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Efficiency Improvement of Aluminum Recycling Process

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Abstract

Aluminum has been used as a raw material in the automotive, aerospace, cookware and construction industries, including daily appliances. The manufacturing of aluminum ingot from aluminum scraps involves the recycling process where the aluminum scraps are melted and recast together with the modification of chemical composition. Since the recycling process has to account some operations to prepare and manage the scraps, the process is generally ineffective in terms of time and activities related. This in turn leads to the increased waiting time and cycle time of the process. This research therefore aims at increasing the efficiency of aluminum recycling process with emphasizing on the cycle time reduction. The ECRS technique and 5W1H activity analysis were employed to eliminate wastes in each operation of the process. The casting techniques were used to reduce scarp melting time which shared the largest portion of the whole production time. After the process improvement, wastes can be eliminated, thus increasing the efficiencies of man and machines from 34.12% and 59.46% to 50.68% and 61.95%, respectively. The average production cycle time can be reduced from 25.91 hours to 20.13 hours, thus saving the manufacturing cost by 421,327.65 baht accordingly.

Keywords : Improvement, Aluminum, Recycle, Casting, ECRS technique

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1. Introduction

Aluminum recycling process is of significance for economic, energy, environmental and resource savings since the process attributes a lower production cost than the primary aluminum production [1-3]. The aluminum scraps are molten through the casting process, where the material is refined to meet the specification. In order to efficiently recycle aluminum, the scrap sampling, scrap purchasing and metal yield have to be managed properly. This is due to the fact that such factors directly affect the recycling cost and obtained product quality. Specifically, the metal yield is a crucial factor in the aluminum scrap recycling process. The metal yield is subject to many parameters such as the surface area to volume ratio, scrap shape, type of alloy, scrap history, contaminants and the amount of required flux additives in the melting process [4-5]. The different ratio of surface area to volume of scrap can introduce the different degree of surface oxidation to the scarp as well as the melting rate. The type and amount of contaminant, e.g. oxides, water, oil and paint, can also alter the chemical composition of aluminum ingot manufactured. Xiao and Reuter [5] found that an increase in contamination on scrap reduces the metal recovery. This is due to the chemical reaction between contaminants and aluminum that makes the recycling process difficult to control, thus lowering the metal yield. Regarding the contaminants, Gaustad et al. [6] discussed that the accumulation of impurities in the recycled aluminum is significant to the compositional barrier, where some elements are undesirable such as Fe, Mg and Zn. These contaminants can be eliminated by physical separation and refining technique to purify the metal.

In general, the chemical contents of aluminum product can be controlled by properly selecting the charged aluminum scrap in the melting process. However, there are a wide variety of aluminum scraps in terms of shape and chemical composition. This thus brings a difficulty to the process control for gaining the efficiency of recycling process.

Typically, each recycling batch takes a very long cycle time in changing scraps to an ingot. The production is likely uncertainty and ineffective in terms of processing time and sequence. Thus, the increased production cost and delayed product delivery could be evident inevitably. In order to lessen the uncertainty, the production scheduling has to be taken into account.

Wastes and ineffective management of time and activities are also the major problems of the recycling process. Weerawat et al. [7] applied the plant layout principle and simulation to reduce the walking distance and material flow in the production line. Furthermore, the ECRS technique (standing for Eliminate, Combine, Rearrange and Simplify) and 5W1H analysis (standing for Who, What, Where, When, Why and How) can be applied for leading the process to a more efficient one. Many contributions used the ECRS technique to reduce the idle time and losses in the productions

[8-10]. Although the ECRS technique can be used to guide for the waste reduction, the improvement of recycling process is still limited to some extent in which the process is significantly subject to the melting rate of scraps. Some new recycling methods were proposed to increase the process performance [11-12]. However, these techniques were only viable in the lab scale. The efficiency improvement technique is therefore needed for the aluminum recycling process in a more practical way than the existing approaches.

This study aims at reducing the cycle time of the aluminum recycling process. The process analyses and improvement were carried out, based on the reverberatory furnace equipped with the controlled fuel rate. The root cause of production uncertainty associated with the processing time and activities was justified and discussed. The presented methods and findings of this work would provide an essential guideline on the process improvement and control for metal recycling or related industries

2. Aluminum Recycling and Manufacturing

2.1 The current operations and problems

The aluminum recycle process can be divided into six activities, i.e. scrap charging, mixing and stirring, scrap melting, temperature correcting, chemical content checking and cleaning the molten aluminum as sequentially shown in Fig. 1. This working procedure can be repeated by additionally charging scraps into the furnace, where it is mixed and stirred in the leftover molten aluminum. A small amount of liquid aluminum is sampled to examine its chemical composition. Some additional scraps as well as additives are added into the furnace in order to correct the chemical content. Once the composition and volume of molten aluminum satisfy the production requirement, it is then cast into the aluminum ingots and ready for supplying the manufacturing industries.
In this study, all data of aluminum recycling process were taken from a company as a case study. The cycle time for each production batch can be varied by the production volume as shown in Fig. 2. This value can be varied depending on the scarp type and chemical composition of aluminum (approximately 17-23 tons/batch). In Fig. 2, the distribution of production time is plotted, where the average production time is 25.91 hours with the standard deviation of 4.23 hours.

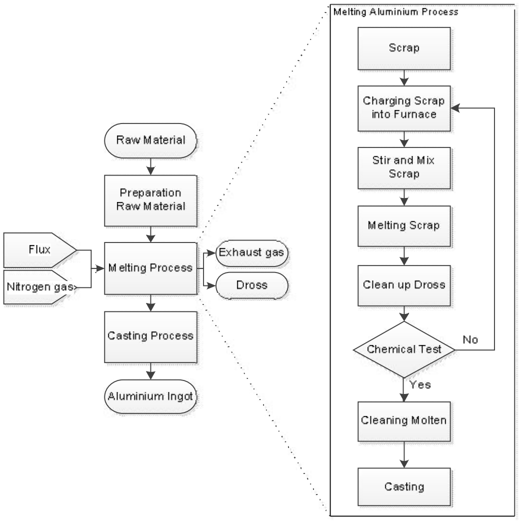


Fig. 1. Procedure of aluminum recycling process

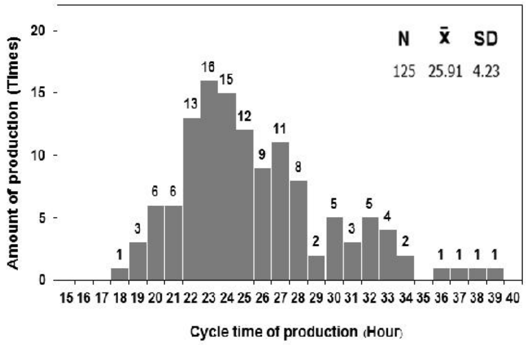


Fig. 2. Cycle time of aluminum recycling process before the improvement

By categorizing the processing time of each batch, it was found that the scrap melting time shared up to 51.5% of the total production time as shown in Fig. 3. The scrap charging and cleaning dross took 19.4% and 12.4%, respectively. By minimizing time required for these processes, the overall production time can be reduced. Nevertheless, some constraints due to the process limitations have to be taken into account, so that the detailed activities of each procedure are needed to be exposed and analyzed.

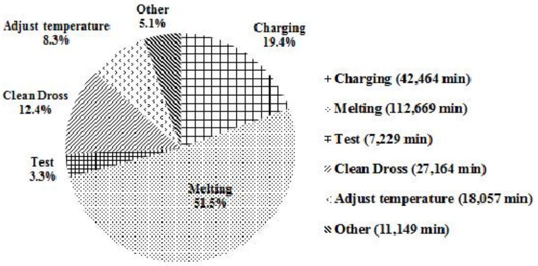


Fig. 3. Proportion of processing time in the aluminum recycling process

2.2 Process activities and effects

Regarding Fig. 1, the first activity is scrap charging process. The charging, mixing and stirring of scraps in the furnace are basically done after another in the continuous manner. The charging time is dependent on the amount of scrap and scrap shape by which the time increases with the scrap volume and bulgy shape.

After completely charging the scraps into the furnace, the melting scrap process takes place in the subsequent step. This activity consumes a high proportion of working time to entirely change the solid aluminum scraps into the liquid aluminum. This is related to the heat energy that transfers form the surface of scrap to its inner core and then induces the solid-liquid phase change to yield the complete and homogenous molten aluminum. The melting time also depends on the amount and shape of scraps, where the increase in amount and size of scraps increase the melting time required. Moreover, the temperature (650-700 ºC) and amount of molten aluminum remained in the furnace are also the important factors affecting the time to completely melt all scraps. During the charging and melting processes, the furnace temperature is occasionally adjusted to maintain the molten stage of aluminum and expedite the melting rate of scraps being charged.

A small amount of liquid aluminum is taken form the furnace and solidified in a prepared mold. The solid aluminum sample is then characterized by the Spectrometer to determine its chemical composition.

This chemical testing is done from time to time during the melting process until the composition can confirm to the requirement. Once the composition is corrected by adding some additives into the furnace, the cleaning process begins to clean up dross in the furnace. This activity includes cleaning spurt flux by feeding nitrogen gas into the molten aluminum. As a result, the dross is formed and floats on the surface of molten aluminum, where the dross is swept out of the furnace. A small amount of liquid aluminum mixing with dross is inevitably taken from the furnace. This molten aluminum is later solidified and becomes a solid piece called “sow”, and it can be reused as the raw material after dross is separated.

Besides the main activities expressed above, there are some non-value added activities involved into the production such as machine breakdown, power outage and of course the melting process. According to Fig. 3, the waiting time due to the scrap melting process is considered as a significant loss in the aluminum recycling process. This crucially impacts the production efficiency, needing to be minimized or even eliminated. In some production batches, the melting and refining processes are separately done in different furnaces, by which the scrap charging and melting operations are performed in the first furnace until all solid pieces are completely melted. The liquid aluminum is then transferred to another holding furnace in order to do the chemical refinement as well as cleaning purpose. Such transferring of liquid metal is truly a time consuming activity to be eliminated.

To clearly understand the activities and time required in the aluminum recycling process, the man-machine chart drawn from the current production is shown in Fig. 4. It appears that the times for charging of 350 minutes (20.9%), melting of 812 minutes (48.5%), composition testing of 56 minutes (3.3%), cleaning of 146 minutes (8.7%) and adjusting the temperature of 150 minutes (9.0%). In addition, there are some activities, i.e. waiting for transfer and transferring liquid metal, that are inefficient and approximately consume 160 minutes (9.6%) in the production. From the figure, the cycle time of this production batch is 1,618 minutes and the total scrap supplied into the furnace was 22,843 kg. It can be noted that the melting time is relatively long at the beginning stage of production. This is attributed to the fact that most of the charged scraps are still in solid pieces, thus requiring time to heat and completely melt the scraps. The man and machine efficiencies of this production can be calculated by:

$$E_{man} = t_{man} / CT \qquad (1)$$

where E_{man}, t_{man} and CT are man efficiency, operating time undertaken by the operators and cycle time, respectively.

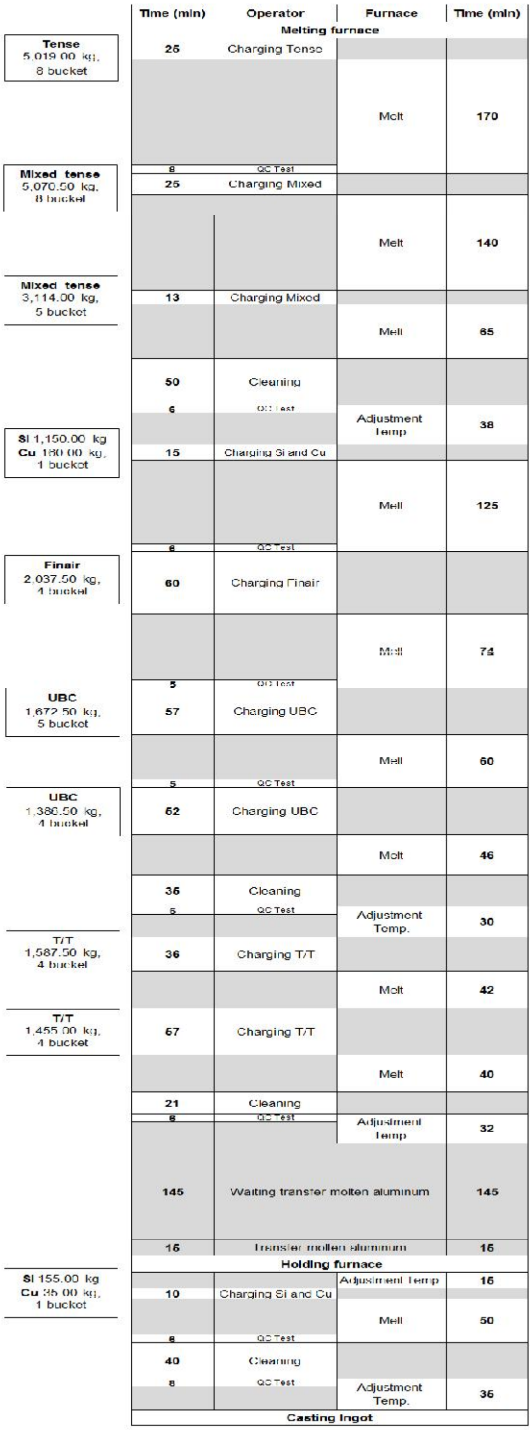


Fig. 4. Man-Machine chart shows the relationship between operator and machine before improvement

According to Eq. (1) and the data given in Fig. 4, t_{man} and CT are 552 and 1,618 minutes, respectively. Thus, the man efficiency for this production is 34.12%. The machine efficiency ($E_{machine}$) can be similarly determined by using:

$$E_{machine} = t_{machine} / CT \quad (2)$$

where $E_{machine}$ and $t_{machine}$ are machine efficiency and machine operating time. Regarding the information shown in Fig. 4, the machine operating time is 962 minutes, resulting in the machine efficiency of 59.46%.

The calculated man and machine efficiencies revealed that this production was apparently inefficient, needing the elimination of non-value added activities as well as manufacturing wastes to increase the process efficiency. This can be done by resolving and modifying some activities through the ECRS technique and 5W1H analysis that is a method of asking questions about a process or a problem taken up for improvement. Especially, the melting time should be shortened to reduce the cycle time of this aluminum recycling process.

3. Results and Discussion

3.1 Modification and analysis of process activities

By employing the ECRS technique to reduce the ineffective time, from the metal transfer activity from the melting furnace to the holding furnace can be eliminated as shown in Fig. 5. Since the liquid aluminum needs not to be transferred between the furnaces, the reheating step or temperature adjustment can be eliminated as well, thus saving the production time of about 175 minutes for this case study.

According to the present activities, each type of scrap was separately and sequentially charged into the furnace. However, more than one type of scrap as well as additive elements can be together charged into the furnace in order to reduce the melting time. This is associated with the combining rule of the ECRS technique. The comparison between the present and proposed procedures on the melting time is given in Table 1.

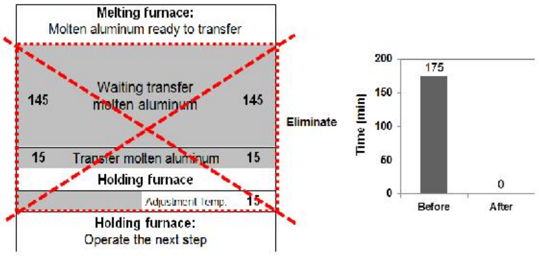


Fig. 5. Eliminating the molten aluminum transfer step

Table 1 Procedures of charging process

Activities	Time (min)	
	Charging	**Melting**
Present: separately charging		
Step 1: Si and Cu	11	112
Step 2: Al ingot	10	123
Propose: Combined charging		
Step 1: Si, Cu and Al ingot	10	138

In the cleaning operation, the separation of dross from the sow can be performed as an external activity. This is due to the process that is unrelated to the main recycling process as shown in Table 2. Therefore, the production can be kept continuously without any disruption due to the sow and dross extractions in the ongoing process. According to Fig. 4, it can be noted that the cleaning of liquid aluminum is performed occasionally in the recycling process. This involves the flux spurting into the molten aluminum, where the impurities can be extracted from the molten by the flux and then formed as the floating dross on the surface of liquid metal. However, the flux spurting process is not necessarily to be done every time in the cleaning activity. It is rather enough to perform the spurting in the last cleaning step before the ingot casting.

Table 2 Rearrangement activities in the cleaning

Activities of cleaning	Internal	External
Filling flux into the sprayer	●	
Spurting flux into the molten	●	
Heating the flux	●	
Sweeping dross out of the furnace	●	
Weighing dross	●	
Chopping dross into the small pieces		●
Extracting the sow		●
Collecting the scraps	●	
Weighing the scraps	●	

Table 3 Improved activities in the aluminum recycling process by using the ECRS technique

Process	Activity	Improvement	Result
Charging	Charging scrap	Combine & Rearrange	Reduced the melting of scrap Reduced the melting of scrap
Melting	-		
Cleaning	Spurting flux	Simplify	Reduced the number of cleaning activity
	Extracting the sow	Rearrange	Reduced the waiting time caused by the sow extraction
Chemical testing	-		
Others	Transferring the molten between furnaces	Eliminate	Eliminated the waiting time consumed in the transferring steps

The summary of process improvements using the ECRS technique is listed in Table 3.

3.2 Analysis of scarp feature

In addition to using the ECRS technique, the reduction of melting time can be further achieved by considering the charging order of scraps. Despite the fact that there is a variety of scrap shape and size, these scrap features importantly affect the melting time. By orderly charging the scraps regarding these features, the overall melting time can be minimized. After analyzing the process, it was suggested that the relatively thick metal pieces have to be firstly charged into the furnace, followed by the thin or smaller pieces. This is owing to the rapid oxidation of aluminum that usually takes place at the early state of melting operation. If too small aluminum pieces are applied in the furnace, they can be vigorously oxidized and in turn vaporized quickly, thus lessening the production yield. The thick and bulk aluminum pieces are rather supplied at first in order to encourage a substantial amount of liquid metal, whose internal energy can expedite the melting of smaller scraps consecutively charged into the furnace.

The scraps used in the aluminum recycling process can be catagorized into two main groups, i.e. (1) base raw material and (2) adjusting raw materials. The former is the main portion of aluminum in the furnace, while the latter is used to modify the chemical composition of molten. The base raw material is usually the aluminum scraps taken from many sources such as machinery parts, engine parts, used aluminum wheels, as well as aluminum ingot and sow as shown in Fig. 6. The scraps classified in this group are large and thick, requiring a relatively long melting time. Table 4 indicates the melting rate of scraps associated with the scrap features in the condition without molten aluminum in the furnace. It is apparent that the the used wheel provided the highest melting rate among the others listed in the Table 4. This is due to the car wheel's structure that consists of many gaps and holes for liquid aluminum to infiltrate, exchange heat and then melt the wheel. By contrast, the ingot or sow dross are too bulky and thick to heat up the whole piece in a short period of time.

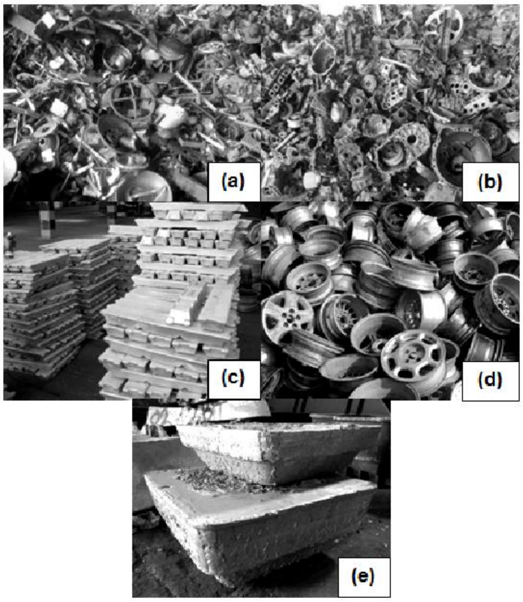


Fig. 6. Scraps used as the base raw material: (a) mixed tense; (b) tense; (c) al ingot; (d) used wheel; (e) sow

The adjusting raw materials or "new scrap" shown in Fig. 7 are usually obtained from the aluminum injection molding. The feature of this scrap is mostly small and thin, so that it can be melted as well as become oxided quickly [13]. However, this kind of scraps likely has a certain chemical composition. They are normally used in the refinining process to adjust the composition of molten in the furnace. The appropriate method to melt these scraps is to mix and stir them sinking in the molten aluminum. To avoid the oxidation and lessen production yield, the scraps should not be directly contacted with flame during the melting phase.

Table 4 Melting rate of base raw scraps in the condition without molten aluminum in the furnace

Scrap	Weight (kg)	Melting time (min)	Melting rate (kg/min)
Mixed tense	6,038.33	180.40	33.79
Tense	4,768.30	159.33	30.50
Al ingot	3,847.13	201.07	19.44
Used wheel	4,899.75	113.30	43.25
Sow dross	2,100.97	195.53	10.87

Fig. 7. Scraps used as the adjusting raw materials

3.3 Melting time reduction

The melting rate of scrap is subject to the surface area where it is in contact with flame and molten metal in the furnace. If the scrap has large surface area, the melting time will be shorten and vice versa. In addition, cracks or porous in scrap can increase the melting rate when they are infiltrated by the molten. Therefore, the surface area to volume ratio should be increased to reduce the overall melting time.

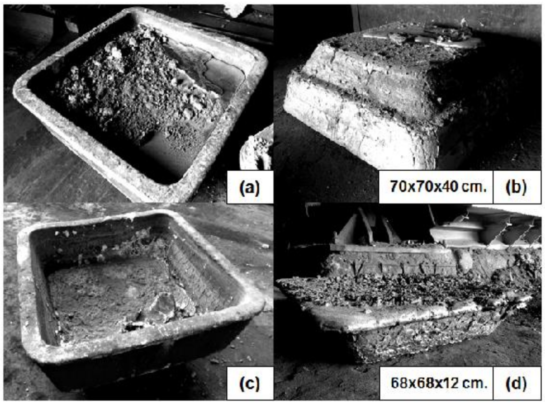


Fig. 8. Aluminum sow: (a) container fully filled by the sow; (b) size of sow obtained from (a); (c) smaller volume of molten in the container; (d) size of sow obtained from (c)

In spite of casting the sow until it completely filled in the container as shown in Fig. 8(a), the sow volume was kept to be smaller by pouring the molten aluminum that was already separated from dross in the shot-by-shot manner as shown in Fig. 8(c). This can decrease the quantity of molten aluminum in the container, thus reducing the sow size and time in melting process. In addition, the sow can be charged into the furnace while it is still at high temperature. This can also fasten the melting process.

Furthermore, a number of molten aluminum should be remained in the furnace after pouring into the ingot mold. The heat energy accumulated in the molten can shorten the melting time for the next batch. When the residual molten aluminum was left in the furnace, the decrease in melting time for each type of scrap can be seen in Table 5.

Table 5 Melting rate of base raw scraps in the condition with molten aluminum in the furnace

Scrap	Weight (kg)	Melting time (min)	Melting rate (kg/min)
Mixed tense	3117.48	68.55	45.25
Tense	3204.67	79.13	40.46
Al ingot	2979.85	131.10	22.97
Used wheel	2731.96	45.50	59.40
Sow dross*	276.33	13.83	20.12

* Sow had smaller size and heat accumulation.

3.4 Work plan improvement

According to the ECRS and some techniques suggested in the previous sections, the aluminum recycling processes were modified and the man-machine chart of the improved production place is shown in Fig. 9. It can be noticed that the cycle time is about 1,180 minutes for the scrap quantities of 22,936.00 kg.

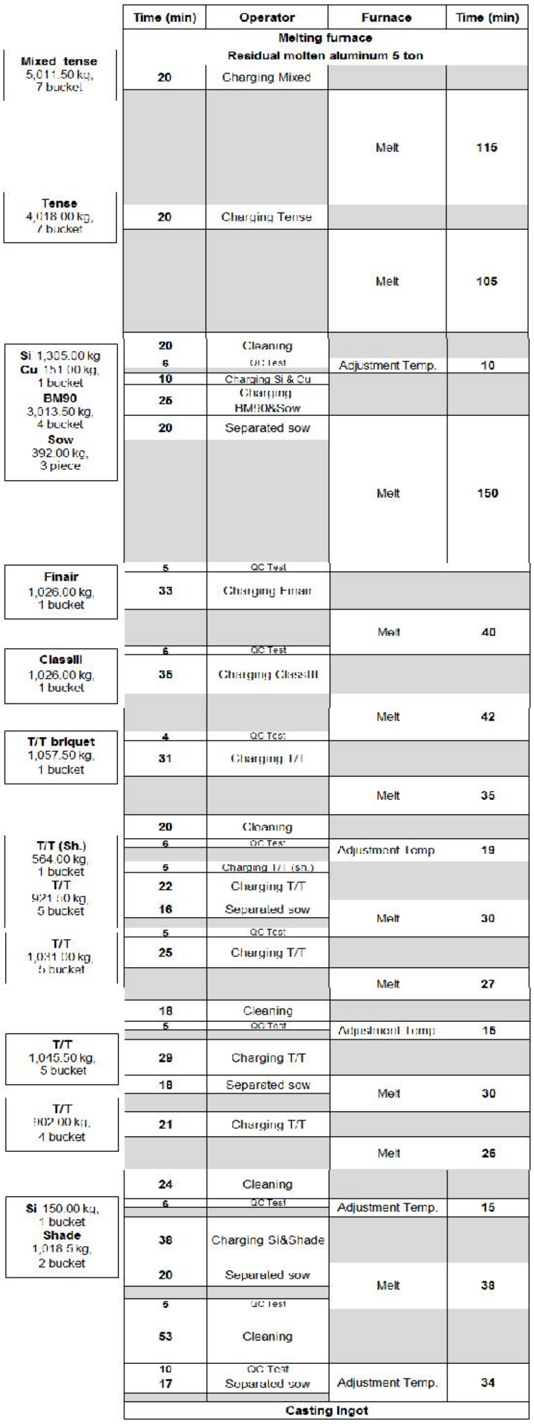
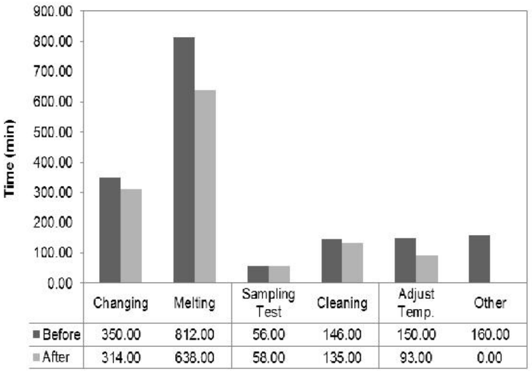


Fig. 9. Man-Machine chart shows the relationship between operator and machine after improvement

By using Eq. (1) and data given in Fig. 9, the t_{man} and CT are 598 and 1,180 minutes, respectively. Thus, the man efficiency for this improved production can be 50.68%, while the man efficiency before the improvement was only 34.12%. The machine operating time and machine efficiency associated with Eq. (2) were 731 minutes and 61.95%, respectively. Apparently, the machine efficiency was found to be increased from that of 59.46% in the former production plan.

Fig. 9 indicates the times for charging of 314 minutes (26.6%), melting of 608 minutes (51.5%), composition testing of 58 minutes (4.9%), cleaning of 125 minutes (10.6%) and adjusting the temperature of 75 minutes (6.4%) which presents no waiting time in the improved working plan. The cycle time of each production step is shown in Fig. 10, comparing the time consumed before and after improvement.



	Changing	Melting	Sampling Test	Cleaning	Adjust Temp.	Other
■ Before	350.00	812.00	56.00	146.00	150.00	160.00
■ After	314.00	636.00	58.00	135.00	93.00	0.00

Fig. 10. Time consumed in the main activities of the aluminum recycling process (before and after the improvement)

In the perspective of production cost, the fuel consumption in the melting process can be reduced significantly as shown in Fig. 11. This can save the fuel consumption of 4,406.58 m^3, equivalent to 421,327.65 baht to be economized.

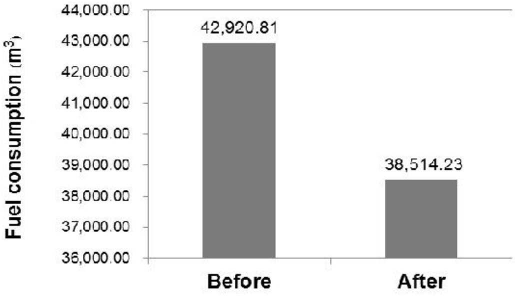


Fig. 11. Fuel consumption in production before and after the improvement

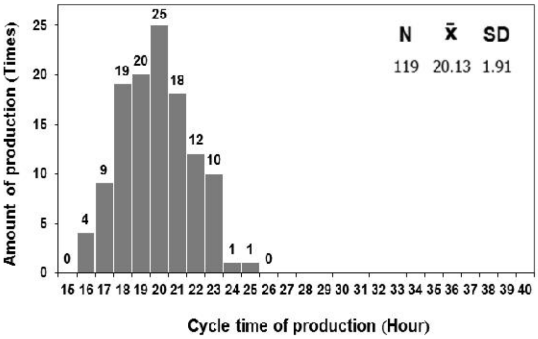


Fig. 12. Cycle time of production after the improvement

However, there are a wide variety of raw materials involved in the recycling process, yet the uncertainty of cycle time for each production batch. Therefore, the cycle time with regard to the new production plan (Fig. 9) was collected from a number of production batches to practically confirm the improvement. The average cycle time of the improved process was about 20.13 hours as shown in Fig. 12. This can save 6 hours in the aluminum recycling process compared to that consumed before the improvement.

4. Conclusions

The ECRS technique was used to improve the recycling of aluminum scrap, in which the melting process shared a large portion of time in the production. By eliminating, combining, rearranging and simplifying the activities, the average cycle time can be reduced from 25.91 hours to 20.13 hours. In addition, the efficiency of man and machines can be increased from 34.12% and 59.46% to 50.68% and 61.95%, respectively.

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