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Current Status of Tire Recycling in Taiwan

Shanshin Ton[1], Taipau Chia[2], Ming-Huang Lee[3], Yeh-Chung Chien [2], Hung-Yee Shu[4]
[1] Dept. Env. Eng. & Sci., Feng Chia Univ., Taichung 407, Taiwan, R.O.C.
[2] Dept. Ind. Safety & Health, Hung kuang Inst. Tech., Taichung 433, Taiwan, R.O.C.
[3] Dept. Material & Mineral Resource Eng., National Taipei Univ. of Tech., Taipei 106, Taiwan, R.O.C.
[4] Dept. Env. Eng., Hung kuang Inst. Tech., Taichung 433, Taiwan, R.O.C.

There are more than 15 millions cars or motors in Taiwan. According to the statistics from Environmental Protection Administration, the number of resulting scrap tires are near 110 thousand tons each year. The tire recycle programs in Taiwan were first conducted in 1989 and executed by ROC Scrap Tire Foundation. However, the current efficiency of the tire recycling industry still needs to be improved to minimize the environmental problem or fire hazards caused by scrap tires storage. Ten major tire-recycling factories are surveyed in this study. The investigations include the source of scrap tire, the shredding process, the market of products, the management of wastes disposal, and the difficulties of these sectors. As the varieties of the shredding machines of the recycle factories, there are three kinds of final products which include powder, granular, and chips. The wastes, wires and fibers, produced by the shredding process are the major problems for all the factories.. The percentage of the wire and fiber removal from rubbers still needs to be increased. The best approaches found in this study to increase the efficiency of scrap tire recycling processes are proposed which include the improvement of magnetic separation system, fiber/rubber separation system, and the minimization of waste disposal. A categorized standard of the processing outputs is suggested as a reference for the decision-making of the tire-recycling factories.
Keywords: scrap tire, tire recycling, wastes management.

Introduction

Discarded tires present a number of environmental, health and safety hazards to public and become a serious public nuisance [1]. Rainwater accumulated in tire piles create an ideal environment for mosquitoes, which are known to transmit diseases to human beings. Another hazard induced by piles of tires is the tendency to catch fire. A massive tire fire can burn for weeks causing the rubber to decompose into oil, carbon black and heavy smoke, which may pollute ground, surface water and atmosphere.

There are more than 15 millions cars or motors in Taiwan. Approximately 11 million scrap tires are generated each year currently. The numbers of scrap tire are expected to increase as the increasing living standards [2]. In 1989, the Environmental Protection Administration (EPA) issued the Guideline of the Scrap Tire Recycling to foster the cleanup of tire piles and the establishment of locality-based collection centers. ROC Scrap Tire Foundation, a private sector, conducted and executed the first tire recycle program in Taiwan [3]. Since 1998, EPA had worked to strengthen the programs of recycling waste materials by funding the Resource Recycle Foundation. Surcharge has been collected from imported tires and every tire produced locally to set up the Foundation. Reimbursement Program issued by the Foundation provides a financial rebate to those who process scrap tires.

Current practices of scrap tires include landfill, direct use, recycling as crumb rubber, and combustion for thermal energy [1,2]. Besides the method of landfill or direct use, which utilize the whole tire, it is necessary to cut the scrap tire into pieces if crumb rubber and combustion fuel are needed. However, the current efficiency of the tire recycling industry still needs to be enhanced. Not only the capacity of the scrap tire recycling factories needs to be increased, but also the techniques of recycling process which performed to achieve the setting goal needs to be improved. All these related topics are discussed in this paper.

Methods / Procedures

In order to reinforce scrap tire processing efficiency, literature review, on-site visiting and data collection for current operation of tire recycling industry are applied in this research. The methods and procedures of this research are presented in Figure 1.

On-site visiting and Interviewing

On-site visiting and interviewing were scheduled to meet ten major scrap tire shredding process factories around the country. The information obtained from on-site visiting include the source of scrap tires, the capacity and the floor plan of shredding process, the market of the end products, the management of the wastes disposal, the safety and hygiene conditions of working place and the difficulties of these sectors.

According to the collected data, the efficiency of current tire recycling process, the sufficiency of the environmental protection actions and the benefit of these sectors are evaluated.

The promotion of scrap tire recycling techniques and the alternatives of using recycling by-products

The products of scrap tire shredding process include rubber, wires and fibers. Currently, rubber is the only product that is profitable from this process. Wire and fibers are wasted by-products and needed to be disposed. In this study, the quantities of disposal wastes for each factory are estimated to evaluate the possibility of recycling these by-products. Locally or regionally, by-product utilization facilities are suggested based on the results of cost/benefit analysis. Due to the varieties of the floor plan design, the improved programs have to perform in each plant individually. The promotion of general scrap tire recycling techniques is suggested after the evaluation of machinery efficiency.. Mechanical improvement, wire recycling techniques and fiber re-utilization are also summarized.

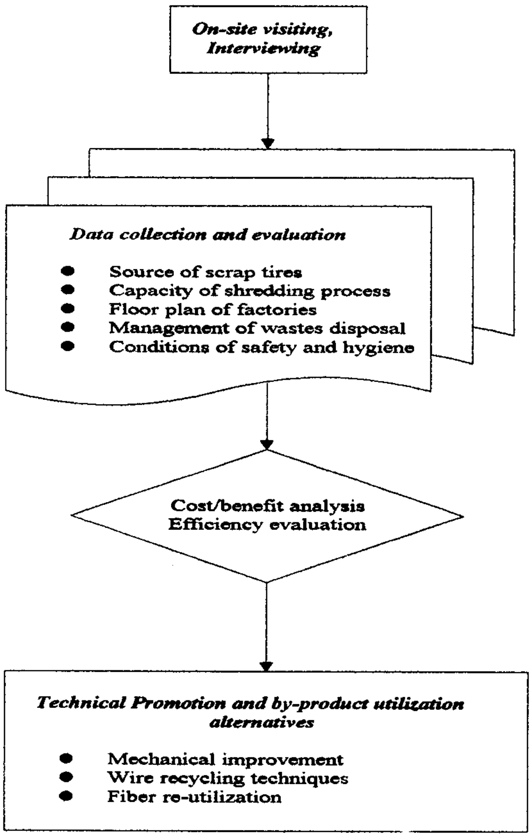

Figure 1 Flow chart of methods and procedures

Results and Discussion

On-site visiting and interviewing had been accomplished twice for some selected factories in this study. In the first round, ten major shredding process factories were visited. The plant managers or executive officers were interviewed to obtain the required information. Six factories with larger capacity were selected for the second round to confirm the data collected earlier. Validation of the cost/benefit analysis was checked at the same time as well. Samples in every processing step were taken for further study [2]. Layout of the floor plan and its outcome of a typical shredding process are summarized in Figure 2.

Evaluation of the operation status

According to the on-site visiting records, the capacity of tire recycling plant is ranged from 400 tons/mo. to 1,800 tons/mo., totally 10,350 tons per month (Table 1). The total annual capacity of the factories calculated from this investigation is close to the annual amount of scrap tires evaluated by EPA in Taiwan.

Table 1 Operation capacity of ten major shredding process factories in Taiwan

Item / Factory	Capacity (tons/mo.)	Percentage %
A	1200	11.6
B	900	8.7
C	500	4.8
D	1800	17.4
E	950	9.2
F	1650	15.9
G	1700	16.4
I	450	4.4
J	800	7.7
K	400	3.9
Total	10350	100%
Average	1035.0	-
Median	925	-

Comparatively, the tire recycle industry in Taiwan can be categorized as small and medium size business. However, these factories present very little resemblance. The major differences between each factory found in this study include machinery, floor plan design, work performance and the end products. The end products of these factories are divided into three categories, rubber chip (size > 1 inch), granular (size 1~15 mesh) and powder (size < 20 mesh). Crumb rubber, granular and powder, are produced from 41% (by weight) of the total scrap tires in Taiwan. Rest of the scrap tires are shredded into 1 ~ 2 inches rubber chips and are utilized for combustion fuel (Table 2).

Table 2 The end product of ten major shredding process factories in Taiwan

End products	Factory	Capacity
1.Powder (Grinding) (2850 t/m, 28 %)	A	1200 t/m
	C	500 t/m
	F	800 t/m
	J	350 t/m
2.Granular (Shredding) (1350 t/m, 13 %)	B	900 t/m
	J	450 t/m
3.Chip (Shredding for Fuel) (6150 t/m, 59 %)	D	1800 t/m
	E	950 t/m
	F	850 t/m
	G	1700 t/m
	I	450 t/m
	K	400 t/m

Note: Powder < 20 mesh; Granular 1~15 mesh; Chip > 1 in.

Difficulties and facts of the operation of shredding processing for tire recycling industry were obtained by interviewing with the plant managers or executive officers during the on-site visiting, as indicated in Table 3.

Table 3 Difficulties and facts of the operation of shredding processing for tire recycling industry in Taiwan

Item \ Factory	A	B	C	D	E	K	F	G	I	J	Sum
1.Short of scrap tire supply	V	V	V	V	V	V		V	V		8
2.No market for the production	V	V				V		V		V	5
3.Parts worn out than expectation						V		V	V	V	4
4.Failure of tire recycle system	V			V	V						3
5.High cost of wastes disposal		V	V	V							3
6.High investment demand			V	V							2
7.Failure of certified system					V		V				2
8.Shortage of man power										V	1

Eighty percent of the factories reported the shortage of scrap tire supply. In general, one third of the profit (ca. 1 NTD/kg) is paid for scrap tires transportation. In the case of tire shortage, almost all the factories have to pay higher price to get their supply. It resulted not only in the reduction of the operation capacity of these sectors but also in the profit of the reimburse fee from the Resource Recycling Foundation.

Five out of the ten factories worried about the market of the end products. Most of them produced crumb rubber rather than rubber chips. The market of production stands for the promise of their success. Further, the performances of the machinery that do not meet owner's expectations become an issue for some factories. In fact, enhancing the efficiency of these shredding machines is necessary.

Three factories pointed out that the wastes disposal fee is unaffordable. The disposal fee is varied from 1.5 NTD/kg to 6 NTD/kg for different counties that depend on the local regulation. In order to save this expense, many of them stacked the waste wires and fiber tissues in the backyard of the factories. However, factories that produced rubber chips for the use of combustion fuel don't have to pay for the wastes disposal fee. Therefore, for those who produced crumb rubber strongly suggested the necessity for the society to maximize the utilization of recycling by-products.

Environmental, safety and hygiene conditions of the scrap tire recycling factories from on-site investigations are evaluated and listed in Table 4.

Table 4 Environmental, safety and hygiene conditions of the scrap tire recycling factories

1. **Noise**-high, especially at the first shredding step
2. **Air pollution**-particulates, fiber tissues and odor
3. **Ventilation**-poor
4. **Luminance**-moderate
5. **Cooling water**- no treatment
6. **Fire hydrant**-without or poor
7. **Personal protection**-few respirators and safety helmets
8. **Machinery safety equipment**-none
9. **Wastes disposal**- piles of stock in the factories

Generally, the safety and hygiene conditions of the tire recycling factories also need to be improved. As most of these factories are small or medium size business, it is not easy for them to accomplish the improvements alone. Also they need training programs to instruct the labors follow the safety rules.

Cost/benefit analysis of tire recycling industry

As indicated earlier, the total process capacity of the tire recycling industry is close to the amount of scrap tires actually generated in Taiwan. The majority, ca. 60%, of the factories gained their profit only from the reimburse fee of scrap tire processing. When the certified end products are produced, e.g. 1 in. chips, > 5 mesh crumb rubber, the factories can apply for the reimburse fee from the Foundation according to the quantities of shredding process. However, different types of the end products may have different floor plan designs for the treatment. The machinery, equipment maintenance, operation cost and the income from the production are the main concerns.

The unit operation cost (UC) of the factories is closely related to the techniques of the shredding process. It is also served as an indicator to evaluate the efficiency of the factory. The internal cost including initial investment of plant and machinery, operation cost, transportation fee for scrap tires and products are the essential cost to run the business. Waste disposal fee is the only external cost for the shredding process since they rarely pay for the environmental and safety protection charge. The major benefit of tire recycling industry is the reimburse fee for their processing capacity plus the sales of their end products.

In this study, the UC is calculated by the formula indicated below for each factory and the results are shown in table 5.

$$\text{Unit operation cost (UC)} = [(T+W+E+O)-I] \div C \quad (1)$$

Where

T = transportation fee
W = waste disposal fee
E = equipment investment

O = operation fee
I = income
C = monthly capacity in average

The UC for each factory varied from 2.56 NTD/kg to 5.15 NTD/kg. Only three of them have the UC less than the reimburse fee, 3.2 NTD/kg. However, if the initial investment is not taken into account, the net UC is ranged from 1.67 NTD/kg to 4.0 NTD/kg. It indicated that most of the recycling plants didn't make enough profit from this business. The capacity and the end products of the factories are the key points to determine their future profit.

Improving techniques on shredding process

It is found that the efficiency of the machinery in most of the recycling factories still needs to be improved. Due to the varieties of the floor plans for each plant, the improved programs should be designed individually. From the practical and economical aspects, the best approaches found in this study to increase the efficiency of scrap tire recycling processes are the improvement of magnetic separation system, fiber/rubber separation system, and the minimization of waste disposal. The detail discussions of the promotion of magnetic separation system and fiber/rubber separation system are summarized in the project report [2]. The performance in each technical improvement is evaluated and the results are listed in Table 6.

Table 6 Evaluation of the performance in each technical improvement

Condition / Item	Before	After	Note
1.Magnetic separation system	70% of steel are selected from rubber crumb under traditional magnetic separation system	85% of steel had been collected from the new design	Rubber/steel separation 25 mm sieve size
2.Shaken screen/ separation system	35% of rubber are mixed with fiber	Only 10% of rubber are remained	Rubber/fiber separation, Adjustable blower speed
3.Gravity separation system	~ 45% of rubber are mixed with fiber	Only 15% of rubber are remained	Rubber/fiber separation, Adjustable blower speed

Less steel remained in the improved magnetic separation system of shredding process reduce the chance of wearing out the cutting edge of the machine. It is said that eventhough the adhesion of rubber on the steel may increase about 5%; the saving in the machinery maintenance can compensate the lost of the crumb rubber. Furthermore, the carbonization of waste wires that used to minimize the waste disposal may produce useful and profitable by-products, non-oxidized steel, for smelting mill. It also helps to enhance the efficiency of the tire recycling industry.
The techniques used for promoting the rubber/fiber separation system in this study have many adventages for scrap tire recycling. First of all, it reduces the amount of rubber in the fiber mixture to about 15%, which is acceptable for the reutilization of fiber. Secondary, the production of crumb rubber is increased due to the improvement of the separation techniques. The results of these improved techniques show that the wastes disposal is no longer needed and the sales of the by-products can be increased.

Alternatives of the utilization of shredding process end product

To enhance the efficiency of tire recycling is a task to reduce the UC for this industry. The works mentioned above have shown good results. However, to broaden the markets of its end products is a more direct way to achieve the goal. After evaluating the market of raw materials and its end products, categorized standards of the processing outputs are suggested as a reference to the tire-recycling factories for their decision-making (see Table 7).

Table 7 Recommended standards for the end product of scrap tire shredding process

Products	Impurity	End-use
Rubber chip >1 inch	No regulation	Aux. Fuel (cement Kilns, power plant)
Wire Re-shredding (15mm sieve)	2.5 % of rubber	Smelting mill (Arc furnace)
Wire Carbonization (25mm sieve)	Free of rubber	Smelting mill (Arc furnace)
Fiber Shaken/sieve Gravity separation	10 % of rubber 15 % of rubber	Pellet, Plastic production, filling of recycle production
Fiber 1 inch (Cryogenic process)	Free of rubber	Direct reuse
Crumb rubber 5 mesh	< 1 % of wire < 4 % of fiber	Playground cover, Runway base
Crumb rubber 10~15 mesh	< 1 % of wire < 2 % of fiber	Floor tiles, exercise mat
Crumb rubber 15~25 mesh	< 0.5 % of wire < 1 % of fiber	Activated rubber
Powder 25~40 mesh	< 0.1 % of wire < 1 % of fiber	Activated rubber, rubberized asphalt

Conclusion

The current statuses of ten major scrap tire factories around the country are evaluated in this study. The information obtained from on-site visiting include the capacity and the floor plan of shredding process, the market of the end products, the management of the wastes disposal, the safety and hygiene conditions of working place and the difficulties of these sectors. According to the collected data, the efficiency of current tire recycling process, the improvement actions and the benefit of these sectors are evaluated. The conclusions for this study are listed as followed.

1. The capacity of tire recycling plant in Taiwan is ranged from 400 tons/mo. to 1,800 tons/mo., totally 10,350 tons per month, which can be categorized as small and medium size business.

2. The percentage of end products of tire recycling is 28% for powder, 13% for granular and 59% for chip.

3. The results of the cost /benefit analysis of the factories indicated the quantities of the capacity and the quality of the end products are the key points to determine their future profit.

4. The improvement of magnetic separation system resulted in 15% more of steel had been collected from the new design; the improvement of shaken screen/ separation system resulted in only 10% of rubber remained in fiber tissue; the improvement of gravity separation system resulted in only 15% of rubber remained in fiber tissue.

5. The carbonization of waste wires conducted in this study produced useful and profitable by-products, non-oxidized steel, for smelting mill.

6. Standards of the end product of scrap tire shredding process are recommended in this study.

7. The safety and hygiene conditions of the tire recycling factories need to be enhanced.

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Table 5 Cost/benefit analysis and unit operation cost of shredding process for each factory

Factory	Capacity (kg/mo.)	Products	Payment and income					Unit operation cost (NT$/kg)
			Transportation (NT$/mo.)	Wastes disposal (NT$/mo.)	Reimbursement of instrument (NT$/mo.)	Operation cost (NT$/mo.)	Income (NT$/mo.)	
A	1,200,000	Powder	1,200,000	1,039,600	1,458,258	1,950,000	1,208,000	3.7
B	900,000	Granular	900,000	896,600	721,270	1,380,000	682,800	3.57
C	500,000	Powder	550,000	650,000	575,375	950,000	150,000	5.15
D	1,800,000	Chip	2,092,500	650,000	515,193	2,100,000	0	2.98
E	950,000	Chip	1,034,150	0*	835,242	1,820,000	254,000	3.62
F	1,650,000	Powder, chip	1,683,750	300,000	1,077,888	2,520,000	915,500	2.83
G	1,700,000	Chip	1,387,500	0*	507,160	2,450,000	0	2.56
I	450,000	Chip	494,000	0*	408,121	970,000	94,400	3.95
J	800,000	Powder, granular	800,000	0#	1,545,405	1,950,000	653,000	4.55

* Rubber chips are served as fuel, no wastes need to be disposed.
# Piles of wastes are stocked in the factory, no disposal fee was paid.

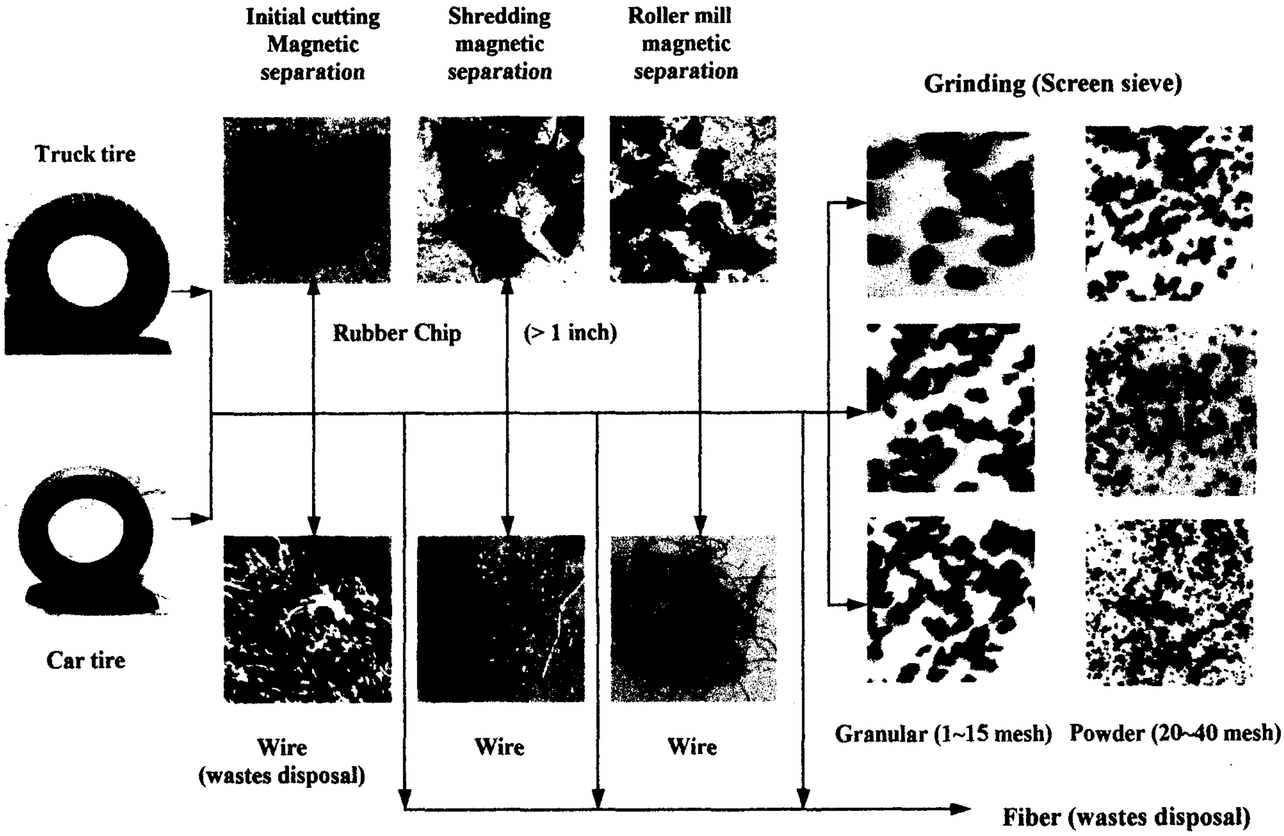

Figure 2 Illustration of the layout and outcomes of the shredding process for scrap tire recycling.