CHAPTER 3 WASTE AUDIT AND MATERIAL RECOVERY

3.1 INTRODUCTION

Waste audit is an essential starting point for identifying waste types, sources and quantities, as well as the areas where waste minimization can be incorporated into an existing plant's processes or equipment.

The objectives of conducting waste audit in this study are manifold:

1. to identify every waste stream in a specified production line,
2. to quantify and characterize the waste generated and
3. to establish how and why the waste is generated.

Due to budget limitations and time constraint, identification and evaluation of waste minimization option was confined to the reuse or recycling possibility of the waste. With respect to this, the brake lining samples made of the reclaimed brake lining dust were sent to Bendix Mintex Pty. Ltd (parent company of Don Brake in Australia) for performance testing.

In addition, the project also looked into solidification/stabilization of waste as a treatment option, which formed the second component in the project and will be discussed in detail in Chapter 4.

3.2 DESCRIPTION OF WASTE AUDIT PROCEDURE

The waste audit was undertaken as the following steps:

I. Audit scope was determined,

II. Background information was collected,

III. Input materials, products and waste streams data were identified and characterized,

IV. Comprehensive plant analysis was carried out and

V. Data was evaluated and waste audit reporting.

3.2.1 Determination of Audit Scope

This is a crucial step prior to the audit being carried out. It helps to determine the issues and elements of the process and the site worthy of detailed investigation.

3.2.2. Collection of Background Information

A preliminary site tour was conducted and Ms. Jayanthi, the Health, Safety and Environmental Officer gave a brief description of the facility and its operation.

A simplified waste audit protocol/worksheet, based on the worksheets recommended by US EPA Waste Audit Guidelines (1990), was prepared and used to gather necessary background information on the facility (refer to Appendix I). This includes the information on raw materials, production process, waste material generated and waste management cost. This information was then used to develop and organize the plant survey and help identify data gaps, sampling points and possible problem areas.

3.2.3. Identification and Characterization of Input Materials, Products and Waste Streams

The activities included:

(a) Identification of every possible waste stream using flow diagram of the production process,

(b) Collection of input material and production data. The components of interest included hazardous components, material handling and storage, production rate, and

(c) Collection of quantitative data on the identified waste streams which included volume, generation rate and waste management cost.

3.2.4. Comprehensive Plant Analysis

A comprehensive plant assessment was performed to fill gaps identified during the review of the background information and to achieve a better understanding of the possible root causes of waste generation. This was mainly achieved through a site inspection. Besides following the process line from the arrival and storage of raw materials to the shipping of final products; operation at various time during a shift was monitored; housekeeping procedures were observed; operators, supervisors and relevant personnel were interviewed as well.

To identify and quantify the existing and potential waste streams, a study was carried out to measure the weight loss of the brake lining after each step of the production process, from preforming/molding stage to chamfering. This was accomplished by observing and following the process line closely for a period of 7 weeks. Four types of brake lining references were selected based on the production priority. Data was collected on random sampling basis where weight of samples were measured before and after a process step, in order to determine the weight loss from each of the process step. For each brake lining reference, four replicate set of data were collected and the average was calculated. The results are presented in terms of percentage loss in a simplified material balance for the brake lining production process.

3.3 WASTE AUDIT RESULTS

3.3.1 Audit Scope

Waste audit only focused on manufacturing process of brake lining and excluded other production line and office waste generated from office operation due to the great amount of brake lining dust generated in this production line. Four types of brake lining references were selected based on the production priority.

3.3.2 Collection of Necessary Background Information

Not all the necessary background information was available, because it was not their normal operating practice to prepare the document and some of documents were not revealed due to confidentiality. The status of the availability of the background information is presented in Table 3.1.

Table 3.1 Status of availability of background information

Background information	Availability
I. Design Information	
1. Process flow diagram	✓
2. Material and energy balance	x
3. Operating manuals and process description	✓
4. Equipment list, specification and data sheet	✓*
5. Plant layout and elevation plan	✓
II. Raw Material & Production Information	
1. Material safety data sheets	x
2. Product and raw material inventory records	✓*
3. Operating procedures	✓
III. Environmental Analysis Information	
1. Waste analysis reports	x
2. Waste manifest	x
3. Waste transport and disposal records	✓
4. Environmental audit reports	x
IV. Economic Information	
1. Waste treatment and disposal cost	✓
2. Product, utility and raw material cost	✓*
3. Operating and maintenance cost	✓*

Note: x Information not available
✓ Available information
* Information available but not revealed by the facility

3.3.3 Identification and Characterization of Input Materials, Products and Waste Stream

Input Materials

The waste generated was closely related to the type of material used in the manufacturing process. Asbestos, iron powder, friction dust, glass fiber and resin are among the major raw materials. The characteristics of asbestos like high tensile strength, inflammability, corrosion and friction resistance, make it well suited for friction products, such as brake linings for automobiles and industrial machinery. Asbestos and other fibrous materials are used extensively as the major constituents and primary reinforcing fiber in the making of brake linings (Anderson, 1995).

Among the input materials mentioned above, asbestos, glass fiber and friction dust which are in the form of light fiber or fine particles are considered as hazardous. If inhaled, it can cause lung cancer in the long run.

The input materials are delivered to the facility by truck or lorry, it was either packed in paper or plastic bag, in 20 kg per pack. All the input materials are stored in the warehouse which is next to the production line before being utilized. Forklifts are used to transfer the input materials from storage to mixing room and then to the molding machines.

The paper and plastics used to pack the input materials were disposed of together with the brake lining dust as it contained trace amount of hazardous materials.

Inventory of input materials is always maintained at a sufficient level with 15% extra, in order to avoid the problem of expired input materials. The expected shelf life of this input material ranged from 1 to 2 years.

Products

The final product of brake lining is in the form of solid block, as shown in the Plate 3.1. The brake lining has a long shelf life (> 10 years) due to its solid nature and is not degradable.

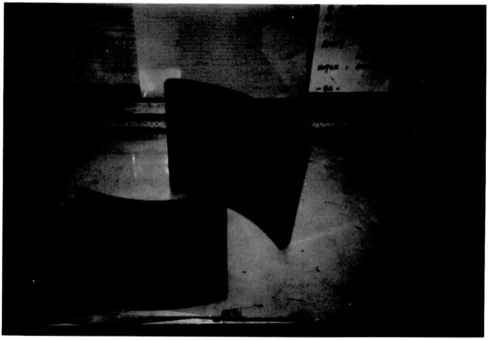


Plate 3.1 Brake lining

The brake linings are packed using plastic for every 10 pieces and 4 packets are then put in one carton box. It was stored in warehouse before sending to customers. The carton boxes are not returnable after sending to customers.

Waste Stream Assessment

Various waste types are generated, ranging from empty asbestos shipping containers, processed wastes to housekeeping waste from sweeping or vacuuming and pollution-control device waste from capture system. Figure 3.1 illustrates the waste generated from each of the process step. Various waste types associated with the process, from input materials storage to packing, is summarized in Table 3.2.

Majority of the waste generated is in the form of dust, namely brake lining dust. It is generated continuously as the production line is running, particularly during grinding, drilling and chamfering. Sucking system is used to suck the lining dust generated into the baghouse, the dust is then collected from the hopper. The lining dust collected is homogeneous without contamination with other unwanted materials. Plate 3.2 shows the dust hopper outlets where the lining dust is collected in drums lined with plastics sheets. The dust is then packed in double layered high-density polyethylene plastic bags and placed into 200 L metal drums.

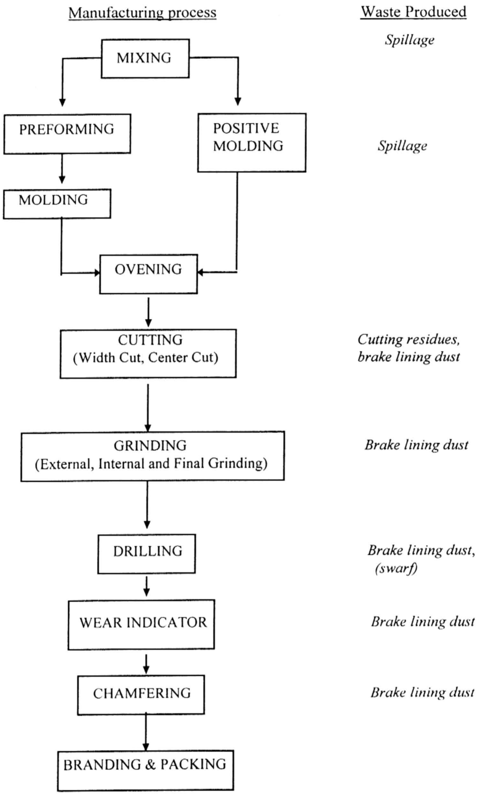


Figure 3.1 Manufacturing process of brake lining and the waste generated at each step

Table 3.2 Summary of the waste type generated at each step.

Activity / Process	Waste Type
<u>1. Raw materials and storage</u> Glass fiber, friction dust, resin, zinc oxide, brass particles, etc.	Spill residues[1], plastic bags[2], damage containers[2], wooden pallets[2], damage metal drums[2].
<u>2. Operation and Process</u> I. Mixing II. Preforming/Molding III. Cutting IV. Grinding V. Drilling VI. Chamfering	 Spill residues[1], plastic bags[2]. Spillage/fallout[1] of mixture from preform presses, waste generated when improper mixing[1], wrong density or contaminated with unwanted materials[3]. Cutting residues[3], rejected brake lining due to off-specification[3] Brake lining dust[1]. Brake lining dust[1]. Brake lining dust[1].
<u>3. Miscellaneous</u>	Worn gloves[2] (rubber and cotton), worn masks[2], plastics[2] (used as wrappers), paper[2], rags[2], scrap parts[2], carton boxes[2], sand paper[2], empty paint cans.

1. Scheduled waste
2. Non-scheduled wastes that are already contaminated with scheduled wastes are considered as scheduled wastes
3. The off-specification brake lining will be crushed and recycled as reclaimed material

<u>Current Waste Minimization Practices in Don Brake</u>

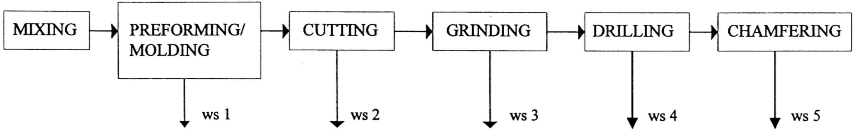
1. The dimension of certain molds have been modified in order to produce brake lining with the exact dimension, without cutting or grinding.
2. Off-specification brake linings are reworked/recovered by crushing into powder and is then mixed with virgin mix to produce brake lining for after-market.
3. Plastic containers are used for internal goods-delivery.
4. Good house-keeping is ensured to minimize spillage and avoid expired input materials.

Plate 3.2 Brake lining dust collected from hopper

3.3.4 Comprehensive Plant Analysis and Data Evaluation

Weight loss from each process step

Figure 3.2 displays the weight loss of brake lining at each step of the brake lining manufacturing process. The process of ovening is omitted because it does not contribute to significant weight loss (<0.1%). For each brake lining reference, four replicate set of data were collected and the average was calculated. The results are presented as average percentage lost and standard deviation for each of the lining reference.



Brake Lining Reference: 47441-4070 (0.85kg)

0.79% (±0.26%)	-	12.59% (±1.34%)	4.12% (±0.33%)	0.61% (±0.15%)

Brake Lining Reference: 47443-1350 (1.0kg)

0.47% (±0.20%)	-	10.64% (±1.16%)	3.63% (±0.58%)	1.07% (±0.30%)

Brake Lining Reference: 44066-90118 (1.5kg)

0.46% (±0.20%)	-	13.03% (±1.07%)	6.87% (±0.84%)	0.49% (±0.09%)

Brake Lining Reference: 12022-37501 (Billet 4.8kg , cut to 3 pieces - 1.6kg/pc)

0.59% (±0.18)	29.89% (±1.41%)	8.40% (±0.63%)	2.17% (±0.35%)	0.74% (±0.25%)

Figure 3.2 Weight loss of brake lining at each step of the manufacturing process (with standard deviation showed in bracket)
Note: ws: waste stream

As can be seen in the Figure 3.2, for the small pieces (0.85kg, 1.0kg and 1.5kg), the grinding process generated the greatest percentage of brake lining dust (~ 8 - 13%), followed by drilling process (~2.0 - 7.0%), chamfering (~0.49 - 1.07%) and preforming/molding (~ 0.46 - 0.79%). On the other hand, brake lining in billet form (4.8kg) are required to cut into 3 pieces (1.6kg/piece). The cutting process generated the highest percentage of weight loss (~ 30%), followed by grinding (~8.4%), drilling (~2.17%) and chamfering (~0.74%).

The total weight loss of each of the brake lining reference is summarized in Table 3.3.

Table 3.3 Total weight loss per piece of brake lining

Brake Lining Ref:	Total weight loss (g)	% Weight loss
474410-4070 (0.85kg/pc)	135 - 180	15.88 - 21.18
47443-1350 (1.0kg/pc)	140 - 170	14.00 - 17.00
44066-90118 (1.5kg/pc)	270 - 350	18.00 - 23.33
12022-37501 (4.8kg/billet) cut into 1.6kg/pc	540 - 720	33.75 - 45.00

Simplified Material Balance

Material balance, which is based on the principle of mass conservation, is an important tool to identify losses and to verify quantitative data of material input and output of a production process (National Academy Press, 1990).

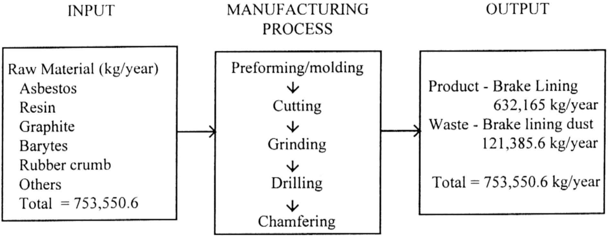


Figure 3.3 Simplified material balance for the brake lining production

A simplified material balance diagram applied to only raw materials (excluding labors and power) entering and exiting the automobile brake lining manufacturing unit is shown in Figure 3.3. This material balance is not chemical specific and involved less-complicated analytical methods. The estimated values are based on the quantity of input materials used and the production of brake lining for the month of September to November, 1997.

Generation Rate

The rate of generation of the brake lining dust are reported as in Table 3.4.

Table 3.4 Generation rate of brake lining dust for the years 1996 and 1997

	1996	1997
Annual (metric tons/year)	294	342.5
Maximum (metric tons/month)	29.2	33.46
Average (metric tons/month)	24.5	28.54

Source: Don Brake (M) Sdn. Bhd.

Waste Management and Disposal cost

Table 3.5 Waste management and disposal cost for the years 1996 and 1997

Cost Element	Unit Price (RM)	1996 (RM)	1997 (RM)
Plastic bags	1.50/bag	11,760	13,700
Metal drums (200 liter)	15/container	49,000	57,083
Transportation fee	67/metric tonne	19,698	22,947.5
Disposal fee	495/metric tonne	145,530	169,537.5
Total Disposal Cost		225,988	263,268

Source: Don Brake (M) Sdn. Bhd.

3.4 MATERIAL RECOVERY - RECYCLING OF BRAKE LINING DUST

The objective of this study is to investigate the recycling possibilities of the brake lining dust.

3.4.1 Preparation of Samples

Description of Procedure:

Prior to the mixing process, the iron component in the brake lining dust was separated manually using a magnetic bar. The brake lining dust without iron dust was then added to the virgin mix according to the following percentages:

a) 5% (=20.8kg) in Batch 1

b) 10% (=41.6kg) in Batch 2

The formulation of D381 was selected as control to run this test because this formulation contained a large proportion of reclaimed materials and it is meant for making second grade brake lining. The reclaimed material is the crushed off-specification brake lining. The component in the mix is presented in Table 3.6.

Table 3.6 Component of material in virgin mix (D381), Batch 1 (DX410) and Batch 2 (DX411)

Component	Virgin mix D381 (kg)	Batch 1 DX410 (5% dust) (kg)	Batch 2 DX411 (10% dust) (kg)
Raw Material	137	137	137
Reclaimed Material	229	208.2	187.4
Asbestos	50	50	50
Brake Lining Dust (witout iron dust)	-	20.8	41.6
Total	416	416	416

Bendix Mintex Pty. Ltd. (in Australia) specified that 9 sets (18 pieces) of sample must be prepared according to the reference 4515E ANCHOR & CAM (for left and right hand side testing) for performance testing purpose. The specific gravity (SG) of each sample was measured after the grinding process before sending the samples to Australia for performance testing.

Specific gravity was measured in the laboratory of Don Brake Bhd, according to the following formula:

$$SG = \frac{\text{weight in air (g)}}{\text{weight in air (g) - weight in water (g)}}$$

Result of Specific Gravity

The results of the SG test for D381, DX410 and DX411 are presented in Table 3.7.

Table 3.7 The result of SG test for Virgin mix (D381), Batch 1 (DX410) and Batch 2 (DX411).

	D381		DX410		DX411	
	ANC	CAM	ANC	CAM	ANC	CAM
1	2.130	2.187	2.254	2.230	2.256	2.227
2	2.243	2.209	2.276	2.200	2.269	2.187
3	2.237	2.199	2.257	2.217	2.283	2.201
4	2.248	2.176	2.284	2.209	2.243	2.214
5	2.259	2.141	2.278	2.192	2.271	2.204
6	2.184	2.187	2.258	2.220	2.266	2.206
7	2.221	2.157	2.263	2.195	2.299	2.220
8	2.207	2.139	2.261	2.211	2.273	2.211
9	2.242	2.183	2.199	2.228	2.221	2.228

According to the specification, the standard SG value for a brake lining is in the range of 2.130 - 2.299 (Source: Don Brake Sdn Bhd). As can be seen in the Table 3.7, The SG for D381, DX410 and DX411 are well within the specified range (2.12 - 2.32).

3.4.2 Performance Testing

Objective:

To evaluate the performance characteristics of 5% (DX410) and 10% (DX411) reclaimed brake lining dust in a virgin mix and to compare with the virgin mix of D381.

Description:

Inertia dynamo meter tests were carried out on each material. The brake type used was a 16.5" * 7" Rockwell "S" cam brake fitted with 4515E Cam and Anchor linings supplied by Don Brake Malaysia. Axie load of eight tons were used to calculate the required inertia of 983.45 kg/m^2 which equates to a wheel load of four tons.

The performance characteristics are reported in terms of the following characteristics: effectiveness, fade, post burnish effectiveness, post fade effectiveness and speed spread.

The definition and implication of terms relating to friction material performance testing are given below:

(a) Effectiveness - the level of torque output from a brake for a given input. (i.e. for an air brake system, air pressure is versus torque out).

(b) Fade - the characteristics experienced when friction material is subjected to high temperature during braking. Fade (or reduction of effectiveness) is created by the high temperature melting the resins in the friction material which turn to a liquid and work as a lubricant between the friction material and the disc or drum.

(c) Green Effectiveness - referred to the performance of the new friction material during the initial braking when the friction material is first installed in the brake.

(d) Speed Spread - referred to the performance level of the friction material with respect to various vehicle speeds. (Most friction materials have better effectiveness at low speed when compared to high speed, i.e. 30km/h compared to 110km/h).

(e) Post Burnish Effectiveness - referred to the performance level of the friction material after approximately 200 - 300 low effort brake application. (This procedure is referred to as Burnishing or Bedding in the friction material to the drum or disc).

(f) Post Fade Effectiveness - referred to the performance of friction material after being subjected to high temperature testing during the Fade sequence.

(g) Instability during the first fade - the variation in pressure applied to the friction material required to maintain a constant (straight line torque output during the first fade sequence).

<u>Results Summary</u>

The results provided by Bendix Mintex Pty Ltd are reproduced as in Table 3.8.

Table 3.8 Results of performance testing

Characteristics	D381 (virgin mix)	DX410 (5% dust)	DX411 (10% dust)
Preburnish 50 kph	4.2	3.1	4.5
Postburnish 30 kph	5.4	6.5	5.5
Postburnish 50 kph	5.6	6.4	5.3
Postburnish 80 kph	5.2	5.9	5.1
Postburnish 110 kph	4.6	4.7	4.6
First Baseline	6.1	6.2	6.0
First Fade	5.7	5.7	5.7
First Recovery	5.6	5.7	5.8
Second Baseline	6.1	6.5	6.5
Second Fade	6.0	6.8	6.7
Second Recovery	6.2	6.2	6.2
Post Fade 30 kph	7.3	7.4	7.5
Post Fade 50 kph	6.6	6.8	6.6
Post Fade 80 kph	5.2	5.6	4.9
Post Fade 110 kph	5.2	5.4	5.3

Based on the results in Table 3.8, the effectiveness of the DX411 (containing 10% reclaimed lining dust) is similar to the D381 (containing virgin mix). With respect to the characteristic of fade, D381, DX410 and DX411 showed similar result in the first fade, however for the second fade of DX411 is slightly better than DX410.

The results also indicated that DX410 (containing 5% reclaimed lining dust) exhibits lower green effectiveness and greater spread in post burnish and post fade effectiveness. On the other hand, fade of DX410 shows some instability during the first fade test, whereas second fade test is comparable with DX411 and is better than D381. There are no significant differences between DX411 when compared to D381 and hence the recycled product (DX411) shows great potential for recycling the brake lining dust.