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ScienceDirect
Procedia CIRP 40 (2016) 13 – 17
www.elsevier.com/locate/procedia

13th Global Conference on Sustainable Manufacturing-Decoupling Growth from Resource Use

Using Sustainable Manufacturing Process to Produce Solid Shaft from Al - Zn Alloys Chips and Copper Chips without Melting

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Abstract

Sustainable manufacturing process is a promising technology to reduce the waste and cost. Solid-state metal conversion is one of the most important processes to eliminate the required energy for melting and casting steps due its ability to produce solid shafts directly from solid chips. In this paper, direct recycling process for Al-Zn alloy and Copper chips generated through cutting processes is proposed. Cold pressing is utilized and the pressed chips are extruded with diameter of 12 mm and pressures of 10, 20, and 30 ton. This technique produce a significant deformation process leading to achieve proper material bonding. The results show high possibility to produce solid parts directly from solid chips without any melting and rolling process. The produced parts have mechanical properties closed to those obtained by the conventional forming technology. This method is relatively simple and demonstrate a clean recycling technology to reduce the waste and maximize the productivity.

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Keywords: sustainability; manufacturing; recycling; chips; solid-state.

1. Introduction

During manufacturing process of metal products, different types and sizes of chips are produced. The resulting chips may loss considerable parts through traditional recycling process because of oxidation. Furthermore, the expenses of labor, consumed energy, and environment preservation will raise the general cost of process [1]. On the other hand, energy conservation is a challenging task worldwide. The main aim is to reduce the usage of primary natural resource by developing and improving lightweight materials [1]. For instant, primary aluminum production is the most energy intensive one and requires almost 200 gigajoule per ton [2]. Therefore, sustainable policy becomes the focus for modern industrial societies to reduce the usage of primary resource, pollution control and prevention [1, 3, and 4].

Most of the aluminum castings are solid as ready to use components and functional parts with high benefit after several machining operations [3]. However, machining operations usually generate considerable amounts of waste in the form of chips usually about 3-5% of casting weight [3]. The energy requirement of re-melting aluminum scrap is about 10 gigajoules per ton [2]. By increasing the application of aluminum lead to produce large quantity of aluminum machined chips. Therefore, it is very necessary to develop an efficient recycling process [1].

The chips deriving from the machining of semi-finished aluminum products are very difficult to recycle by conventional methods due to their elongated spiral shape, small size, surface contamination with oxides, etc., [5]. During the last years, several recycling methods of machining chips and other aluminum wastes have been reported. They are based either in solid-state transformation into extruded and sintered products or involving melting operation [3]. On the other hand, aluminum waste recycling has different advantages such as energy saving due to re-melting in about 95%, reduction in solid waste disposal and CO2 emission [4].

Recycling methods of aluminum chips are classified into conventional and non-conventional techniques [1]. In conventional recycling methods, there is no improvement of mechanical properties can be expected because the process include recycling, re-melting and solidification. This

Peer-review under responsibility of the International Scientific Committee of the 13th Global Conference on Sustainable Manufacturing
doi:10.1016/j.procir.2016.01.039

solidification lead to generate coarse grain and that required additional process to control the microstructure. Moreover, large amount of slag are ejected from the re-melting process [6]. Direct conversion methods for recycling of aluminum chips can be considered as non-conventional recycling processes. It is relatively simple and economic process, consumed less energy, saving resource, and do not harm the environment. It is considered as sustainable manufacturing process [1, 5].

Since the 1980, several efforts have been spent to increase the energy efficiency of melting furnaces, which lead to reducing the energy consumption for recycling of aluminum scrap. However, there is an average material loss of 20% during re-melting which cannot be avoided. This is due to the high surface area to volume ratio of chips, contamination with oxides, especially in case of thin chips; the material loss can reach to 50%. Therefore, energy consumption and cost of labor will increased, as well as the expenditures on environmental protection will increase the general cost of the process [2, 5]. Recently, solid-state recycling method of aluminum, Al-alloys, copper alloy, and zinc alloys chips have been introduced without the melting process to overcome the disadvantages of conventional method [1,7].

The scientist has been discovered new types of engineering that include sustainable engineering and green engineering to reduce energy and natural resources consumptions. "Sustainable engineering is defined as the design of human and industrial systems to ensure that humankind use of natural resources and cycles do not lead to diminished quality of life due either to losses in future economic opportunities or to adverse impacts on social conditions, human health, and the environment" [8]. On the other hand, "Green engineering is defined as the design, discovery, and implementation of engineering solutions with an awareness of potential benefits and problems in terms of the environment, the economy, and society throughout the lifetime of the design". The goal of green engineering is to minimize adverse impact while simultaneously maximizing benefits to the economy, society, and the environment. It is focusing on the increasing the efficiency of a process to reduce the amount of pollution generated to be as eco-efficiency [8]. This will shift the industrial processes from linear (open loop) system in which the resource and capital investments move through the system to become waste to ecological closed loop systems where wastes become inputs for new processes [8].

In this work, solid-state recycling process is proposed to realize the direct recycling of aluminum – zinc alloy chips and copper metal chips as the green engineering forming technology. Moreover, it will be used to produce solid shaft directly from solid state without melting and any other additive elements or process to improve the mechanical and the microstructure of products.

2. Experimental work

2.1. Manufacturing of extrusion die and punch

The pressing mold that used to produce solid shaft directly from solid chips are manufacturing in our workshop and the main stages for manufacturing process are shown in figure 1.

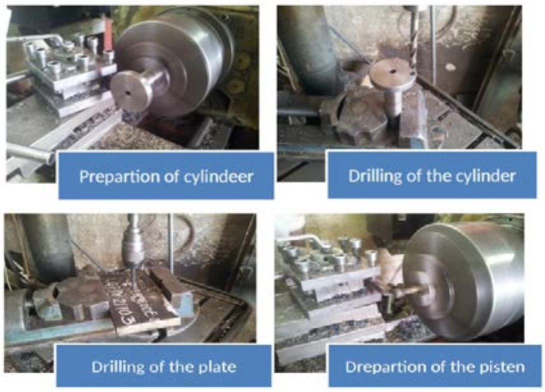

Fig. 1. The main stages for manufacturing of pressing mold.

The stages for manufacturing die and punch are included four stages. Preparation of cylinder by using turning machine, then drilled by drill machine to get holes, cutting plate by sawing machine and drilled by drilling machine, and manufacturing the punch or piston by turning machine. Finally, assembled these parts to be as shown in figure 2.

Fig. 2. Assemble of pressing mold (die and punch).

2.2. Materials

Different size and shape of Al-Zn alloy and copper metal chips are collected from the workshop as a waste of cutting operation such as turning, milling, and sawing process as shown in figure 3. The size of chips that used in this research were measured by using sieving with mish between 0.300 to 3.00 mm as shown in figure 4. The size of chips were distributed into 70% between 3-2 mm and 30% less than 1 mm. The length of chips in the range of 3.20 to 11.85 mm and width in the range of 0.39 to 3 mm. Moreover, the shape of chips were used are square and rectangular geometry chips. They used to produce solid shaft form solid chips by using the direct conversion method without heating and melting.

a) Copper Chips b) Al-Zn alloy Chips

Fig. 3. Chips that generated from cutting operation as waste a) copper chips, and b) Al-Zn alloy chips.

Fig. 4. Sieving tools used to measure size of chips.

2.3. Chips compaction and extrusion

Al-Zn alloy and Copper metal chips were compacted and extruded by using direct conversion method without re-melting and heating. They are pressed inside a thick walled steel tube with an inner diameter of 13 mm and punch with length of 180 mm as shown in figure 2. Each compaction step was stopped when the maximum force reached to the value that selected for each experiment. Different pressing pressures in the range of 10, 20, and 30 tons are used to produce solid shaft directly from chips. The pressing pressure was applied from one side and two sides (in the opposite direction) as shown in Table 1.

Table 1. Experimental condition for direct conversion methods for Al-Zn alloy and Copper metal chips.

Experiment No.	Metal type	Press load (ton)	Press direction
1	Al-Zn	10	One side
2	Al-Zn	20	One side
3	Al-Zn	10	Two side
4	Al-Zn	20	Two side
5	Al-Zn	30	Two side
6	Copper	10	Two side
7	Copper	15	Two side
8	Copper	20	Two side
9	Copper	30	Two side

3. Results

3.1. Shape of products

Figures 5-9 show the shape of shafts that produced from Al-Zn alloy chips and copper metal chips with different pressing pressure by applied direct recycling method.

Fig. 5. Direct recycling shaft produced from chips of Al-Zn alloy with press pressure of 10 tons applied from one side

Fig. 6. Direct recycling shaft produced from chips of Al-Zn alloy with press pressure of 20 tons applied from one side.

Fig. 7. Direct recycling shaft produced from chips of Al-Zn alloy with press pressure equal to a) 10 tons and b) 20 tons applied from two sides.

Fig. 8. Direct recycling shaft produced from chips of Al-Zn alloy with press pressure of 30 tons applied from two sides.

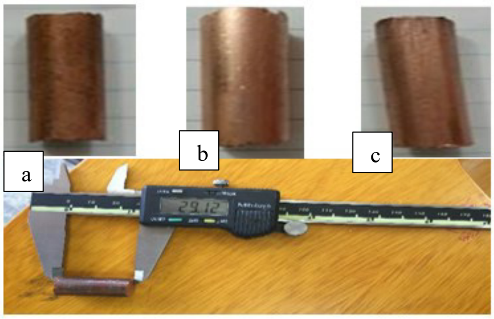

Fig. 9. Direct recycling shaft produced from chips of copper metal with press pressure of a) 10 tons, b) 20 tons, and c) 30 tons applied from two sides.

3.2. Hardness

The hardness of metals produced by conventional forming process and direct conversion method were examined by micro hardness device and the results show in tables 2 and 3.

Table 2. Hardness of metals produced by conventional method [9, 10].

Item No.	Metal type	Note	Hardness (HV)
1	Al-Zn	Without	60-65
2	Copper	annealing	77-99

Table 3. Hardness of recycling solid shaft produced by direct conversion method.

Experiment No.	Metal type	Press load (ton)	Press direction	Hardness (HV)
1	Al-Zn	10	One side	20.99
2	Al-Zn	20	One side	24.18
3	Al-Zn	10	Two side	25.282
4	Al-Zn	20	Two side	34.763
5	Al-Zn	30	Two side	63.70
6	Copper	10	Two side	72
7	Copper	15	Two side	73
8	Copper	20	Two side	80
9	Copper	30	Two side	85

3.3. Density

Tables 4 and 5 show density of metals produced by conventional method and direct recycling chips produced by direct conversion methods.

Table 4. Density of metals produced by conventional method [9, 11].

Item No.	Metal type	Note	Density (g/cm^3)
1	Al-Zn	Without	2.69
2	Copper	annealing	8.92

Table 5. Density of direct recycling chips produced in this research work.

Experiment No.	Metal type	Press load (ton)	Press direction	Density (g/cm^3)
1	Al-Zn	10	One side	2.276
2	Al-Zn	20	One side	2.293
3	Al-Zn	10	Two side	2.438
4	Al-Zn	20	Two side	2.4899
5	Al-Zn	30	Two side	2.545
6	Copper	10	Two side	7.837
7	Copper	15	Two side	7.847
8	Copper	20	Two side	8.34
9	Copper	30	Two side	8.38

3.4. Microstructure

A light microscope examined the microstructure of the extruded profile. The specimen was prepared by grinding one side using emery paper gradually from 140-1200 µm. Then polished with alumina and etching. Figure 10 and 11 show the microstructure for extruded Al-Zn alloy and Copper metal produced by direct recycling process.

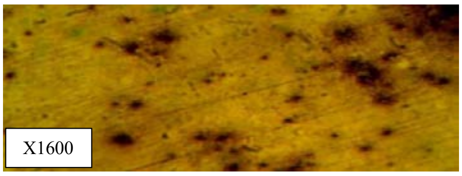

Fig. 10. Microstructure of Al-Zn alloy after pressing chips.

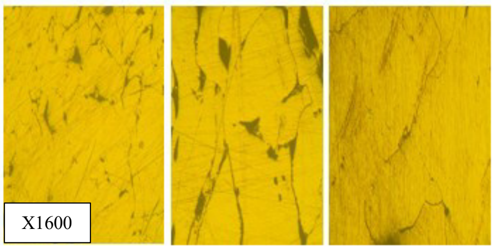

Fig. 11. Microstructure of copper chips metal after pressing under 10, 20, and 30 tons.

4. Conclusions

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 alloy. There is no needed to prepare powders for forming and sintering the products.

The magnitude and direction of pressures significantly affected the hardness and density of produced parts. From the investigation found that higher cold pressing pressure leads to higher density of cold pressed samples and higher hardness. In addition, pressing from two side is better than one side, which led to uniform distribution of pressure and homogenous product with approximately same hardness and density everywhere in the products recycling chips.

The results show that when the pressing load equal to 10 and 20 tons and applied from one side, the results parts become brittle and incoherent. However, when the pressing pressure increased to be 30 tons and the pressure applied from two sides in the opposite direction, the products shaft become strong and coherent parts with density and hardness closed to original parts as received. In addition, the results show that smaller and simpler chips prove to be better-input materials for cold compression. However, large and complex chips were exhibited lower relative densities and hardness. The final density of cold extruded chips were 95% and 94% of density of parts produced by conventional methods (casting and rolling) for Al-Zn alloy and Copper respectively. The result is agree with the result that got by Chiba et al which found that cold extruded chips was 97% of cast materials [12]. On the other hand, final hardness of cold extruded chips were equal to 98% of the parts produced by cast and rolled.

Direct recycling method with cold compression and extrusion has many benefits including cost and energy saving other than environmental protection by reducing the hazardous gas emission. Additionally, the process was simple, which required less energy and do not harm the environment. It is clean recycling technology. It is promising approach to overcome the problem of material loss during re-melting of chips and to further improve the energy balance.

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