the required energy for melting due its ability to produce solid parts directly from solid chips. Sustainable development is the development that meets the needs of the present without compromising on the ability of future generations to meet their own needs.

The main goal of this chapter is to explain the main advantages of sustainable manufacturing process and their effects in minimizing or eliminating production and processing wastes through eco-efficient practices, and it encourages adopting new environmental technologies. Therefore, this chapter discusses short introduction about sustainability, sustainable manufacturing process, solid waste management, and two case studies that include experimental works for recycling plastic waste and nonferrous waste materials by using sustainable manufacturing process to reduce waste and eliminate its influence on the environment. In addition, the main method for saving energy and materials, reduce waste, and elimination pollution well defined as well as the process that used to transfer the waste into useful products and their results will explain.

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2. Sustainability

Humans that require everything for their survival and well-being depend directly or indirectly on the natural environment. Our health, economy and security are required high quality of environment. Sustainability is being used by international organizations as a common approach to address the three sustainability pillars that include social, environmental, and economic issues. The potential economic value of sustainability is recognized to not merely decrease environmental risks but also to optimize the social and economic benefits of environmental protection. Sustainability is used to create and maintain conditions under which humans and nature can exist in productive harmony that permit fulfilling the social, economic and other requirements of present and future generations [1].

Sustainability has been applied in the field of engineering, manufacturing, design, technology, economics, environmental stewardship and health. Therefore, sustainable development becomes a key objective in human development due to increasing human activity. For that reason, sustainable manufacturing process requires balancing and integrating economic, environmental and societal objectives [1].

The growing identification of sustainability as both a process and a goal ensures long-term human well-being. The recognition that current approaches for decreasing existing risks, however successful are not capable of avoiding the complex problem. But current and future human generations at risk due to overpopulation, the gaps between rich and poor, reduction of natural resources, biodiversity loss and climate change will reduce. Human beings are at the center of concern for sustainable development. The principle makes clear that human well-being and quality of life is the objective of sustainability. Therefore, sustainable is defined as meeting the needs of the present without compromising on the ability of future generations to meet their own needs. It is improving the quality of human life while living within the carrying capacity of supporting ecosystems, through vague conveys: the idea of sustainability having quantifiable limits.

A large number of tools can be applied to address component parts of an analysis. Several principles are important in applying the suitable sustainability tools. They can be usefully applied in the sustainability assessment and management process. Small subset of the most appropriate tools includes risk assessment, life cycle assessment, benefit cost analysis, ecosystem services valuation, integrated assessment models, sustainability impact assessment, and environmental justice tools [2].

Risk assessment is a tool widely used for characterizing the adverse human health and ecologic effects of exposures. Therefore, risk assessments can be classified into four major steps that include a hazard identification, close-response assessment, exposures assessment, and risk characterization. On the other hand, life cycle assessment is defined as a cradle to grave analysis or cradle to cradle of environment impacts of various products, to determine how changes in processes could lower the environmental impact, and to compare the environmental impacts of different products [2].

The main tool that is widely used for evaluating the net benefits of alternative decisions is the benefit cost analysis. It measures the change in welfare for each individual affected by policy choice. It is used to find a social net benefit and then rank the alternative. On the other hand, ecosystem services are goods and services that contribute to human well-being and the valuation measured in money terms can be used in benefit cost analysis to capture a more complete picture of the net benefit of alternative actions. On the other hand, sustainable impact assessment can be used to analyze the probable effects of a particular project on the three pillars of sustainability. It is used to develop integrated policies that take full account of the three sustainable development dimensions and long-term considerations of those policies [2].

3. Solid waste management

Waste is defined as any substances or objects that the holder discards or intends to discard. It can be classified into non-hazardous waste such as packaging waste and hazardous waste like chemical waste [3]. Therefore, waste disposal should be seen as a last resort. Not only does waste disposal mean that valuable resources and energy are being thrown away but also biodegradable waste in landfill can emit methane. On the other hand, landfill space is becoming restricted.

Waste management has become a significant business issue for small businesses in recent years. All goods and products contain raw materials and energy. If they are discarded, we are effectively throwing away valuable natural resources. Waste disposal can also have adverse impacts on local air pollution and greenhouse gas emissions. Therefore, waste management can be defined as the collection, transport, processing, recycling and monitoring of waste materials that are produced by human. It is generally undertaken to reduce their effect on health, environment and carried out to recover resources from it [3].

The manufacturing strategy for environmentally kind products involves design process, which accounts for environmental impacts over the life of the products. Therefore, environmental improvements are related to manufacturing processes that are linked to reduction, reuse, recycling, and remanufacturing. However, eco-friendly comprises eco-design, eco-extraction, eco-manufacturing, eco-construction, eco-rehabilitation, eco-maintenance, eco-demolition, and socio-economic empowerment. Recently, sustainable eco-friendly road construction is increasingly receiving more attention worldwide. It is green our infrastructures of road constructing and reducing environmental impacts. It is also spurred by the increase in demand for eco-cities and eco-developments that are more environmentally friendly. Eco-friendly road construction can also be viewed as a response of stakeholders to the calls for sustainable development which arose from the growing awareness of the negative impact of road construction on our environments.

The quality of recycling wastes varies because of insufficient information on the properties of the manufacturing products, and lack of acknowledgement for using recycling materials as input material in new construction products, as well as lack of acknowledgement about the important elements and necessary actions for recycling the wastes.

The difficulties encountered in recycling are labor costs, lack of government awareness and support toward recycling, and limited real-life applications of recycled materials to allow for evaluation for their performance. The main benefits of recycling are reduction of material hauling and disposal costs and preservation of landfill capacity which lead to elongation of landfill design life and sometimes cheaper materials compared to virgin materials. Recycling helps in greening our infrastructures by conserving natural resources, decreasing energy use, reducing greenhouse gas emissions and air pollution, reducing the extraction of the virgin materials and minimizing their consumption, and environmental protection [4].

Different kinds of materials can be recycled in road construction such as fly ash, silica fume, ground granulated, blast furnace slag, reclaimed asphalt pavement, and plastic wastes such as polystyrene, polyethylene, and reclaimed concrete. Recycling waste materials can function as fine and coarse aggregates and supplementary cementing materials depending on the properties of the wastes intended to be optimized and the desired applications [4].

Eco-friendly road construction is one that is beneficial or non-harmful to the environment and is energy and resource efficient. To be eco-friendly, it must imbibe certain basic elements, namely eco-friendly, eco-extraction, eco-manufacturing, eco-construction, eco-rehabilitation, eco-maintenance, and eco-demolition. Utilization of waste materials will minimize negative impact on the environment and minimize the use of virgin materials [4].

An increasing in global plastic production and consumption due to increase or over population, development, and industrialization as well as lifestyle changes, the challenges posed by plastic wastes, which constitute of 25% of municipal solid waste. On the other hand, utilization of wastes from polyethylene constitutes 60% of plastic bottles. As a result, product packaging becomes the major contributor to environmental waste. Therefore, sustainable waste management will help to

1. Minimize waste.
2. Reuse waste.
3. Recycle waste for further use.
4. Energy recovery.
5. Disposal.

4. Sustainable manufacturing process

Sustainable manufacturing is defined as the creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities and consumers and are economically sound [1, 5, 6]. Traditionally, manufacturing is defined as the process that is used to describe the physical transformation of materials or converting input materials into products. Sustainable production emphasizes a life cycle perspective in the manufacture, recycling, and disposal of goods and services, instead of the traditional focus on discrete activities. It encourages continuous to improved efficiency of using energy and resources [5]. Therefore, sustainable production is defined as the creation of goods and services using processes and systems that are non-polluting, conserving energy and natural resources [1, 6]. Nowadays, sustainable manufacturing has evolved beyond the life cycle view and the key business has benefits from sustainable manufacturing, which includes financial performance, business excellence, and relationship with stakeholders as follows [6]:

A. Financial performance:

- Increase sale.
- Improve efficiency and productivity by reducing resource use and waste.
- Reduce dependence and expensive or hazardous materials.

B. Business excellence:

- Stay ahead of regulations.
- Win access to capital.
- Gain strategic foresight.

C. Relationship with stakeholders:

- Enhance repetition.
- Demonstrating green know-how and setting a positive example.
- Improve employee's morale and retention.
- Build better community relations.

Companies across the world face increased costs in materials, energy and compliance coupled with higher expectations of customers, investors and local communities because they throw away valuable natural resources as waste. Waste disposal has adverse impacts on the local air pollution and greenhouse gas emissions. Sustainable waste management is vital for

- saving valuable natural resources.
- avoiding unnecessary emission of gas.
- protective public health and natural ecosystems.

5. Case study

There are two case studies conducted in the field of recycling of solid wastes materials that included polyethylene waste and non-ferrous metal waste. They were used to study the possibility to use waste materials as a raw material for producing solid parts or use as an additive material to improve the properties of products. They used and produced by applying a sustainable manufacturing process that reduces the waste, cost, environmental pollution and impact.

5.1. Recycling of polyethylene waste

The amount of plastic waste that is destined to the landfills is increasing each year. Disposal of plastic waste in the environment is considered to be a big problem due to its very low biodegradability and presence of large quantities. Therefore, finding alternative methods of disposing waste by using friendly methods is becoming a major research issue [7–10].

Humans have always produced waste and disposed them in some way. Nowadays, the types and amounts of waste produced and the method of disposal are changed, as well as the human values and awareness of what should be done with it. The applications of plastic materials and their composites are still growing rapidly due to their low cost and ease of manufacture. Therefore, a high amount of waste plastic is being accumulated, which creates big challenges for their disposal [7, 10].

One of the environmental issues in most regions of Iraq is the large number of package made from polyethylene materials such as shampoo sachets, carry-bags, nitro packs, milk and water pouches, and vegetable packages, and so on, which are deposited in domestic waste and landfills. The largest component of the plastic waste is polypropylene, polyethylene terephthalate, and polystyrene [7, 9, 10].

Today, sustainability has obtained top priority in construction industry. Recently, plastics were used to prepare coarse aggregates, thereby providing a sustainable option to deal with the plastic waste. Therefore, recycling of plastic waste is an important topic in order to decrease environmental pollution and prevent waste of resources [9–11].

Recently, plastic waste is one component of municipal solid wastes, which is becoming a major research issue to study the possibility of disposal of the waste in mass concrete especially in self-compacting concrete, in lightweight concrete, and in pavements. It can be used as a component of a composite construction material, as an inorganic filling material, and an aggregate of concrete [8–11].

Recycling of plastic waste in concrete has advantages since it is widely used and has a long service life, which means that the waste is being removed from the waste stream for a long period. Moreover, using post-consumer plastic waste in concrete will not only be its safe disposal method but may improve the concrete properties like tensile strength, chemical resistance, drying shrinkage and creep on short- and long-term basis [7, 10].

They maximize the benefits of economy, environment, and society and minimize adverse impact. This leads to an increase in the efficiency of a process and reduces the amount of pollution, which will shift the industrial processes from open-loop system to closed-loop systems where the resource wastes become inputs for new processes [10, 12].

Plastic has different properties such as durable and corrosion resistant, good isolation for cold, heat and sound, saving energy, economical, has a longer life and light weight. Solid-state recycling process is proposed to realize the direct recycling of polyethylene as the green engineering forming technology [6, 8, 9]. Researchers have found that there is a possibility to produce a good quality of cement by using the waste of polyethylene. The results show that the addition of polymeric material in a fraction less than 10% in the volume of cement matrix does not imply a significant variation in the mechanical properties of cement. However, the density and compression strength of cement decreased when the percentage of polyethylene aggregate exceeds 50% by volume as well as when the weight of normal concrete had been reduced [13–18].

5.1.1. Polyethylene waste plastic cement

Polyethylene waste materials are used to produce plastic cement directly from solid state to improve the mechanical properties and workability of products. High-density polyethylene waste is mixed with Portland cement to investigate the possibility to produce plastic cement and study the effect of replacing sand by fine polyethylene waste with different percentage on the properties of product.

High-density polyethylene boxes or crates have been collected from municipal and landfills as a waste of human activities. Then, they are cut into small size by using a special cutting and grinding machine to get fine particles. The result grinding polyethylene wastes are sieved to separate the fine particles from the coarse particles to be ready for mixing with Portland cement and water as shown in **Figure 1**.

Portland cement and fine polyethylene waste are mixed by water to get concrete mix without using sand to study the effect of replacement sand by fine polyethylene waste. Different percentages of fine polyethylene waste are used to produce plastic cement. The ranges of polyethylene used are 15, 20, 25, 30, 35, 40, 50, 60 and 80% of the mixing materials with fixed water content of 25% [10].

Portland cement and fine polyethylene waste are mixed with water to get a homogeneous concrete to cast on the small mould. Samples are left in the mould until dry and then are immersed in water for 3–4 days for solidifying and curing to increase their cohesion. After that, samples are taken out from water to dry and their properties are tested. The second step is to immerse these samples again in water for 7 and 28 days to study their stability and the effect of water on their properties.

5.1.2. Results and discussion

Polyethylene is a semi-crystalline material with excellent chemical resistance, good corrosion resistance, and good fatigue and wear resistance. It provides good resistance to organic

Figure 1. Polyethylene waste after cutting and grinding [10].

solvents and strength with low moisture absorption. Moreover, it is a lightweight material, non-toxic material, resistance to stain and offers excellent impact resistance and high tensile strength.

The shape of wet plastic cement is produced by mixing and casting materials without using any vibration or press. The products have a good shape and of light density, which are dependent on the percentage of fine polyethylene waste. The density of plastic cement that is produced in this research lies in the range of 1.972–1.375 gm/cm^3. It is 1.375 gm/cm^3 when the percentage of polyethylene equals 60% [10].

The moisture of plastic cement that is produced in this research was measured after immersing for 7 and 28 days in water. The results show that after 28 days the moisture percentage will be less than the moisture of plastic cement that was immerged for 7 days. The range of moisture after immersing for 7 days is 23.4–10.5% and after immersing for 28 days is 11.6–3.60%. The lower percentage of moisture is equal to 3.60 and 3.79%, which has been obtained when the percentage of fine polyethylene in mixing concrete equals 25 and 30% with immerged time equal to 28 days. Plastic cement with waste polyethylene up to 60% has a good workability because it is possible to make hole by using a drill machine as shown in **Figure 2**.

Plastic cement has a good compressive strength and yield strength. Yield points for different specimens have been found which lie in the range of 568–971 N after 7 days and from 571 to 2352 N after 28 days. It is dependent on the percentage of fine polyethylene waste as shown in some examples in **Figures 3** and **4**. By increasing the plastic waste ratio, the compressive strength values of waste plastic cement decrease at each curing age. This trend can be attributed to the decrease in adhesive strength between the surface of the waste plastic and the cement paste. It seems that the bonding between the plastic particles and the cement paste is weak [10].

It was found that there is a possibility of producing plastic cement from the waste of polyethylene materials that generated from human activities like food packages or crates. The density of produced plastic cement depends on the percentage of waste polyethylene in the concrete mix design. It increased with increasing percentage of waste up to 30% and then decreased gradually. The maximum density of product is 1.972 gm/cm^3, which is less than the density of cement mortar that produced from sand and Portland cement. The density of plastic cement that was produced by using high-density polyethylene waste materials was reduced with 15% of traditional concrete. In addition, the moisture of plastic cement lies in the range of 10.5–23.4% for products immerged 7 days in water. However, for products

Figure 2. Sample of plastic cement produced in this research with a hole [10].

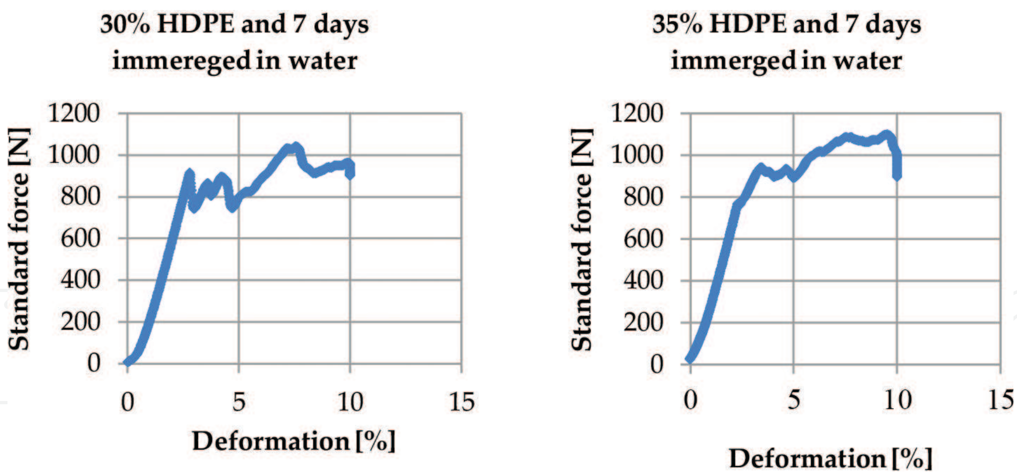

Figure 3. Compressive strength of produced plastic cement with 30% HDPE and 35% HDPE after immerging for 7 days in water [10].

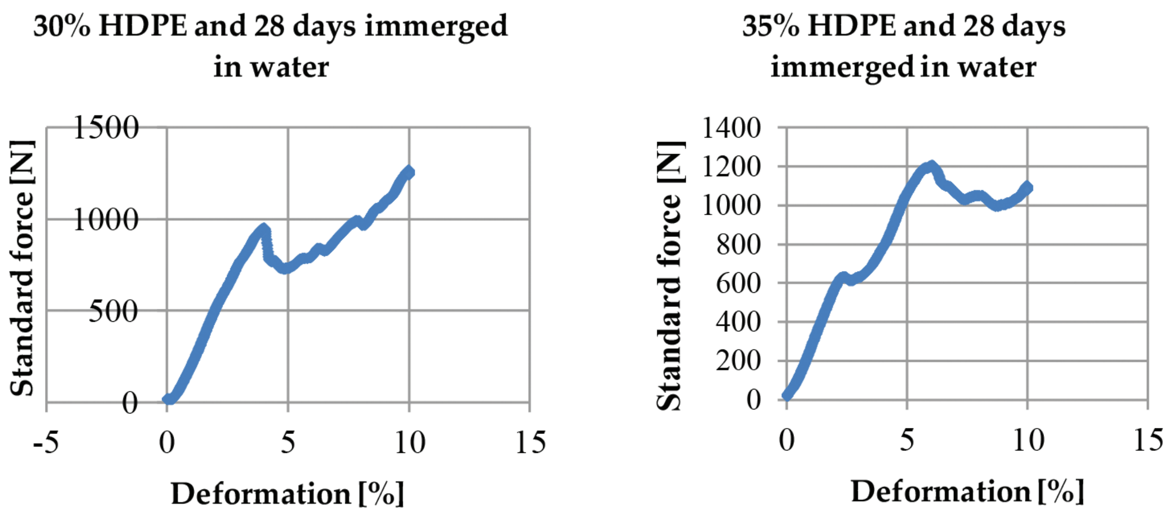

Figure 4. Compressive strength of produced plastic cement with 30% HDPE and 35% HDPE after immerging for 28 days in water [10].

immerged 28 days, the moisture was decreased to be in the range of 3.6–11.6%. The best moisture percentage for products is 3.6 and 3.79% for products with 25 and 30% waste polyethylene, respectively [10].

The best compressive strength for a product was found in the mixture to be 25, 30, and 35% polyethylene. The yield points for them are 971, 915 and 945 N, for immerged 7 days, respectively, and 2352 for mixed of 25% and 1271 N 30% after immerged 28 days. The stress-strain behavior is plastic behavior, which has several stages of deformation. It works as semi-crystalline polymer, flexible concrete and not brittle as Sand-Portland cement concrete. Therefore, their stress-strain diagram exhibited both elastic and plastic deformation before fracture. Moreover, the products with 25–30% waste polyethylene have good workability to make holes without any problem. However, when the percentage of waste decreases or increases, the workability will be weak and power was generated during the cutting operation [10].

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Solid-state recycling process becomes an effective and powerful methodology to realize the green state forming from recyclable wastes to useful parts. The developed process can be considered as a typical green forming or environmentally manufacturing process for lightweight materials. It has many benefits including simple, cost and energy saving, and clean recycling because it does not harm the environment. From the above information, it was found that the best and suitable percentage of waste polyethylene is 25–35%, which gives good properties of mixture [10].

5.2. Recycling of non-ferrous metal waste

One of the most important processes that use to eliminate waste, cost, and energy required for recycling non-ferrous metal waste is solid-state metal conversion process that belongs to sustainable manufacturing process. It is a promising technology to eliminate remelting and casting process due to its ability to produce solid parts directly from solid state without remelting, reducing the waste and cost [19].

Different types and sizes of chips were generated during manufacturing operation like turning, milling, and sawing. These chips are accumulated in the workshops and factories which need to be removed and remelted to cast as a useful part. The traditional recycling process becomes costly because it is required by a high number of employees and consumed high energy as well as generated high emission and pollution which are the main challenging task worldwide [19, 20].

The idea of recycling waste is to eliminate and reduce the usage of primary material resources and reduce energy consumption. The traditional recycling methods consume high energy and generated waste again. The amount of waste generated from casting metal can be estimated as 3–5% of casting weight, which is produced as chips again. The energy required to produce 1 ton of primary aluminum is 200 GJ and for remelting aluminum scrap is 10 GJ per ton. In addition, it is difficult to recycle metal chips due to their elongated spiral shape, small size, and surface contamination. Therefore, it's very important to develop an efficient recycling process that prevents generation of chips again. For that reason, sustainable policy becomes the focus for modern industrial societies to reduce the usage of primary resource, pollution control and prevention [19–21].

Nowadays, several recycling methods have been used to transfer chips into useful part which can be classified as conventional and non-conventional recycling method. In conventional recycling method, there is no improvement of mechanical properties and large slag will generate from remelting process and solidification [25]. In addition, 20% of materials will be lost during remelting process, which cannot be avoided. Conversely, in case of thin chips, losses can reach to 50%; therefore, energy consumption and cost of labor will increase as well as the expenditure on environmental protection will increase too. However, non-conventional recycling process was done by extrusion and sintering process, which leads to save 95% of energy that was consumed in conventional recycling process and can reduce solid waste disposal, and CO_2 emission as well. Direct conversion method is one of the non-conventional recycling methods that are relatively simple, economic, and environmental-friendly process, which can be considered as a sustainable manufacturing process [19–24].

Recently, solid-state recycling method of non-ferrous metals like aluminum, copper, zinc, and their alloy chips has been introduced without the melting process to overcome the disadvantages of conventional method [25, 26]. Therefore, scientists have discovered new types of engineering that include sustainable engineering and green engineering that are used to minimize adverse impact and maximize the benefit to economic, social and environmental [19, 27].

In this work, solid-state recycling process was implemented to realize the direct recycling of aluminum-zinc alloy chips and copper metal chips as the green- or sustainable-forming technology. It is used to produce solid part directly from solid state without melting.

5.2.1. Produce solid part metal chips without melting

Al-Zn alloy and copper metal chips that are generated through cutting or manufacturing processes have been used to recycle by using direct conversion method. Chips were cold pressed with a load of 10, 20, and 30 tons and then extruded to produce shaft with a diameter of 12 mm. A significant deformation process was produced that leads to achieve proper material bonding.

Different sizes and shapes of Al-Zn alloy and copper metal chips are collected from the workshop as a waste of cutting operation, which sieve with a mesh between 0.300 and 3.00 mm as shown in **Figure 5**. They were mixed to produce 70% of chips in the size of 1–3 mm and 30% less than 1 mm. The length of chips was up to 11.85 mm and the width in the range of 0.39–3 mm. These chips were compacted and extruded directly without remelting or heating. The pressing was applied from one side and two sides in the opposite direction.

5.2.2. Results and discussion

The results show high possibility to produce solid parts directly from solid chips without any melting and rolling process. The developing process can be considered as a typical green-forming or environmental manufacturing process for lightweight alloys. It saves money because there is no need to prepare powder for forming and sintering the products as the process used for powder metallurgy. The magnitude and direction of pressing significantly affected the properties of produced parts.

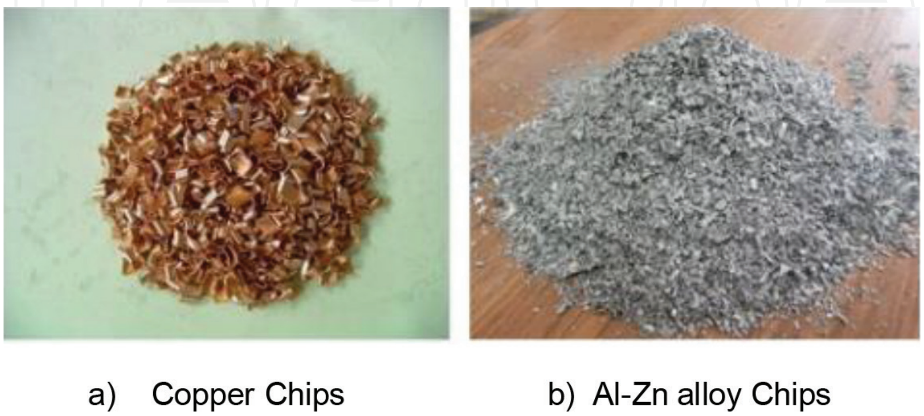

Figure 5. Chips of copper and Al-Zn alloy [19].

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The experimental works show that higher cold-pressing pressure leads to higher density of cold-pressed samples and higher hardness. In addition, pressing from two sides is better than one side because uniform distribution will be obtained with high homogeneity product. The produced parts have approximately the same hardness and density everywhere as same as the standard parts. The pressing from one side leads to produce brittle and incoherent parts. However, pressing from two sides produced strong and coherent parts with density and hardness close to original parts as received as shown in **Figure 6**. Moreover, the result shows that the smaller and simpler chips are better input materials for cold compression; otherwise, there is a need to heat chips before or during pressing process.

Figure 6. Samples of shafts produced from Al-Zn alloy and copper chips [19].

The density of cold extruded Al-Zn alloy and copper metal chips reached 95% of the density of parts produced by conventional method. In addition, the hardness of cold extruded chips was equal to 98% of the parts produced by cast and rolled [18, 28–30]. The result that was obtained in this research agreed with the result that was obtained by Chiba et al., which found that cold extruded chips were 97% of cast materials [29, 31]. Therefore, direct recycling method or solid-state recycling method is a promising approach technology that helps to overcome the problem of material loss during remelting of chips and energy saving with environmental protection by reducing gas emission.

Solid-state recycling process becomes an effective and powerful methodology to realize the green state forming from recyclable wastes to useful parts. The developed process can be considered as clean recycling technology and typical green-forming or environmentally manufacturing process for lightweight alloy. There is no need to prepare powders for forming and sintering the products.

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