# Recycling Magnesium Alloy Housings for Notebook Computers

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**Magnesium alloy housings are lightweight and strong, have excellent heat removal characteristics, and are in widespread use in portable personal computers and similar devices. Another characteristic of magnesium alloy is that it can be remelted for recycling. There are two ways to recycle magnesium alloy housings, one is for recycling excess material generated during the molding process and one is for recycling collected magnesium alloy housings that have been painted. In the first process, adjusting the composition of the magnesium alloy in the remelting process yields a material with the same strength and corrosion resistance as the virgin material, even after repeated recycling. In the second process, the paint is removed from the magnesium alloy housings by immersion in a solution. The alloy is then remelted without generating much gas or dust, and its composition is adjusted to produce a recycled material having the same performance as the virgin material. The technology for recycling excess material was first applied to the production of the Fujitsu PC FMV-BIBLO notebook computer, which was marketed in 1999. The technology for recycling painted magnesium alloy housings will be applied full-scale starting in fiscal 2002.**

## 1. Introduction

Japan's Recycling Law was recently revised to require special collection of personal computers discarded by corporations beginning in April 2001 and the same for individuals beginning in April 2002. This law also applies to four other kinds of household electronic devices. By weight, the housing of a PC accounts for about 30%. This percentage makes the method of discarding and recycling a key factor in the recycling of PCs. The use of magnesium alloy (Mg alloy) and other similar metals to make sturdy housings for portable PCs is becoming popular. Mg alloy is an excellent choice because it is sturdy and has good recycling characteristics.

As shown in **Figure 1**, there are two processes for recycling Mg alloy housings: a process for recycling excess material generated during molding and a process for recycling collected painted Mg alloy housings.

Initially, there was little data regarding the repeated recycling of Mg alloy, so the material's characteristics had to be determined before the recycling of Mg alloy housings could be promoted. Currently, painted Mg alloy housings are rarely recycled.

This paper introduces some technologies for recycling the excess material generated during molding of Mg alloy housings and for recycling painted Mg alloy housings.

## 2. Experiments

### 2.1 Issues regarding the recycling of Mg alloys

Mg alloys are now becoming popular for the housings of notebook PCs and cellular phones. Mg alloys have a specific gravity that is about 70% that of aluminum, a high specific strength, and

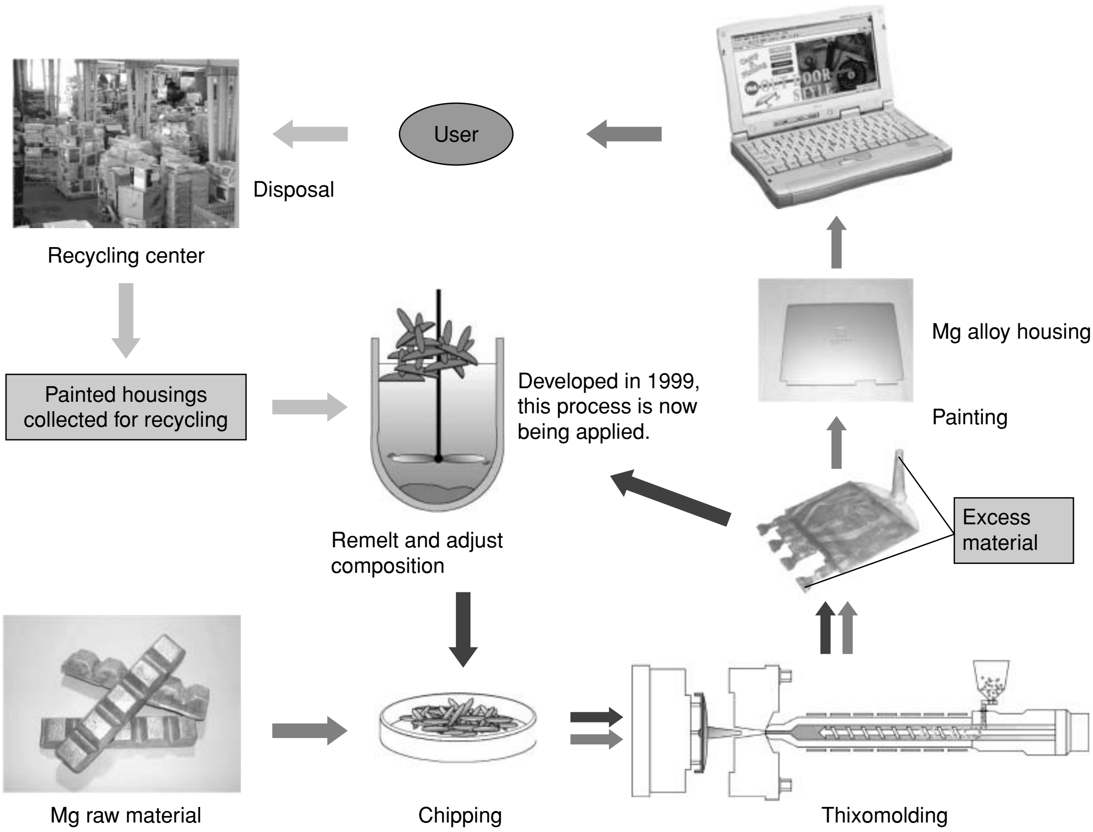



Figure 1
Recycling of Mg alloy housings.

excellent heat removal characteristics. Mg alloy housings are molded by die casting or thixomolding, in which an injection molder injects semi-solid, laminar-flow Mg alloy into a mold using the thixotropy of the alloy. Compared with ordinary die casting, thixomolding is safe with a low possibility of combustion because the temperature of the molten alloy can be kept low and the supply of molten alloy can be fully automated. Because of these features, Fujitsu uses thixomolding to manufacture most of its housings.

Whether the molding method is die casting or thixomolding, the housing weight accounts for only about 30 to 50% of the Mg alloy that is injected. The remaining 50 to 70% is wasted in the sprue and runner. Therefore, to reduce the environmental impact and reduce costs, it is important to establish a method for recycling the excess material.

In an article on die-cast moldings, Sato et al.[1] reported that recycled Mg alloys satisfied JIS standards. Also, it has been reported that recycled thixomolding material satisfies JIS standards and have the same properties as the virgin material.[2),3)] However, the data available for repeatedly recycled material has not been adequate, and this had to be resolved to promote the recycling of Mg alloy housings.

Notebook PCs collected from the market are encased in painted Mg alloy housings. Tatsuishi et al. reported the generation of poisonous gases and a decrease in material yield when die-cast moldings using a small amount of painted Mg alloy were recycled.[4] Matsunaga et al. reported on the recycling of thixomoldings that have been sandblasted to strip off the paint.[5] This method, however, has disadvantages regarding productivity and safety. Notebook PCs with paint that is several dozens of microns thick are no longer recycled.

We investigated recycling techniques for housings made of painted Mg alloy with the goal of recycling used notebook PC housings.

## 2.2 Methods of reclaiming Mg alloy for recycling

The Mg alloy of housings is reclaimed in two ways. One way is to remelt the housings and the waste material from the molding process to produce ingots, which are then converted into chips. The other way is to directly convert the housings and waste material into chips at the molding site without remelting. We compared these two methods and decided to use the remelting method based on its superior productivity, the superior quality of the material it produces, and the high level of noise generated by crushing nonstandard-shape moldings.

## 2.3 Characteristics of repeatedly recycled materials

1) Repetition process

The characteristics of repeatedly recycled materials produced by the remelting method were studied. We repeated the following procedure 10 times with alloy composition AZ91D (**Table 1**):

- Create chips from virgin material.
- Mold the chips.
- Randomly sample three moldings.
- Remelt the remaining moldings, runners, and sprues; produce new ingots from the melt; and create new chips from the ingots.

2) Recycled materials

The following recycled materials were experimentally produced by remelting:

- 100% recycled material
- Recycled material adjusted with aluminum and manganese

3) Moldings

Using the process described above, the authors created and evaluated LCD covers for the FMV-BIBLO MS, as shown in Figure 1. We used a thixomolding machine (JLM650-MG, The Japan Steel Works, Ltd.) at a cylinder temperature of 615°C and a mold temperature of 250°C.

4) Composition changes

The Mg alloy composition of each recycled material was checked. Each sample was measured by an ICP emission spectroscopic analyzer (SPS1700HVR, Seiko Instruments Inc.) for nine different elements (Al, Zn, Mn, Si, Fe, Cu, Ni, Be, and Cl) and other substances at concentrations of 10 ppm or more. For the measurements, about 0.5 g of each sample was dissolved in 10 ml of hydrochloric acid with ultrapure water added to adjust the total volume to 100 ml.

5) Strength characteristics

Test specimens measuring 50 × 100 mm were cut from the sample moldings and subjected to a three-point bending test. The test conditions conformed to JIS K 7055. We used a universal material tester (INSTRON 5581, Instron Corporation) at a load speed of 2 mm/min and a span length of 30 mm.

In addition, test specimens (64 × 12.7 mm) were cut from the sample moldings and subjected to an Izod impact test (B-121202403, TOYO SEIKI Co., Ltd.). The test conditions conformed to JIS K 7110.

6) Corrosion resistance

Corrosion resistance was evaluated using a saltwater atomization test. The test method conformed to JIS Z 2371. The resistance was evaluated by measuring the weight change after saltwater atomization. The test conditions were as follows:

- Test liquid: 5% NaCl
- Temperature: 35 ± 2°C
- Salt spray time: 100 h

## 2.4 Paint stripping process

Paint is either stripped mechanically or chemically from painted notebook PCs. Sandblasting, which is a mechanical method, is the most popular. However, with sandblasting, there is a

Table 1
Elements of AZ91D (ASTM standard).

| Element | Mg | Al | Zn | Mn | Si | Cu | Fe |
|---|---|---|---|---|---|---|---|
| Ratio (wt%) | Remainder | 8.3 ~9.7 | 0.4 ~1.0 | 0.2 ~0.4 | ≦0.1 | ≦0.03 | ≦0.005 |

danger of explosion due to the generation of Mg dust. Therefore, the authors stripped off the paint by jetting an abrasive in water. Chemical methods treat the housing with a solution to strip off the paint. Since the type and manufacturer of the paint vary greatly between housings, the stripping characteristics are not constant. Therefore, we evaluated several stripping agents and conditions.

1) Wet blasting

In wet blasting, water containing an abrasive is forced through a nozzle at high speed using compressed air. To evaluate the stripping performance of wet blasting, we checked the amount of paint residue remaining on the housings for various jet nozzle speeds. The abrasive was alumina #200.

2) Solution treatment

In the paint-stripping test, we immersed nine kinds of PC Mg alloy housings painted with different manufacturer's paints into one of three stripping agents (A to C), which consisted primarily of alkali elements. Each painted Mg alloy housing was immersed for 1.5 hours, and the stripping agents were heated to 70°C. After immersion, the housings were washed with water and the degree of stripping evaluated.

### 2.5 Recycling of painted Mg alloy housings

1) Samples

From the painted Mg alloy housings stripped by the wet blasting and solution treatment described in the previous section, we created the following materials by remelting.

- Material recycled from unpainted Mg alloy housings
- Material recycled from painted Mg alloy housings without stripping
- Materials recycled from painted Mg alloy housings having 50%, 80%, or 90% of their paint removed. (Removal amount was controlled by adjusting the jet nozzle speed.)
- Material recycled from Mg alloy housings after stripping by solution treatment using stripping agent C

2) Amount of gas

The amount of gas generated during the remelting of the Mg alloy housings described in the previous section was measured. For this measurement, a gas collection pipe was attached to the suction cover of the melting furnace and a stainless steel pipe was extended to outside the melting furnace. A Tenax tube was connected to the pipe to collect the gas using a pump, and TCT-GC-MS analysis was done. Before measurements, the Tenax tube was purged for three minutes to eliminate moisture.

3) Amount of dust

The amount of dust generated during remelting was also measured. For this measurement, a filter with a glass fiber filter paper was attached to the pipe to collect dust while the gas was being collected. The filter paper was dried and weighed to determine the amount of dust.

4) Metal yield

After the Mg alloy housings were remelted, the amount of metal yielded from the recycled material was obtained by measuring the amount of sludge remaining in the melting furnace.

5) Composition analysis

The compositions were evaluated in the same way as in Section 2.3 4).

6) Comparison of physical properties

The moldings described in Section 2.3 3) were created from the recycled materials and measured for their bending characteristics as described in Section 2.3 5) and their corrosion resistance as described in Section 2.3 6).

## 3. Experimental results and discussion

### 3.1 Effects of repeated recycling

1) Amount of Fe and Mn

Mg alloy that was recycled repeatedly was analyzed for any changes. **Figure 2** shows the changes in the amount of Fe, and **Figure 3** shows the changes in the amount of Mn.

Figure 2 shows that repeated recycling increases the percentage of Fe in the material. The reason for this is that the alloy becomes contaminated with Fe when the ingots are chipped (mainly from broken off pieces of chipping blades).

Figure 3 shows that repeated recycling decreases the percentage of Mn. This is because Mn accepts the increased Fe as an inter-metallic compound between Al and Mn and settles it out during refining done to purify the molten alloy.

The amount of Mn probably decreased because Mn combined with the Fe added during chipping or the thixomolding process and precipitated as sludge.

As shown in Figures 2 and 3, the addition of Al and Mn to adjust the composition during remelting suppresses the decrease of Mn and controls the amount of Fe, even over multiple recyclings.

2) Strength

**Figure 4** shows the results of the bending test and Izod impact test.

Young's modulus in the repeatedly recycled material indicates that the material has almost the same bending strength, with a slight variation of about 10%, regardless of how many times it is recycled. The Izod impact strength shows the same tendency as the bending strength. These results indicate that even repeated remeltings do not destroy the bending and Izod impact strengths.

3) Corrosion resistance

**Figure 5** shows the results of the corrosion resistance test. The figure shows that the corrosion of recycled material progresses as recycling is repeated. The corrosion of a molding created from a material recycled 10 times was more than 30 times greater than that of a molding created from virgin material.

The primary impurities responsible for Mg alloy corrosion are Fe, Cu, and Ni. Since these

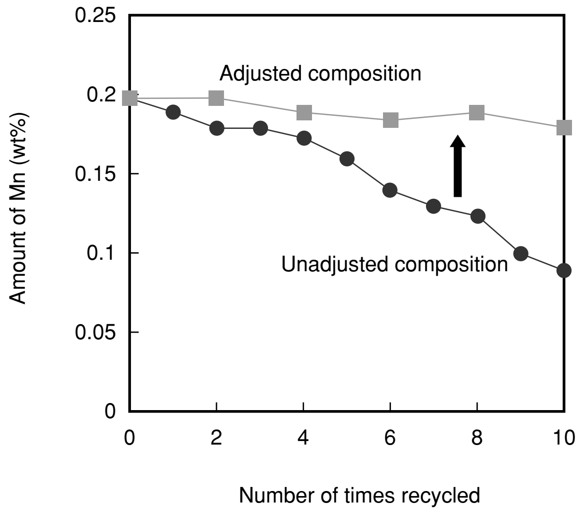



Figure 3
Change in amount of Mn.

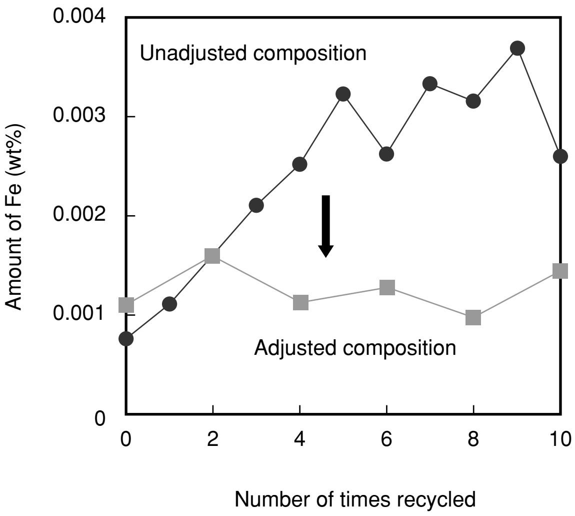



Figure 2
Change in amount of Fe.

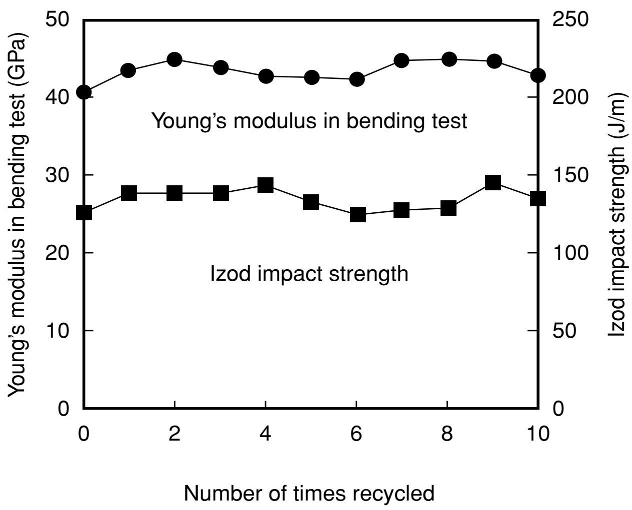



Figure 4
Strength characteristics.

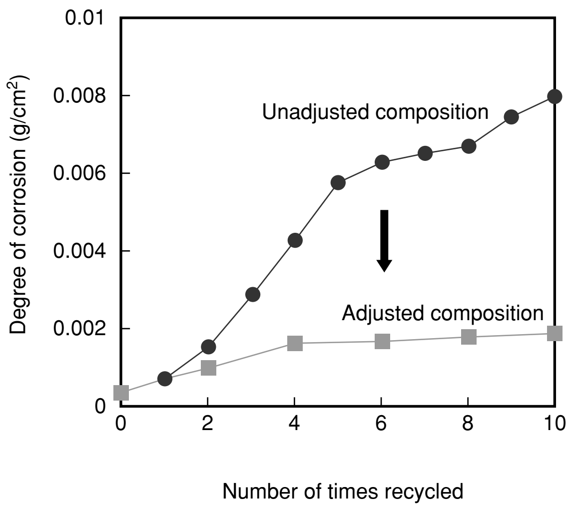



Figure 5
Corrosion resistance.

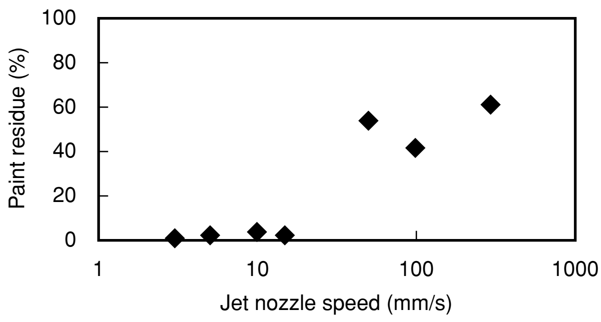



Figure 6
Stripping performance of wet-blast processing.

metallic elements and their intermetallic compounds form the cathode parts of low hydrogen overvoltages, the Mg is greatly corroded.

The results of composition analysis indicate that repeated recycling increases the amount of Fe and decreases the amount of Mn, and corrosion progresses accordingly. During remelting, the addition of Al and Mn could suppress any decrease in Mn and control the amount of Fe, even for repeated recycling. A molding made of an adjusted composition showed almost the same degree of corrosion as one created from virgin material. The results indicate that corrosion resistance can be maintained in recycled material at almost virgin-material level, even after repeated recycling, if the percentages of Mn and Fe are kept constant by composition adjustment during remelting.

## 3.2 Paint stripping performance

1) Wet blasting

**Figure 6** shows the amount of paint residue measured on painted notebook PCs after stripping at various jet nozzle speeds. The amount of paint remaining on the housing surface is more than 50% of the original amount at 50 mm/s or more and only a few percent at 10 mm/s or less. We found that if the jet nozzle speed is set too low, not only the paint on the housing surface but also the Mg alloy itself may flake off. Therefore, the optimum jet nozzle speed was found to be from 5 to 10 mm/s.

2) Solution treatment

**Table 2** shows the results of the stripping test.

When stripping solutions A and B were used, the paint did not flake off. However, stripping solution C permeated into the paint by osmosis, expanded, and caused all of the paint to flake off.

## 3.3 Recycling of painted Mg alloy housings

1) Amount of generated gas

Among other information, **Table 3** shows the measured amounts of benzine generated from painted, wet-blasted, solution-treated, and unpainted Mg alloy housings during remelting.

The table shows that the least amount of gas is generated when the Mg alloy housing is remelted after the paint has been stripped off by soaking in solution. The next least amount of gas is generated when the Mg alloy housing is remelted after the paint has been stripped off by wet blasting. The amount of gas generated is less than one-half that generated from an unpainted housing. Unpainted housings generated more gas than housings stripped by wet blasting or solution treatment because the remelting burnt off the mold release agent remaining on the unpainted housings. **Figure 7** shows the amounts of various gases generated when areas of various sizes were stripped. The figure shows that stripping a painted Mg alloy housing by 90% or more reduces the total amount of generated gas to about 5% or less of the amount generated from an unstripped housing. These results show that the amount of generated gas greatly depends on the amount of stripping. Because the gases that are generated include the stimulants benzene, toluene, and acrolein, it is essential to strip off all of the paint.

2) Amount of dust

The measured amount of dust generated from processing one Mg alloy housing during remelting is shown in Table 3. The amount of generated dust becomes smaller as the stripping area in-

Table 2
Results of stripping test.

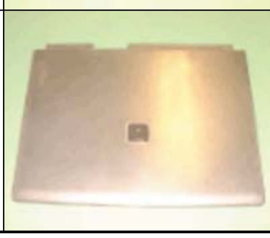
| | Stripping solution | | |
|---|---|---|---|
| | Stripping solution A | Stripping solution B | Stripping solution C |
| Paint manufacturer T<br>Paint A |  |  |  |
| Paint manufacturer A<br>Paint A |  |  |  |
| Paint manufacturer S<br>Paint B |  |  |  |
| Paint manufacturer T<br>Paint A |  |  |  |
| Paint manufacturer A<br>Paint A |  |  |  |
| Paint manufacturer C<br>Paint C |  |  |  |

Table 3
Characteristics of housings made from four types of material.

| | Painted | Wet-blasted | Solution-treated | Unpainted |
|---|---|---|---|---|
| Stripped area (%) | 0 | 90 | 98 | 100 |
| Gas generation (benzene [ng/l]) | 2215 | 15 | 2 | 43 |
| Dust (mg/l) | 1400 | 122 | 39 | 34 |
| Metal yield (%) | 91.3 | 98.0 | 98.7 | 98.6 |
| Composition | Increased Fe | Within standard | Within standard | Within standard |
| Corrosion (mg/cm$^2$) | 0.76 | 0.10 | 0.08 | 0.10 |
| Bend strength (MPa) | 425 | 460 | 470 | 440 |

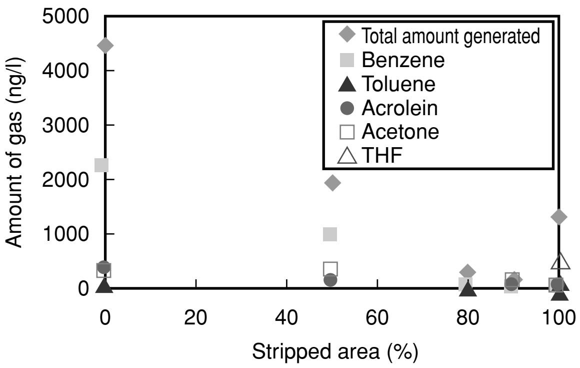



Figure 7
Amount of generated gas.

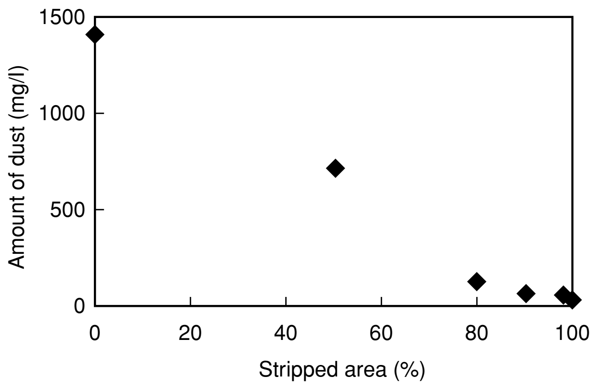



Figure 8
Amount of generated dust.

creases. Housings stripped of 98% of their paint by the solution treatment generate almost the same amount of dust as an unpainted housing.

**Figure 8** shows the measured amounts of dust from Mg alloy housings for six degrees of stripping. As can be seen, housings stripped of 90% or more of their paint generate about 5% or less of the dust generated from an unstripped housing.

The temperature of the furnace used to remelt the Mg alloy was about 680°C. Since this temperature is not high enough to burn the paint and tends to cause incomplete combustion, the percentage of stripped area greatly affects the amount of gas that is generated.

3) Metal yield

The amount of metal yielded by remelting Mg alloy in various states is shown in Table 3. Stripping off the paint with solution increases the yield to almost the yield obtained from unpainted housings. The yield from the wet-blasted housings was also high, differing from the solution-treated yield by not more than 1%. However, the yield from the painted Mg alloy housings was low, because the Ti, alumina, and other impurities in the paint increased the amount of sludge.

4) Composition analysis

Table 3 lists the results of the composition analysis. Both the wet-blasted and solution-treated housings have values within the AZ91D standard range. Also, they produce molten alloy of the same composition as that of unpainted housings. When painted Mg alloy housings are used, Ti, alumina, and other impurities in the paint contaminate the molten metal.

5) Comparison of properties

We molded notebook PC housings from the materials we recycled. As shown in Table 3, we found that the bending strengths and corrosion resistances of the wet-blasted and solution-treated

Mg alloy housings are close to those of painted and unpainted housings. The bending-strength dispersion is within 10%, and the presence or absence of paint before remelting does not affect the bending characteristics. The amount of corrosion in housings molded from recycled painted Mg alloy housings stripped by wet blasting and solution treatment is about 13% and 10.5%, respectively, of the amount in a painted Mg alloy housing.

6) Summary

Paint should be stripped off painted Mg alloy housings before they are recycled. Stripping by wet blasting or solution treatment both produce a recycled material with characteristics equal to those of materials created from recycled, unpainted housings. However, wet blasting is not very effective for removing paint from housings with complicated shapes or from broken pieces of cabinets. Solution treatment is effective for stripping paint off painted Mg alloy housings because the process is not affected by the shape of the housing.

## 4. Conclusion

For recycling of notebook PCs housings made of Mg alloy, we studied a variety of techniques for recycling excess material generated during molding and for recycling painted Mg alloy housings. We found that:

1) Recycled material can be given the strength and corrosion resistance of virgin material by adjusting its composition by adding Al and Mn during remelting.
2) Stripping is essential for painted Mg alloy housings. The percentage of stripped area greatly affects the amounts of gas and dust generated during remelting.
3) Housings made from paint-stripped Mg alloy housings show performance values almost equal to those of virgin material.
4) Treatment with a solution is a more effective way to remove paint than wet blasting.

The procedure for manufacturing an ingot of Mg alloy from seawater or ore consists of two major processes, the Mg refining process and the Mg alloying process. Mg is primarily refined by the electrolytic method.

In this method, a raw material containing Mg is chlorinated into $MgCl_2$, the bound water is separated through several processes, and Mg is obtained from the molten $MgCl_2$ by electrolysis. This process consumes a great deal of power.

For alloying, Mg is melted and refined after specified amounts of Al and Zn are added. If recycled materials are used instead of virgin materials, the energy consumed is only about 4% of that used to obtain the Mg from seawater or ore, because preprocessing is not required. Therefore, using recycled material in manufacturing can reduce the Mg alloy cost to about 70% of the cost for virgin material, including the costs for collection and transportation from a molding factory to a refinery, remelting, and composition adjustment.

The technology for recycling excess material was first applied to the manufacture of mobile notebook PCs marketed in 1999. Full-scale recycling of painted Mg alloy housings will begin in fiscal 2002.

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