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ASBESTOS WASTE AUDIT AND RECYCLING IN AN AUTOMOBILE BRAKE MANUFACTURING FACILITY*

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ABSTRACT

A waste audit study, using a modified protocol based on the U.S. EPA Waste Audit Guidelines, was carried out in a brake manufacturing facility, by observing and analyzing each of the process steps—mixing, preforming, molding, oven curing, cutting, grinding, drilling, wear evaluation, chamfering, and branding and packaging. Additionally, studies on waste minimization through recycling of the waste brake lining dust into the virgin mix and the effect of this recycling on subsequent product performance quality were also carried out. The audit showed that there was generation of waste at just about every step of the process, as evidenced by weight loss calculations on the original mix entering the process. For example, in the cutting step this loss was about 30 percent, in grinding it ranged from 10.64 percent to 13.03 percent, in drilling from 2.17 percent to 6.8 percent, and in chamfering from 0.49 percent to 1.07 percent; in the case of cutting this included both cutting residues and fines while in the rest of the cases these were only fines. Next, in evaluating the recycling of the fines, recycling 5 percent to 10 percent of the lining waste dust into the virgin mix retained the specific gravity of the brake lining samples well within the specification requirement range of 2.12 to 2.32. Additionally, inertia dynamometer tests were carried out on the linings produced from the 5 percent and 10 percent recycling mix, with

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the virgin mix as the control. The performance characteristics studied were effectiveness, fade, post-burnish effectiveness, post-fade effectiveness, and speed spread. Both the 5 percent and 10 percent recycled ones performed as good as the control one, although the 5 percent one exhibited lower green effectiveness and greater speed spread. Finally, based on an analysis of waste management and disposal costs, and in order also to minimize waste generation, a few simple process changes are suggested.

INTRODUCTION

Brake lining (or brake pad) forms an integral part of an automobile brake system designed to slow or stop the movement of an automobile. Don Brake Malaysia, a leading manufacturer of brake linking and other friction materials, produced 474,792 pieces of brake linings in 1997, generating 342.5 tons of brake lining dust, the main waste type from this process. This tonnage represents almost 60 percent of the total waste of 583 tons/year generated by this manufacturing facility.

The use of asbestos, however, as a major component in the brake lining manufacturing process poses high risk to human health and environment. Health implications of asbestos are well documented [1-3]. Deaths due to asbestos-related diseases are expected to rise to at least one million over the next 30 years [3].

Asbestos-containing materials, as defined by U.S. EPA, are materials that contain more than 1 percent asbestos. Only three types (chrysotile, amosite, and crocidolite) of asbestos have been exploited commercially until recently, although asbestos has been in use for more than 200 years. Chrysotile now represents >98 percent of current use worldwide [4, 5]. It has been used in friction materials (brake lining materials, clutch facings, automobile transmission discs, disc brake pads, etc.) from less than 10 percent (wt.) in railroad brake shoes, to over 60 percent in some passenger car drum brake lining segments. Typical asbestos usage range is anywhere from 30 to 50 percent [6]. In 1994, about 9500 tons of asbestos were used in the manufacture of friction materials for both new and aftermarket vehicles [7]. The use of asbestos, however, is totally banned in some developed nations, while the usage is on the increase in some developing countries. Asbestos consumption in the United States dropped from a peak of 800,000 tons in 1973 to 21,000 tons in 1996 [3]; however, the consumption climbed dramatically in Thailand from 21,270 tons in 1970 to 164,000 tons in 1994; in India it grew from 56,000 tons to 132,000 tons during the same period.

The use of cleaner production or waste minimization techniques is gaining more attention and acceptance. Although the implementation of waste minimization may require some additional investment initially, it can provide long-term benefits [8]. U.S. EPA has developed a systematic procedure for waste minimization [9], suitable and applicable to several types of industries and processes. This procedure was improved upon by Crittenden and Kolacskowski [10] and Hunt and Schecter [11] to make it suitable for all types and sizes of industries and flexible enough to cater to variations. Petek and Glavic [12] improvised the scheme by incorporating an integrated approach including optimization, for changing environmental and economic conditions.

Waste audit is an essential step in waste minimization [13, 14]. It provides the necessary data to prioritize waste streams and to identify options for minimizing the high-priority wastes based on composition, quantity, cost of disposal, degree of hazard, potential for minimization, recyclability, and compliance status [15]. Various versions of waste audit are available [16, 17]; however, a typical scheme is comprised of six stages: 1) identification of waste quantity and type; 2) identification of source of generation; 3) setting up of waste reduction priorities; 4) analysis of selection of feasible reduction techniques; 5) cost comparisons; and 6) evaluation of the implications of waste audit.

Waste minimization could be achieved by: 1) prevention/source reduction; 2) reuse/recycling/recovery; and 3) waste treatment. In practice, it is imperative that a combination of two or more waste minimization techniques are used to achieve maximum efficiency. Waste prevention/source reduction could be achieved by good maintenance and operation and production-process modification [18].

Waste recycling/recovery is a desirable option when source reduction options are exhausted. This can be a very cost effective alternative, when it eliminates or reduces waste disposal costs, reduces raw materials usage, and provides an extra source of income, if the waste is saleable. Recycling is characterized by the following five major practices [15]:

1. direct use or reuse of waste materials as a substitute for an input material;
2. recovery of secondary material for a separate end use;
3. removal of impurities from waste to obtain a relatively pure re-usable product;
4. energy recovery; and
5. utilization in pollution control systems.

Whether or not recycling/recovery of waste materials is possible within a production system depends on several factors:

1. quantity, quality, uniformity, and properties of waste;
2. options available for use or reuse;
3. availability and price of the virgin materials;
4. availability of specific technology (reclamation);
5. assessment of the possible impact of the non-recovered material;
6. assessment of long-term liabilities and risks; and
7. logistical constraints.

Recycling of waste water, contaminated solvent, etc., are common in various industries, such as textile [12], semiconductor industry [19], pulp and paper mills [20], and food industry [18]. The recycling of glass, paper, and paper boards has become routine [21]. There is, however, no published information on the recycling possibilities of the waste generated in friction material industries. The research presented here is focused on the identification, quantification, and characterization of the waste generated in an automobile brake lining manufacturing industry. The waste minimization investigation was limited to the reuse or recycling possibility of the waste in producing brake linings.

MATERIALS AND METHODS

Waste Audit

A waste audit was undertaken incorporating the following steps:

1. audit scope determination—to determine the issues and elements of the process;
2. background information collection—a simplified waste audit protocol/ worksheet based on the U.S. EPA Waste Audit Guidelines [22] was used;
3. identification and characterization of input materials, products, and waste types including production rate, handling and storage and waste management cost;
4. comprehensive plant analysis—includes life cycle inventory, observation on the housekeeping procedures, and interview with all relevant personnel.

The analysis was carried out for seven weeks by observing and following the process production line closely. Four types of brake lining references (based on the weight of the lining material) were analyzed to collect weight loss data at each of the manufacturing process. Four replicates were studied.

Recycling of Brake Lining Dust

Prior to the mixing of the lining dust with other raw materials, the iron component in the brake lining dust was removed manually using a bar magnet. The lining dust thus treated was next added to the virgin mix (D381) at 5 percent (wt) and 10 percent (wt), as shown in Table 1.

The formulation in D381 was selected as the control to run this test because this combination contained a large proportion of reclaimed materials (crushed off-specification brake linings) and is earmarked for producing second grade brake lining. Brake linings (nine sets each) manufactured using the virgin mix and 5 percent and 10 percent brake lining dust were next sent to Bendix Mintex (P) Ltd. in Australia for performance testing.

Table 1. Composition of Virgin Mix and Lining Dust Addition

Component	Virgin mix D381 kg	5% dust DX410 kg	10% dust DX411 kg
Raw materials	137	137	137
Reclaimed material[a]	229	208.2	187.4
Asbestos	50	50	50
Brake lining dust (after iron removal)	—	20.8	41.6
Total	416	416	416

[a]Crushed off-specification brake lining.

RESULTS AND DISCUSSION

Waste Audit

Visual observation and plant analysis show that the main waste stream is brake lining dust and hence the focus is limited only to the manufacturing process for brake lining. Thus, other production lines and office waste are excluded. The waste generated is closely related to the type of raw materials used, which include asbestos, iron powder, friction dust, glass fiber, and resin. The final product (brake lining) is in the form of a solid block with a shelf life of more than 10 years. The manufacturing process steps and the waste generated at each step are summarized in Figure 1. The types of wastes generated range from empty asbestos shipping containers, processed wastes, to housekeeping waste from sweeping or vacuuming and from pollution control devices (see Table 2); however, the bulk of the waste is in the form of brake lining dust. The latter is generated at almost all of the manufacturing stages, for example, cutting, grinding, drilling, and chamfering.

A vacuum suction system is used to move the generated lining dust into the bag house. The dust, which is homogeneous, is then collected from the hopper in drums lined with plastic sheets. It is then packed in double layered high-density polyethylene bags and placed into 200L metal drums for ultimate disposal in secure landfills at the Bukit Nanas Hazardous Waste Treatment Center.

Weight Loss at Each Process Step

Table 3 shows the weight loss of brake lining at each manufacturing step. The Grinding step generates the greatest amount of dust for the smaller pieces (0.85,

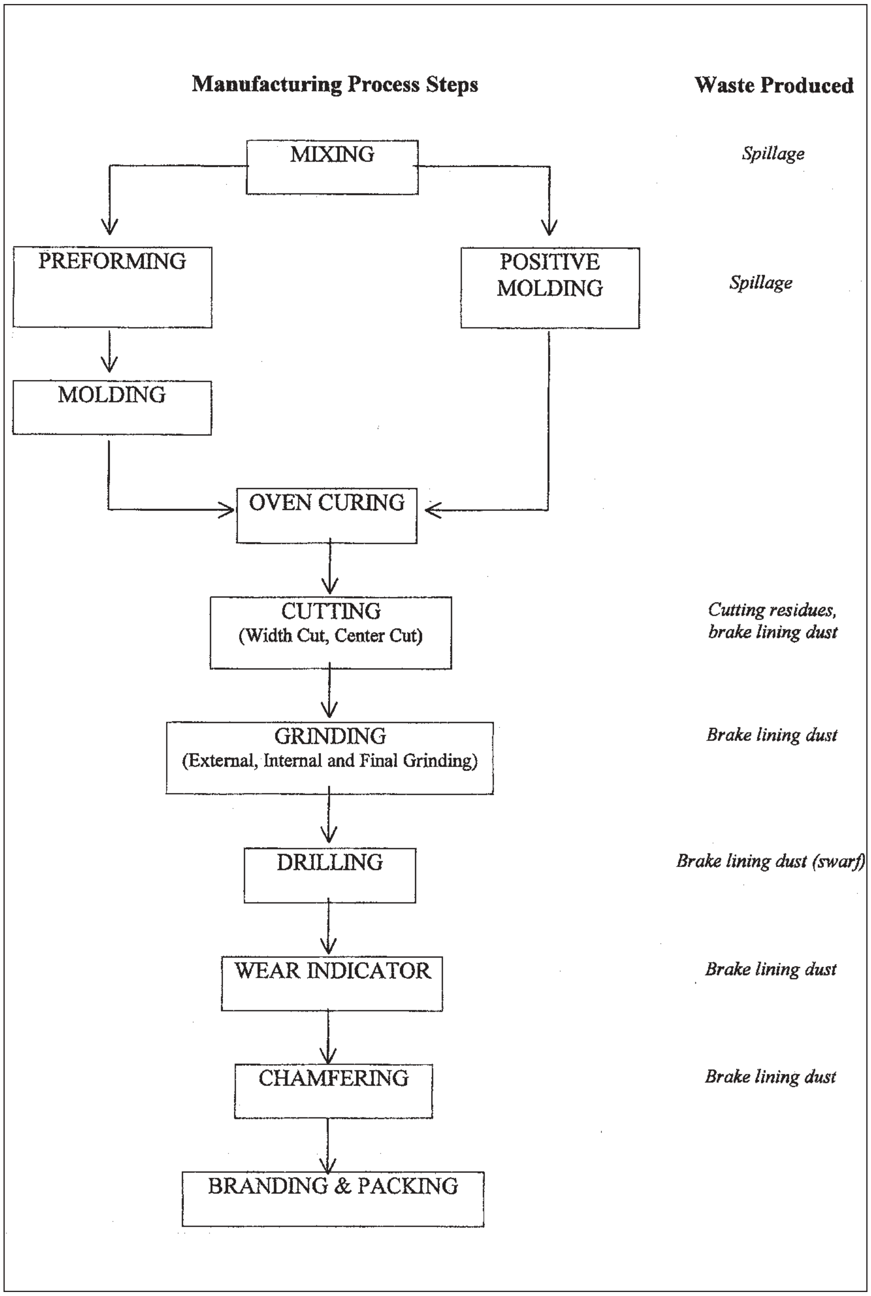

Figure 1. Process steps in brake lining manufacturing and the waste generated at each step.

Table 2. Summary of the Waste Type Generated at Each Step of Brake Lining Manufacture Process

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

[a]Scheduled waste. [b]Non-scheduled wastes that are already contaminated with scheduled wastes are considered as scheduled wastes. [c]The off-specification brake lining is crushed and recycled as reclaimed material.

1.0, and 1.5 kg) and range between 8 to 13 percent (wt). Drilling of brake lining produces 2 to 7 percent dust, followed by Chamfering step (0.5 to 1.07 percent). When brake linings in large billet form (4.8 kg) are cut into smaller pieces (1.6 kg/piece), the maximum quantity of dust is generated and this weight loss is about 30 percent.

The total weight loss increases as the initial weight of the brake lining increased (see Table 4). The overall weight loss ranges between 14 to 23 percent for small pieces whereas the cutting of the billet into smaller pieces gives 34 to 45 percent loss in weight. The maximum generation of brake lining dust ranges from 29 to 34 tons per month whereas the minimum is from 24.5 to 28.5 tons per month. The annual generation, thus, was 294 tons for 1996, while in 1997 it increased to 342 tons.

Table 3. Weight Loss (%) of Brake Lining at Each Manufacturing Step for Four Brake Lining References

Manufacturing Process Steps					
Mixing Brake lining type	Preforming/ molding	Cutting	Grinding	Drilling	Chamfering
1. 47441-4070 (0.85 kg)	0.79 ± 0.26	—	12.59 ± 1.34	4.12 ± 0.33	0.61 ± 0.15
2. 47443-1350 (1.0 kg)	0.47 ± 0.20	—	10.64 ± 1.16	3.63 ± 0.58	1.07 ± 0.30
3. 44066-90118 (1.5 kg)	0.46 ± 0.20	—	13.03 ± 1.07	6.87 ± 0.84	0.49 ± 0.90
4. 12022-37501 (4.8 kg billet cut to 1.6 kg/piece)	0.59 ± 0.18	29.89 ± 1.41	8.40 ± 0.63	2.17 ± 0.35	0.74 ± 0.25

Table 4. Total Weight Loss Per Piece of Brake Lining

Brake lining ref. and initial weight	Total weight loss (g)	% Weight loss
1. 47441-4070 (0.85 kg/pc)	135–180	15.88–21.18
2. 47443-1350 (1.0 kg/pc)	140–170	14.00–17.00
3. 44066-90118 (1.5 kg/pc)	270–350	18.00–23.33
4. 12022-37501 (4.8 kg billet cut to 1.6 kg/pc)	540–720	33.75–45.00

The cost of waste management and disposal was RM225,988 (US$59470) for 1996 and RM263,268 (US$69280) in 1997 (see Table 5). This disposal cost is normally paid as a fee to the Bukit Nanas Hazardous Waste Treatment Centre, where the lining dust is disposed of into a secure landfill.

Recycling of Brake Lining Dust

Specific gravity (SG) of each brake lining sample (9 sets = 18 pieces) is determined after the grinding process, for both left (ANCHOR) and right side (CAM) testing. The SG of brake lining for D381, DX410, and DX411 ranges between 2.13 to 2.29 (see Table 6) while the standard SG specified for brake lining is in the range of 2.12 to 2.32. Thus, recycling 5 percent to 10 percent of the lining dust does not affect the SG adversely and all the SG values are within the specified range.

Performance Testing

Inertia dynamometer tests are carried out on each material (D381, DX410, and DX411). The brake type used is a 16.5” by 7” Rockwell “S” cam brake fitted with 4515E CAM and ANCHOR linings (right and left side, respectively) produced from virgin mix or with 5 to 10 percent lining dust added. An axle load of eight tons is used to calculate the required inertia of 983.45 kg/m^2 which equals to a wheel load of four tons.

The performance characteristics studied are effectiveness, fade, post-burnish effectiveness, post-fade effectiveness, and speed spread. The results are summarized in Table 7. Brake lining manufactured from virgin mix (D381) is used as the reference product and comparable performance is obtained from brake lining DX411 with 10 percent brake lining dust. The results indicate that DX410 (with

Table 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 (200L)	15/container	49,000	57,083
Transportation cost	67/ton	19,698	22,947.5
Disposal fee	495/ton	145,530	169,537.5
Total		225,988	263,268

*1US$ ≡ RM3.80

Table 6. Specific Gravity Test for Virgin Mix (D381), 5% Mix (DX410), and 10% Mix (DX411)

	Virgin mix D381		5% mix (DX410)		10% mix (DX411)	
Set	ANC[a]	CAM[b]	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

[a]ANC = (Anchor) left side. [b]CAM = right side.

5 percent recycled lining dust) exhibits lower green effectiveness and greater speed spread in post-burnish and post-fade effectiveness. DX410 shows some instability during the first fade test, whereas the second fade test gives results comparable to those for DX411 and, in fact, better than those for the control D381. Overall, the performance of DX411, with 10 percent lining dust, is comparable with the control D381 and thus shows great potential for recycling.

CONCLUSIONS

Waste audit results indicate that it is possible to minimize waste generated in an automobile brake lining manufacturing facility by adopting certain simple process and/or structural changes. For example, the dimensions of certain molds are modified in order to produce a brake lining that precisely matches the required product dimension, resulting in the elimination of the cutting or grinding process steps. Additionally, off-specification brake linings are reworked or recovered by crushing them to a fine powder and mixing this powder with the virgin mix to produce brake linings suitable for the aftermarket. Furthermore, brake lining dust (up to 10 percent) could be recycled into the virgin mix to produce brake linings of comparable quality.

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Table 7. Results of Performance Testing* of Brake Linings

Charactertistics	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

*1. Effectiveness = level of torque output from a brake for a given input. 2. Fade = characteristics experienced when friction material is subjected to high temperature during braking. 3. Green Effectiveness = refers to the performance of the new friction material during the initial braking when the friction material is first installed in the brake. 4. Post Fade Effectiveness = refers to the performance of friction material after being subjected to high temperature testing during the Fade sequence. 5. Post Burnish Effectiveness = refers to the performance level of the friction material after approximately 200-300 low effort brake applications. 6. Instability during the first fade = refers to the variation in pressure applied to the friction material required to maintain a constant or straight line torque output during the first fade sequence.

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