UDC 621.798.12: 681.32

Hybrid Housing for Notebook Computers

●Kota Nishii ●Koichi Kimura ●Motonobu Kawarada
(Manuscript received February 4,1998)

Fujitsu has developed a new type of housing for notebook computers. It is a hybrid housing composed of resin and metal which provides a combination of structural strength, efficient heat dissipation, and light weight. This hybrid housing is manufactured by adapting an in-mold method in which resin is bonded to an aluminum plate inside a metallic mold with the aid of an adhesive. At first, we checked that the hybrid housing has the high heat dissipation characteristics required for sub-notebook PCs by using thermal simulation. We investigated the relationship between the aluminum/ resin ratio and heat dissipation characteristics of the hybrid housing model.
We found that the use of aluminum on the bottom (which must be strong and have a high heat dissipation) and the use of resin on the side (which must have good moldability for forming complex shapes) provided the best balance between weight and cooling performance. In the next step, we conducted experiments to find the following: (1) an adhesive suitable for bonding aluminum with resin inside a metallic mold, (2) a resin that minimizes warpage in the housing caused by the different thermal expansion coefficients of its two materials, and (3) a molding process suitable for mass production. Compared to a conventional resin housing, the hybrid housing we developed resulted in a reduction of component temperature in a sub-notebook PC of from 5°C to about 10°C and a 20% weight reduction. This hybrid housing was applied to Fujitsu's sub-notebook PC, the FMV-BIBLO NC.

1. Introduction

The performance of personal computers (PCs) is being rapidly improved by advances in MPUs, high-density mounting technology, etc., and many types of notebook PCs are now on the market. Notebook PCs can be roughly divided into three categories:

1) Compact PCs (desk top substitutes that conserve space: more than 3 kg).
2) Portable PCs (thin notebooks: about 2 kg).
3) Mobile PCs (sub-notebook; about 1 kg). In particular, sub-notebook PCs have many problems, for example, heat dissipation, lightness, and strength, because the electronic components of a sub-notebook PC must provide the same functions as a compact PC but in a smaller spare. Especially, as the amount of heat generated by the MPU increases, heat dissipation becomes a serious problem.[1)]

At present, the main cooling methods used in notebook PCs are fans, finned heat sinks, heat pipes, or a combination of these. However, because of the high power drain, using a fan to cool mobile PCs, which are usually used outside the office, requires a high-capacity battery. In addition, from the view point of mechanical impact tolerance, the use of devices with rotating parts in mobile equipment must be minimized. Therefore, the development of cooling technologies for the housing is becoming as important as reducing the housing weight.

ABS (acrylonitrile-butadiene-styrene) resin and PC (polycarbonate)-ABS resin is the preferred choice of housing materials. However, plastic

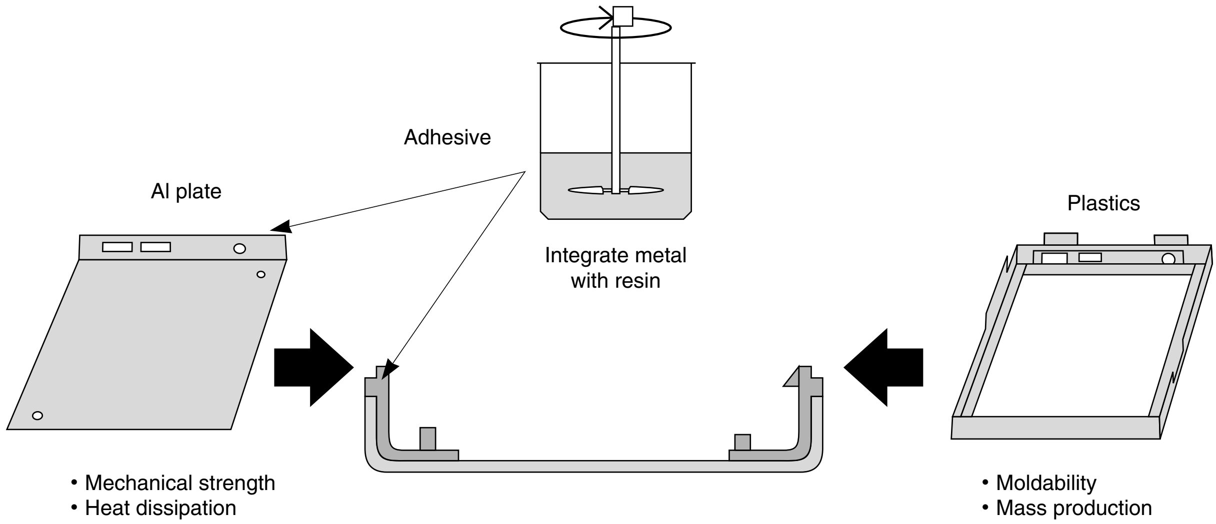

Figure 1.
Metal integrated with resin.

housings have poor thermal conductivity, which hinders thermal diffusion throughout the housing. This is why a plastic housing is not suitable for keeping a device cool. Moreover, the thickness of the plastic housing has to be over 1.5 mm to facilitate molding and achieve sufficient strength.[2] In contrast, a metallic housing such as one made from aluminum plate offers a much higher thermal conductivity; however, it is heavy, difficult to mold into complex shapes, and expensive.[3]

Since 1992, we have considered the probability that future computer housings would need to be both light in weight and have a high heat dissipation. To meet these requirements, we developed a hybrid housing which has the advantages of resin (i.e., good moldability for forming complex shapes like ribs and bosses of housings, and very good mass-producibility) and the advantages of metal (i.e., high strength and high heat dissipation). The method is shown in **Figure 1.**[4]

To apply this hybrid housing to a notebook PC, we next turned our attention to the following: (1) finding the optimal proportions of aluminum plate and resin for good heat dissipation and light weight and (2) developing the molding process. We found no reports regarding item (1). Regarding item (2), we knew of two existing methods of bonding resin with metal. The first is to bond the resin and metal parts together with adhesive after they have been molded separately. However, being a lengthy process, we considered this to be unacceptable for manufacturing notebook computer housings.

The second method is known as insert molding and involves shrinking the resin and adding a metal anchor that is either wrapped around or placed within the resin.[5][6] This method is used for forming small, thick parts such as the main body of cameras. However, it is difficult to use this method for a large, thin structure such as the housing of a notebook PC because of warpage caused by the different thermal expansion coefficients of aluminum and resin. Therefore, it is necessary to improve the insert molding method to make it suitable for manufacturing notebook PC housings.

In this work, we first investigated the relationship between the aluminum/resin ratio and the heat dissipation characteristics of hybrid housings and then chose a ratio which gave a satisfactory compromise between cooling performance and lightness in weight. We then conducted experiments to find the following:

1) An adhesive suitable for bonding aluminum

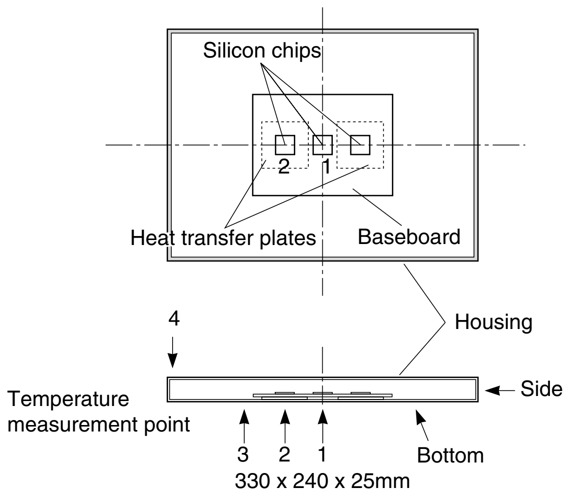

Figure 2.
Analyzed model.

with resin inside a metallic mold.

2) A resin that minimizes the warpage in the housing caused by the different thermal expansion coefficients of resin and aluminum.

3) A molding process suitable for mass production. This paper describes the above investigations and shows that the resulting hybrid housing we produced weighs the same as the equivalent all-plastic housing yet provides superior cooling and mechanical strength.

2. Experiment

2.1 Thermal simulation

To find a compromise between good heat transfer and light weight, we investigated the relationship between the aluminum/resin ratio and the heat dissipation characteristics.

We analyzed the model shown in **Figure 2** via simulation. The model consists of a $330 \times 240 \times 25$ mm housing containing three 20×20 mm silicon chips mounted on a $150 \times 100 \times 1.2$ mm baseboard. Heat conduction to the housing is achieved via two $50 \times 50 \times 2$ mm heat transfer plates. The total heat generated by the chips was set to 5 W. To simplify the analysis, it was assumed that the baseboard conducts heat directly to the bottom of the housing. Five cases were studied:

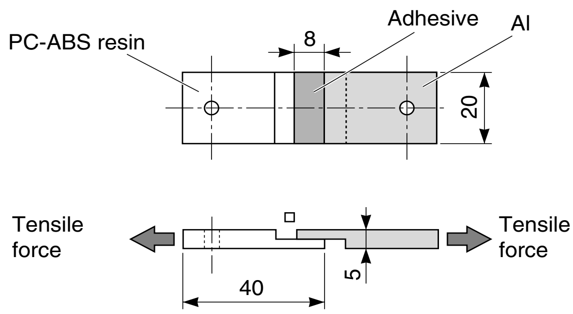

Figure 3.
Test specimen for measurement of bonding strength.

1) all-resin housing, 2) aluminum occupying the baseboard area, 3) aluminum occupying the whole housing bottom, 4) aluminum occupying the bottom and side of the housing, and 5) an all-aluminum housing. The baseboard and transfer plates were also made of aluminum. The thickness of aluminum and resin was 1.2 mm. The value used for the thermal conductivity of aluminum was 138 W/mK (this is the JIS A5052 value). An organic film was formed on the external aluminum surface of the housing to improve its emissivity, which is very small. However, organic film was not formed on the internal aluminum surface of the housing so as to inhibit internal heat radiation. The value of emissivity of the external aluminum surface was 0.9, and that of the internal aluminum surface was 0.1. The thermal conductivity of the resin was 0.26 W/mK, and its emissivity was 0.8. The housing's bottom surface was 2 mm above the surface it reseted on, as is commonly found when a notebook PC is placed on a desk made of wood. A natural convection environment was assumed. To reduce the computation time, the analysis was performed for half of the model after dividing this zone into 30,000 meshes. The finite volume method was used. The sampling temperature was 25°C, which is the standard temperature assumed for an office environment.

2.2 Materials and process for hybrid housing

This sub-section describes how we selected an adhesive that would bond the aluminum to the resin with sufficient strength, how we selected a resin that minimizes the warpage in the housing, and the process for manufacturing the hybrid housing.

2.2.1 Evaluation and choice of adhesive

The measurements of bonding tensile strength were performed using the Instron1195 (Instron Co., Ltd.) shearing tensile tester under the JIS K6849 (tensile velocity: 2 mm/min) conditions. The test specimen for the measurement is shown in **Figure 3**. The test specimen was fabricated as follows: (1) Adhesive was coated onto a $20 \times 40 \times 5$ mm aluminum block. (2) PC-ABS resin was injected after setting the aluminum block into a mold (held at 80°C). The aluminum was JIS A5052 and the resin was PC-ABS (Novalloy CYH107: Daicel Chemical Industrial Co., Ltd.),which is inexpensive and has a high moldability.

To obtain a high bonding strength and high thermal resistance, we examined six adhesive candidates: nitrile rubber, chloroprene rubber, styrene rubber, ethylene acetic acid vinyl, epoxy, and a silan coupling agent.

The aging tests for the adhesives were performed using the same method used for the bonding tensile strength measurements. The measurement items were as follows:

1) The relationship between time and bonding strength at 25°C and 50% R.H. and at 85°C and 85% R.H. (0 to 600 h).
2) The adhesive bonding strength during 10 thermal cycles (–5 to 65°C over 24 hours).
3) The relationship between temperature and bonding strength. We used thermo-hygrostat (PR-2E, TABAI ESPEC) for the treatment of each sample for tests (1) and (2).

2.2.2 Evaluation and development of resin

The thermal expansion coefficient of aluminum is 2.3×10^{-5} 1/K, while that of PC-ABS resin is 7×10^{-5} 1/K. We were concerned that there would be a large warpage due to the difference in thermal expansion coefficients after the resin and aluminum plate were bonded together and the hybrid cooled down from the 80°C mold temperature to room temperature (25°C).

To address this problem we made PC-ABS resins with carbon fiber contents of 0%, 5%, 10%, 20%,and 25% to obtain five different thermal expansion coefficients. The thermal expansion coefficients were measured within the temperature range of 25 to 80°C using a thermal mechanical analyzer (Seiko Electronic Industry Co., Ltd.; TMA5200); the test sample size was $12.7 \times 3.2 \times 4.0$ mm. Next, we molded hybrid housings for the bottom cover ($290 \times 220 \times 15$ mm) of a notebook PC using these resins, and investigated the relationship between the housing warpage and the thermal expansin coefficient. The warpage of the housing was measured using a 3-dimensional measurement machine (Mitsutoyo Co., Ltd.; RV-304). Measurements were taken at 104 points along the Z-axis, and we defined warpage as the planar deviation as measured at three measurement points. The thickness of the aluminum in the hybrid housing was 0.8 mm to match the weight of the all-plastic housing, which was 1.6 mm thick.

2.2.3 Process for manufacturing a hybrid housing

We used an injection molding machine (AUTOSHOT 300D FANUC) to investigate the manufacturing process for the hybrid housing described in 2.2.2 above. We used an oven (PH200, TABAI ESPEC) to harden the adhesive and test the separation of the hybrid housing. There are many ways to coat adhesive onto aluminum plate, for example, the brush painting method, spray method, and screen printing method. However, it is difficult to brush paint adhesive to a uniform thickness, and the spray method is inconvenient because it requires large-scale equipment to use the solvent voluminously and is expensive. Therefore, we chose the screen printing method for the hybrid housing process because of its very good

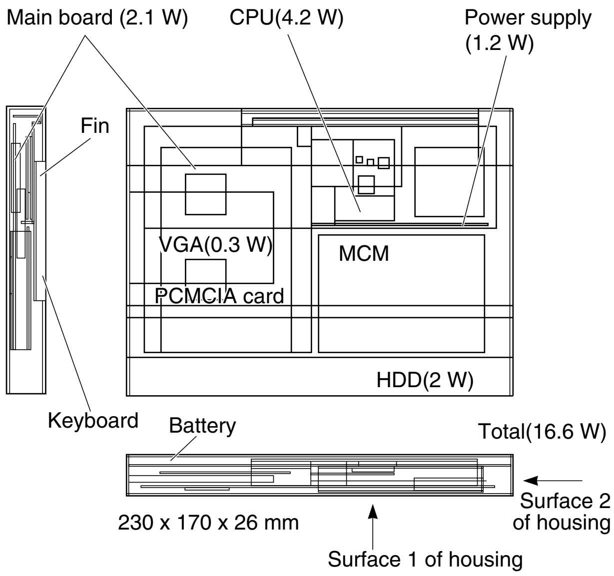

Figure 4.
Mockup model of sub-notebook PC.

mass-producibility and low cost.

2.3 Measurement of hybrid housing

This sub-section describes the method used for measuring the mechanical strength and cooling characteristics of the hybrid housing we developed.

2.3.1 Housing strength

The measurements of static load strength were performed as follows. We compared the strengths of the all-plastic and hybrid housings for the sub-notebook PC by applying a load in 1 kg increments up to a maximum of 20 kg to the center of the housings over an area of 1 cm^2 and then measuring the displacement. The housings were supported by both sides in the direction of widthwise side.[8)]

2.3.2 Cooling

The heat dissipation was evaluated as follows. Mockup models (**Figure 4**) of a sub-notebook PC were assembled using the hybrid housing and the plastic housing, and their heat transfer characteristics were studied. The silicon chips generated the same amounts of heat as in an actual sub-notebook PC (the total heat output was 16.6 W). One of the mockups had a hybrid housing with an aluminum bottom, as described previously, and the other had a plastic housing made of PC-ABS resin. The mockups were placed in a 200 × 100 × 100 cm sealed box 2 mm above the base to allow natural convection. The temperature inside the box was maintained at 25°C. The mockups were left powered on for 4 hours, then the temperature at various points was measured via previously installed thermocouples. We then compared the results with the results obtained from a thermal simulation of the same model.

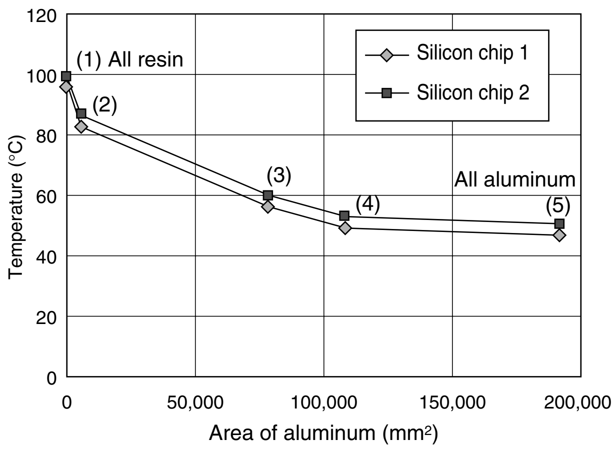

Figure 5.
Simulated relationship between temperatures of silicon chips and area of aluminum.

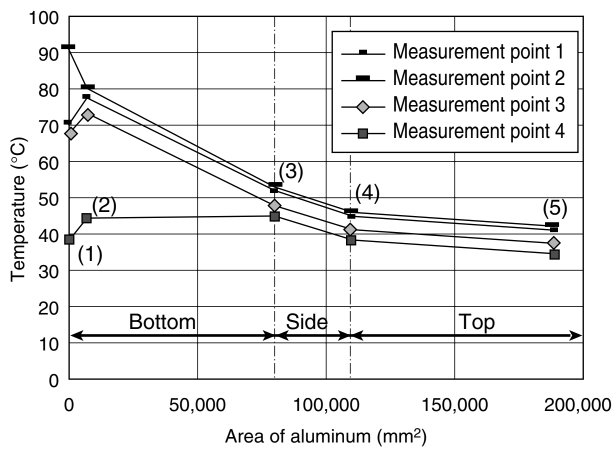

Figure 6.
Simulated relationship between temperature of housing surface and area of aluminum.

3. Results and Discussion

3.1 Simulation

Figure 5 shows the simulated relationship between the chip temperatures and the area occupied by aluminum in the hybrid housing. In hybrid housing model 2 (aluminum occupying the baseboard area) the silicon chips were about 20˚C cooler than in the resin housing. In hybrid housing model 3 (aluminum occupying the whole housing bottom) 40˚C cooler. Figure 5 shows that up to model 4, replacing the resin with aluminum dramatically reduces the temperature. However, when the aluminum area is extended to beyond the housing sides (model 5), the temperature decrease levels off.

Figure 6 shows the simulated relationship between the temperature of the housing surface and the area occupied by aluminum in the hybrid housing. The figure shows that when only part of the bottom of the housing is replaced by aluminum (Case 2), the temperatures at the measurement points which were not in direct contact with the baseboard (points 1, 3, and 4 rose by about 5˚C). The reason for this is that the aluminum conducted the heat from the silicon chips to other areas. When the aluminum covered the entire housing bottom (cases 2 and 3), points 1, 2, and 3 were more than 20 degrees cooler and point 4 was about 5 degrees hotter. The temperatures of all the housing surfaces fell as the aluminum area was extended in cases 4 and 5 to the sides and the upper surface. In case 4, points 1, 2, and 3 were more than 10˚C cooler compared with resin housing. However, when the aluminum was further extended in case 5 to beyond the housing sides, only a small temperature decrease was achieved because it was difficult to conduct the heat to the upper surface. These simulations indicate that the temperatures of components such as the silicon chips and housing can be dramatically decreased by replacing resin in the housing with aluminum.

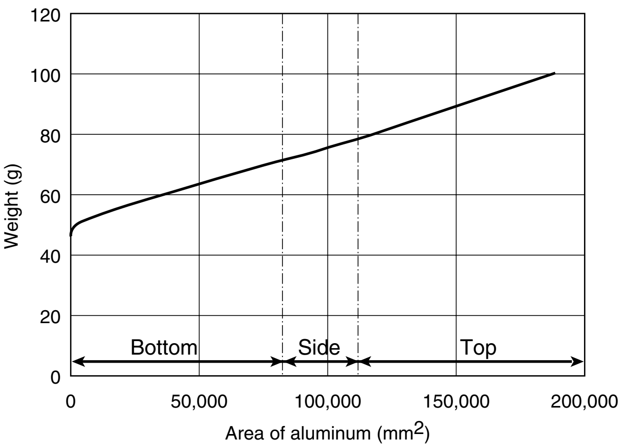

Figure 7.
Relationship between housing weight and area of aluminum parts.

Figure 7 shows the relationship between the housing weight and the area of aluminum in the housing. The weight was calculated based on an aluminum density of 2.7g/cm^3 and a resin density of 1.2 g/cm^3. Extending the aluminum to the sides not only increases the weight but also makes the housing expensive and difficult to mass produce. We found that the use of aluminum on the bottom (which requires a high strength and high heat dissipation) and the use of resin on the sides (which requires good moldability for forming complex shapes) provided the best balance between the weight and the cooling performance.

3.2 Fabrication of hybrid housing

3.2.1 Adhesive

The bonding strength between the aluminum and resin is shown in **Table 1**. The table shows that nitrile rubber adhesive has the highest bonding strength (96 kgf/cm^3) of all the measured candidates. We believe the bonding mechanism to be as follows:

1) The tackifier is p-phenylen-phenol-resol-res-

Table 1. Bonding strength.

Adhesive	Bonding strength(kgf/cm^2)
Nitrile rubber	96
Chliroprene rubber	70
Styrene rubber	45
Ethylene acetic acid vinyl	17
Epoxy	5
Silan coupling agent	0

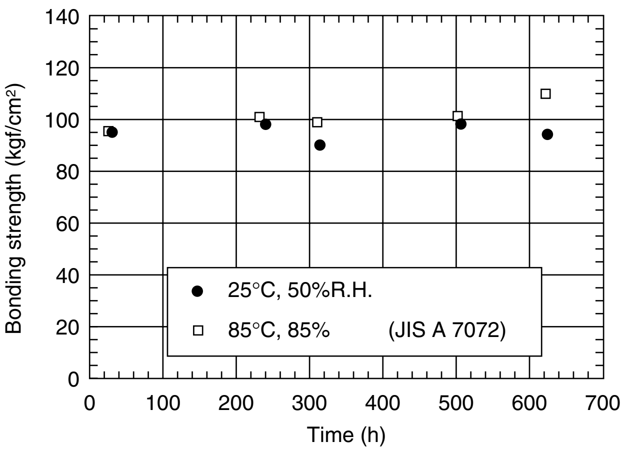

Figure 8.
Change in bonding strength over time at constant temperature and humidity.

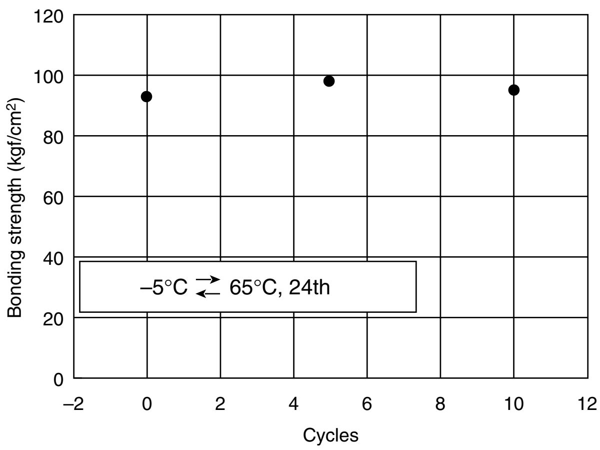

Figure 9.
Change in bonding strength after thermal cycling.

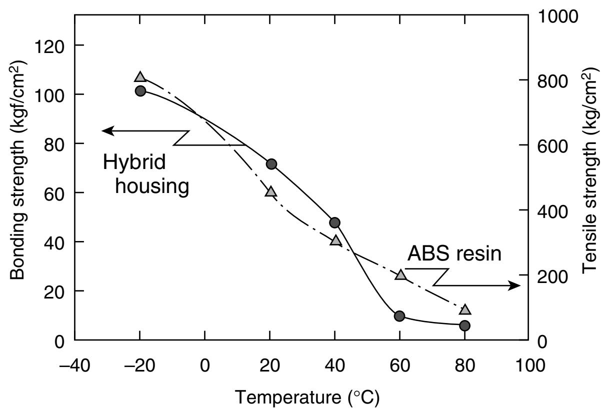

Figure 10.
Relationship between bonding strength and temperature.

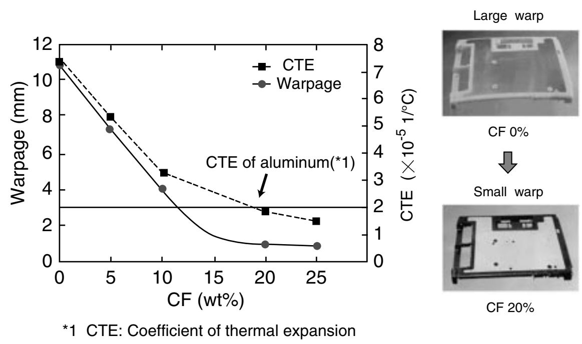

Figure 11.
Reducing warpage through material design.

in, and the non-polarized alkyl radicals (p-phenylen radicals) of the p-phenylen-phenol-resol-resin cross over to the molecules in the PC-ABS resin.

2) Polarized phenol hydroxyl in p-phenylen-phenol-resol-resin enhances stickiness as the hydrogen bonds with the adherend (aluminum). We also think that the high stickiness is due to a strong polarity in the nitrile rubber.

Figure 8 shows the change in adhesive bonding strength over time of nitrile rubber at a constant temperature and humidity. **Figure 9** shows the change in adhesive bonding strength over 10 thermal cycles. **Figure 10** shows the relationship between the bonding strength and temperature. Figures 8 and 9 show that the nitrile rubber adhesive maintains its bonding strength after 600 hours and after 10 thermal cycles. Nitrile rubber adhesive has this high stability due to its constant tensile strength.

However, Figure 10 shows that the bonding strength of nitrile rubber decreases as the temperature increases. The bonding strength is 80 kgf/cm^2 at 25°C, 25 kgf/cm^2 at 50°C, 10 kgf/cm^2 at 60°C, and 3 kgf/cm^2 at 80°C. Like ABS resin, the polymer is weaker at higher temperatures. However, the practical bonding strength required for the hybrid housing is about 10 kgf/cm^2 and is unknown at temperatures above 60°C. Therefore, no problem exists with the adhesive when the tem-

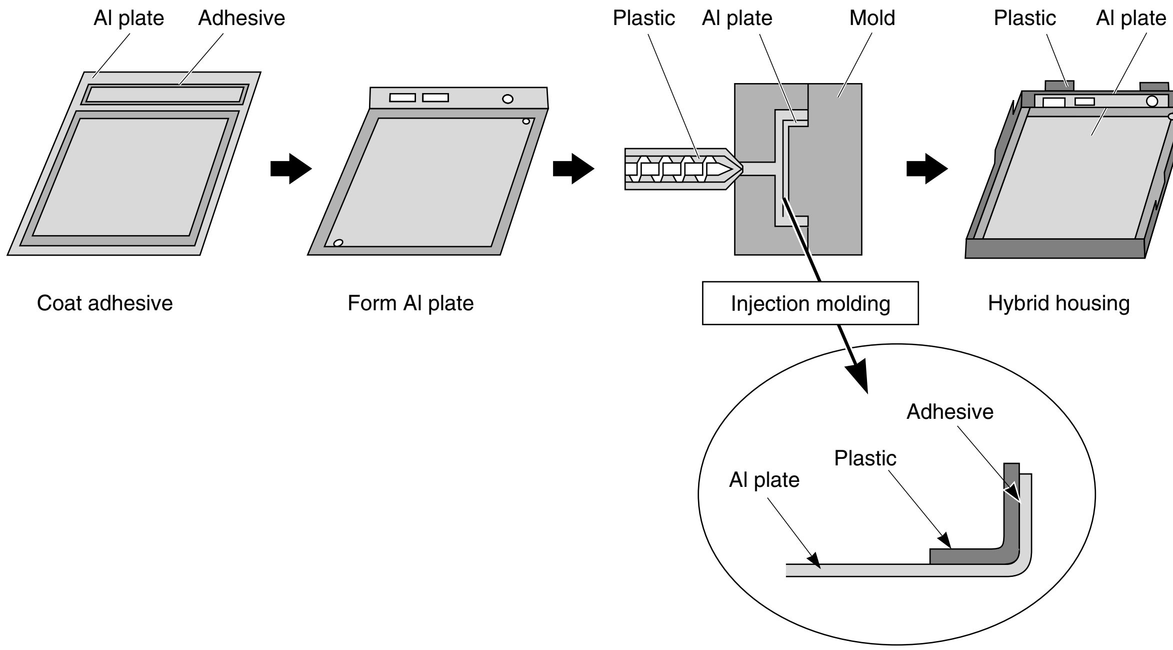

Figure 12.
Molding process for hybrid housing.

perature increases and so nitrile rubber is suitable for the adhesive of the hybrid housing.

3.2.2 Decreasing the warpage by modifying the resin

Figure 11 shows the warpage of the hybrid housing and the thermal expansion coefficient plotted against the CF (carbon fiber) content. The thermal expansion coefficient of PC-ABS resin and the warpage decrease as the CF content is increased. When the CF content is 20wt%, the thermal expansion coefficient is 2.0×10^{-5} 1/K, and when the CF content is 25wt%, the thermal expansion coefficient is 1.9×10^{-5} 1/K. The thermal expansion coefficient of PC-ABS resin is almost the same as that of aluminum (2.3×10^{-5} 1/K), and the warpage of the hybrid housing becomes less than 1 mm, which is the product level. PC-ABS resin containing 20wt% of carbon fiber is therefore suitable for the hybrid housing.

3.2.3 Manufacturing the hybrid housing

After we found a suitable adhesive and resin, we next examined the molding process. **Figure 12** shows the molding process. We used the following insert molding process.

1) Adhesive is spread to a thickness of from 20 to 30 μm by screen printing over a rolled aluminum board that has been degreased and washed.
2) The aluminum plate is then heated to 60°C for 10 minutes to set and harden the adhesive. This prevents the adhesive from moving during the resin injection molding process.
3) The aluminum plate is cut into an arbitrary shape, then holes are drilled and the plate is bent into the desired shape.
4) Caulking nuts are inserted into the aluminum plate to supply ground connections for the printed board.
5) The resin is injected after setting the aluminum plate into the mold, which is held at 80°C.
6) The heat from the resin melts the adhesive, and the resin injection pressure creates a secondary bond with the aluminum plate.

The hybrid housing is manufactured by injection molding, which is the mass-production casting method usually used for plastic housings

Table 2. Separation.

Temperature (°C)	Separation
80	×
90	×
100	○
110	○
120	○

Heating for 5 minutes

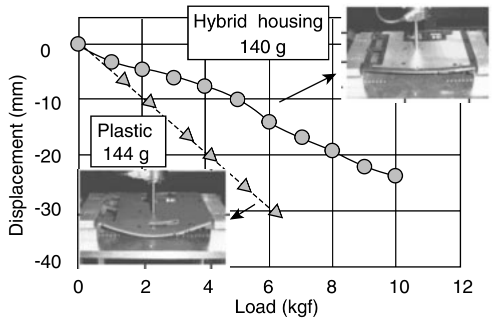

Figure 13.
Strengths of hybrid housing and plastic housing.

of notebook PCs. Therefore, the hybrid housing can be made using existing equipment. Also, the cycle time for the injection molding process of the hybrid housing is almost the same as that for an all-plastic housing (about 60 seconds).

Another feature of hybrid housings is that even though they have a high bonding strength (30 to 80 kgf/cm^2) in the temperature range of 10 to 50°C, because they use a thermoplastic rubber adhesive, we can separate the aluminum from the resin by heating the housing to 100°C for about 5 minutes (**Table 2**).

3.3 Properties of hybrid housing

3.3.1 Strength and lightness

We compared the structural strengths of the hybrid housing and the equivalent all-plastic housing. The results and the two housings are shown in **Figure 13**. Both housings weighed the same. The displacement of the hybrid housing was less than half that of the plastic housing under the same load. In other words, the hybrid housing is more than twice as strong as the plastic housing. The difference is due to the fact that there is a high-strength (flexural strength: 700,000 kgf/cm^2) aluminum plate in the bottom board of the hybrid housing but only resin (flexural strength: 40,000 kgf/cm^2) in the bottom board of the plastic housing.

The relationship between the thickness of the housing and the strength is given by the equation:

$$E \propto \frac{L^3P}{bh^3\Delta},$$

where E is the flexural modulus of the material, L is the length of the housing , b is its width, h is its thickness, P is the load, and Δ is the displacement. From this equation, we can see that Δ is directly proportional to $1/h^3$. This means that, if we allow the flexibility allowed in the resin housing, the thickness, and hence the weight of the housing can be reduced by 20%.

Table 3. Mesured temperatures for hybrid and plastic housings.

Housing	Resin housing (Simulation)	Hybrid housing (Simulation)
MPU	105.1 (97.5)	98.2 (94.8)
HDD	73.4 (69.9)	67.8 (65.9)
Surface 1 of housing	60.3 (56.5)	50.2 (53.9)
Surface 2 of housing	38.2 (32.1)	43.8 (37.8)

in degrees Celsius

3.3.2 Cooling characteristics

As **Table 3** reveals, the temperature at the MPU is 7 degrees lower in the hybrid housing model than in the ordinary plastic housing. The temperatures of other components in the hybrid housing model also show a similar change, for example, the HDD is 5 degrees cooler and housing surface 1 (under the MPU) is 10 degrees cooler. On the other hand, housing surface 2 (resin part of sides of the hybrid housing) is 6 degrees hotter in the hybrid housing model than in the ordinary plastic housing. We believed that this is because the hybrid housing has a larger effective heat transfer area than the plastic housing because its aluminum has a high thermal conductivity (138 W/mK) and can spread heat throughout the housing. In contrast, in the plastic housing model, because the thermal conductivity of plastic is only 0.2 W/mK, heat is concentrated near the heat generating components, which minimize the cooling effect.

We confirmed that the temperature decreased as our analysis predicted by increasing the aluminum area. A hybrid housing, in which resin is integrated with an aluminum plate, provides a temperature reduction of 5 to 10 degrees, which is sufficient for sub-notebook PCs.

As MPU performance continues to improve, the total heat generated by notebook PCs will increase more and more. New cooling technologies, which, for example, transfer heat from the CPU to the LCD housing, will thus be needed.[9)10)] We can further improve the cooling characteristics of notebook PCs because the hybrid housing technology is also applicable to LCD housings.

4. Conclusion

Fujitsu has developed a new housing technology for notebook computers. This hybrid housing consists of resin and metal to offer a combination of structural strength, efficient heat dissipation, and light weight.

First we proved the high heat dissipation characteristics of a hybrid housing by thermal simulation and decided on the best distribution of aluminum and resin of the hybrid housing. Then, we investigated and developed (1) an adhesive suitable for combining aluminum with resin, (2) a resin which minimizes warpage, and (3) a molding process suitable for mass production. The hybrid housing method reduces internal temperatures by as much as 5 to 10°C when compared to conventional resin housings. It also enables a 20% weight reduction over conventional resin housings.

The hybrid housing was used in the FMV-BIBLO NC, which was released by Fujitsu in 1996 (**Figure 14**).

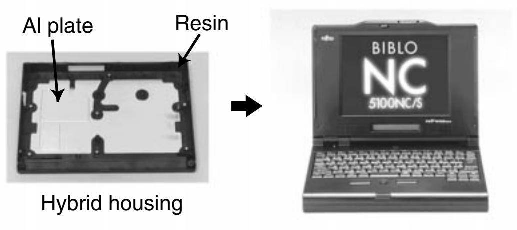

Figure 14.
Application in FMV-BIBLO NC.

References

1) Suzuki et al.: Packaging Technology for Pentium Notebook PCs, Toshiba for Pentium Notebook PCs. Toshiba Review, Vol. 50, No. 8, (1995).
2) Japanese IBM Housing for Personal Computer. Nikkei material 1994.10.3.
3) Nishii et al.: Note Personal-Computer Housing. Plastics No. 8 Vol. 46 (1996)
4) Nishii et al.: Hybrid housing for Notebook. ALUTOPIA, Vol. 27, pp. 15-19 No.8 (1997).
5) Electronic Equipment Housing. Patent open syowa 59-12419.
6) Housing of Electronic Equipment. Patent open, Heisei 1-198099.
7) Kimura et al.: Manufacturing Technology of Hybrid Housings. JSPP'97. Tech. Papers (1997).
8) Shiraishi et al.: Mechanical Strength of Housings. JSPP'90. Tech. Papers (1990).
9) Goto et al.: CPU Cooling by using Hinge Heat Pipe. 33rd National Heat Transfer Symposium (1996-5).
10) Xie et al.: Thermal Solutions to Pentium Processors in TCP in Notebooks and Sub-notebooks. Electronic Components and Technology Conference (1995).

Kota Nishii received the M.S. degree in Applied Chemistry from Keio University, Kanagawa, Japan in 1982. He joined Fujitsu Laboratories Ltd. in 1982, where he is currently engaged in research and development of housing materials for portable equipment. He is a member of the Society of Polymer Science, Japan.

Kouichi Kimura received the B.S. degree from the Faculty of Textile Science and Technology of Shinsyuu University, Nagano, Japan in 1990. He joined Fujitsu Laboratories Ltd. in 1990, where he is currently engaged in research and development of housing materials for portable equipment. He is a member of the Society of Mechanical Engineers, Japan.

Motonobu Kawarada received the B.S. degree in Science from Yamagata University, Yamagata, Japan and the Dr. degree in Science from Tohoku University, Sendai, Japan in 1971 and 1976, respectively. He joined Fujitsu Laboratories Ltd. in 1976 and has been engaged in research and development of materials for computer systems. He is a member of the Physical Society of Japan and the Japan Society of Applied Physics.