HP-PAC: A New Chassis and Housing Concept for Electronic Equipment

HP-PAC replaces the familiar metal chassis structure with expanded polypropylene (EPP) foam. Large reductions are realized in mechanical parts, screw joints, assembly time, disassembly time, transport packaging, and housing development costs.

by Johannes Mahn, Jürgen Häberle, Siegfried Kopp, and Tim Schwegler

Business competition between PC and workstation manufacturers has resulted in shortened life cycles for computer products, faster development and production times, and steadily decreasing market prices. The Hewlett-Packard Böblingen Manufacturing Operation and its Mechanical Technology Center are faced with this trend, along with others, such as tightened environmental protection guidelines and take-back regulations.

These trends call for new concepts—environmentally friendly materials and matching manufacturing methods. Assembly and disassembly times for computer products have to be as short as possible. Assembly analysis of some HP products clearly showed the necessity to reduce parts as well as to improve manufacturing and joining techniques.

At the Mechanical Technology Center, these observations provided the motivation to look for a new packaging and assembly concept for computer products, one that would leverage existing techniques and incorporate new technological ideas.

Our objectives were to reduce the number of components and the number of different part numbers, to achieve considerable savings in the area of logistics and administration, to save time in building a chassis, to automate the mounting of parts on the chassis, and to reduce overall chassis costs.

Genesis of an Idea

After we had critically weighed all of the technologies known to us—namely, producing enclosures and chassis of sheet metal or plastics—the only reduction potential seemed to lie in reducing the number of parts and using snap fits to save on fasteners and assembly times. However, in contrast to our expectations, we could not do this to the extent we had in mind.

Using snap fits is a disadvantage, since disassembly is time-consuming and can lead to destruction of the components or the enclosure. In the future, enclosures not only need to be assembled quickly but also need to be disassembled within the same amount of time to make recycling easier and cheaper.

We could not get out of our minds the idea of fixing parts in such a way that they are enclosed and held by their own geometrical forms. The idea is similar to children's toys that require them to put blocks, sticks, cards, or pebbles into matching hollows and at the same time keep track of positions and maintain a certain order at any time during the game. We applied this idea to our problem and thought about how our game collection would have to look in terms of composition and performance for us to be able to package and insert components for a workstation. It seemed most feasible to apply this idea at the assembly level, that is, to use the new method to fix conventional assemblies such as the disk, speaker, power supply, CPU board, and fan.

The only problem was what kind of material could we use to realize this idea. How could we achieve a form fit and not compromise on tolerances, feasibility, and price? Not to condemn the idea almost seemed impossible. It became obvious that we could no longer use conventional methods and standards to find the ideal material. We were forced to deal with a completely different field. The solution seemed to be to jettison everything we had learned before and direct our orientation towards something totally new.

The material we were looking for had to be pliable and bouncing—like foam, for example. Could foam be used for a form fit?

Raw Material Selection

After the idea had been born to use foam, we started our search for a suitable material. The goal was to embed all components necessary for an electronic device in one chassis made of foam synthetic material. We had plenty of material to choose from, including polyurethane, polystyrene, and polypropylene. The material had to be:

- Nonconductive to hold and protect electronic components
- Able to hold tolerances in accordance with HP standards
- Able to fix components without fasteners.

With the help of our internal packaging engineers and an external supplier we soon found a suitable material: expanded polypropylene (EPP) with a density of 60 g/l.

In comparison to other foam synthetic material, EPP has the following advantages:

- Excellent mechanical long-term behavior
- Moisture resistance
- Resistance to chemicals
- Heat resistance

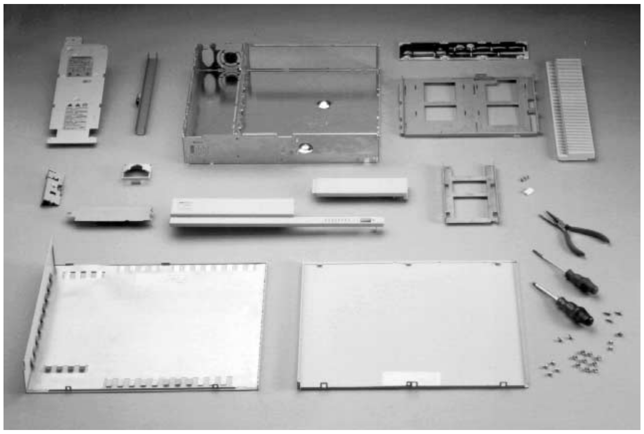


Fig. 1. Parts required for a workstation using the existing packaging concept.

- 100% recyclability. Granules produced from recycled EPP can be used for manufacturing other parts such as packaging material and shock absorbers.

EPP foam parts can be produced in densities of 20 to 100 g/l. Lower density provides excellent shock absorption, while higher density offers tighter manufacturing tolerances. Thus design trade-offs are possible.

From the Idea to a Workstation

The next step was to apply this new concept to an already existing workstation. One workstation seemed suitable for the conversion. The existing concept (see Fig. 1), consisting of sheet-metal chassis (top and bottom), electrical components, sheet-metal enclosure, EMI liner, and plastic parts, was transformed into a foam chassis, electrical components, sheet-metal sleeves, integrated EMI liner, and modified plastic parts (see Fig. 2). In the new technology, all of the components are held by their own geometry in form-fitting spaces in the foam chassis. The connections between them are achieved through cabling held in foam channels (Fig. 3).

Time was saved by processing the foam chassis, the sheet metal, and the plastic parts in parallel. To obtain the foam parts quickly, we rejected the ordinary way of creating drawings with the help of a CAD system and instead created a 2D cardboard layout showing the placement of the components. A packaging company placed their sample tooling shop at our disposal for a few days. The first prototype was built step by step. We milled, cut, and glued, applying a lot of imagination.

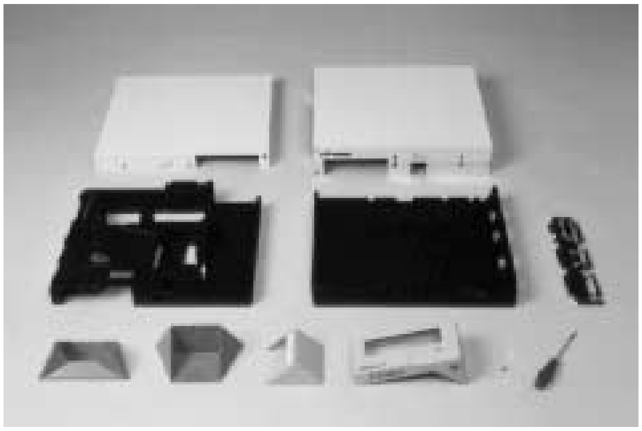


Fig. 2. Parts required for the workstation of Fig. 1 using the HP-PAC concept.

Fig. 3. Channels in the foam carry cooling air (shown) and cabling.

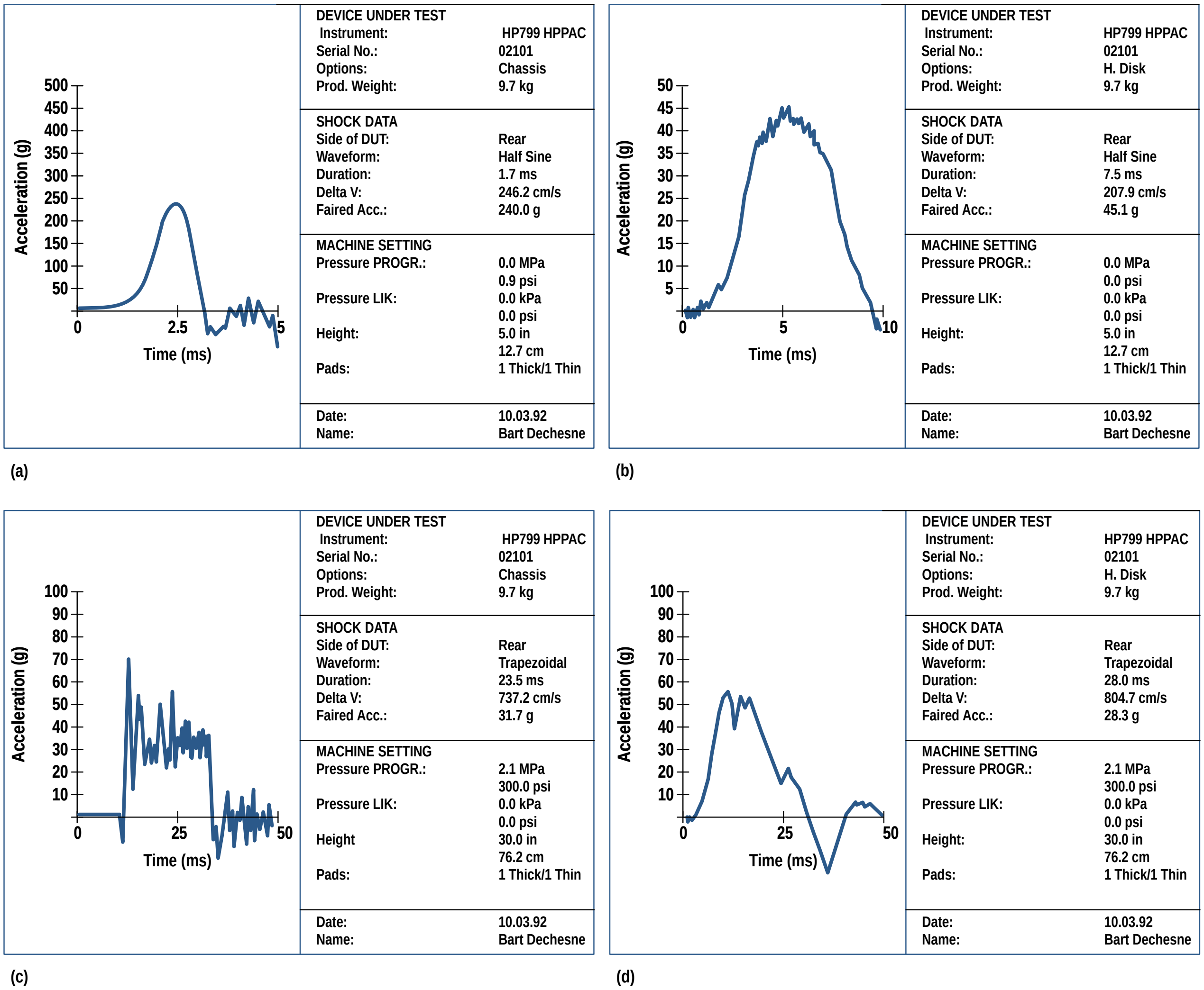
After two days the first prototype was nearly finished. Components were fixed in the necessary form fit and we were all aware that we had taken a step in the right direction. Back at HP we made a few minor changes to the EPP chassis and the remaining enclosure with the help of a knife and finished the prototype.

The major question now was, “Will it run?” We ran software on the workstation and started testing, surrounded by our production staff. The programs worked!

Next, temperature, humidity, and environmental tests were performed. Temperature problems were corrected by altering the air channels through cutting and gluing. HP class B2 environmental tests were passed (see Table I and Fig. 4).

Table I
Thermal Test Results
CPU Temperatures (°C)

Test Point	HP-PAC	Original
UB7	29.1	32.1
UD15	33.0	37.5
UB20	36.6	44.8
UH25	35.7	46.7
TO-220	49.3	59.8
UM10	39.9	44.5
UM25	58.7	67.5
UR30	56.7	73.7
MUSTANG	70.0	82.9
CPU Average	45.44	54.39



DEVICE UNDER TEST
Instrument: HP799 HPPAC
Serial No.: 02101
Options: Chassis
Prod. Weight: 9.7 kg

SHOCK DATA
Side of DUT: Rear
Waveform: Half Sine
Duration: 1.7 ms
Delta V: 246.2 cm/s
Faired Acc.: 240.0 g

MACHINE SETTING
Pressure PROGR.: 0.0 MPa
0.9 psi
Pressure LIK: 0.0 kPa
0.0 psi
Height: 5.0 in
12.7 cm
Pads: 1 Thick/1 Thin

Date: 10.03.92
Name: Bart Dechesne

(a)

DEVICE UNDER TEST
Instrument: HP799 HPPAC
Serial No.: 02101
Options: H. Disk
Prod. Weight: 9.7 kg

SHOCK DATA
Side of DUT: Rear
Waveform: Half Sine
Duration: 7.5 ms
Delta V: 207.9 cm/s
Faired Acc.: 45.1 g

MACHINE SETTING
Pressure PROGR.: 0.0 MPa
0.0 psi
Pressure LIK: 0.0 kPa
0.0 psi
Height: 5.0 in
12.7 cm
Pads: 1 Thick/1 Thin

Date: 10.03.92
Name: Bart Dechesne

(b)

DEVICE UNDER TEST
Instrument: HP799 HPPAC
Serial No.: 02101
Options: Chassis
Prod. Weight: 9.7 kg

SHOCK DATA
Side of DUT: Rear
Waveform: Trapezoidal
Duration: 23.5 ms
Delta V: 737.2 cm/s
Faired Acc.: 31.7 g

MACHINE SETTING
Pressure PROGR.: 2.1 MPa
300.0 psi
Pressure LIK: 0.0 kPa
0.0 psi
Height 30.0 in
76.2 cm
Pads: 1 Thick/1 Thin

Date: 10.03.92
Name: Bart Dechesne

(c)

DEVICE UNDER TEST
Instrument: HP799 HPPAC
Serial No.: 02101
Options: H. Disk
Prod. Weight: 9.7 kg

SHOCK DATA
Side of DUT: Rear
Waveform: Trapezoidal
Duration: 28.0 ms
Delta V: 804.7 cm/s
Faired Acc.: 28.3 g

MACHINE SETTING
Pressure PROGR.: 2.1 MPa
300.0 psi
Pressure LIK: 0.0 kPa
0.0 psi
Height: 30.0 in
76.2 cm
Pads: 1 Thick/1 Thin

Date: 10.03.92
Name: Bart Dechesne

(d)

Fig. 4. Impacts transmitted to a hard disk drive by HP-PAC foam. In (a) and (c) the sensor is on the workstation. In (b) and (d) the sensor is on the hard disk drive held by HP-PAC.

Fig. 4 shows the impacts transmitted by HP-PAC to a hard disk for two different types of shocks (half sine, trapezoid). These impacts could be minimized by optimizing the design of the supports and form fits for the devices.

Savings and Advantages

Comparisons were drawn between a traditional HP workstation and an HP workstation in which the system components such as the CPU board, disk drive, and flexible disk were mechanically integrated using the HP-PAC concept. The HP-PAC workstation showed:

- A 70% reduction in housing mechanical parts
- A 95% reduction in screw joints
- A 50% reduction in assembly time
- A 90% reduction in disassembly time
- A 30% reduction in transport packaging
- A 50% reduction in time and expenditure for the mechanical development of the housing.

Compared to conventional chassis concepts, HP-PAC's advantages include:

- A reduction in the number of chassis parts.
- Separation between functionality and industrial design. The external enclosure is designed after definition of the mechanical interfaces between the enclosure and the chassis and between the enclosure and the components.
- One production step to produce molded parts.
- Simple, fast, and cost-effective assembly of the components (see Fig. 5). The assembly process is almost self-explanatory as a result of the indentations in the molded parts, and no additional joining elements and assembly tools are necessary. Assembly at the dealer's site is feasible.
- Reduced product mass because of the lighter chassis.
- Good protection against mechanical shock and vibration.
- On-the-spot cooling of components as a result of air channels in the foam.
- Cost savings during almost all working processes.
- Reduced transport packaging as a result of the good absorption of the chassis material. Also, less transport volume.

Impact on the Development Process

With HP-PAC, a 100% recyclable and environmentally friendly material is used for the construction of the chassis.

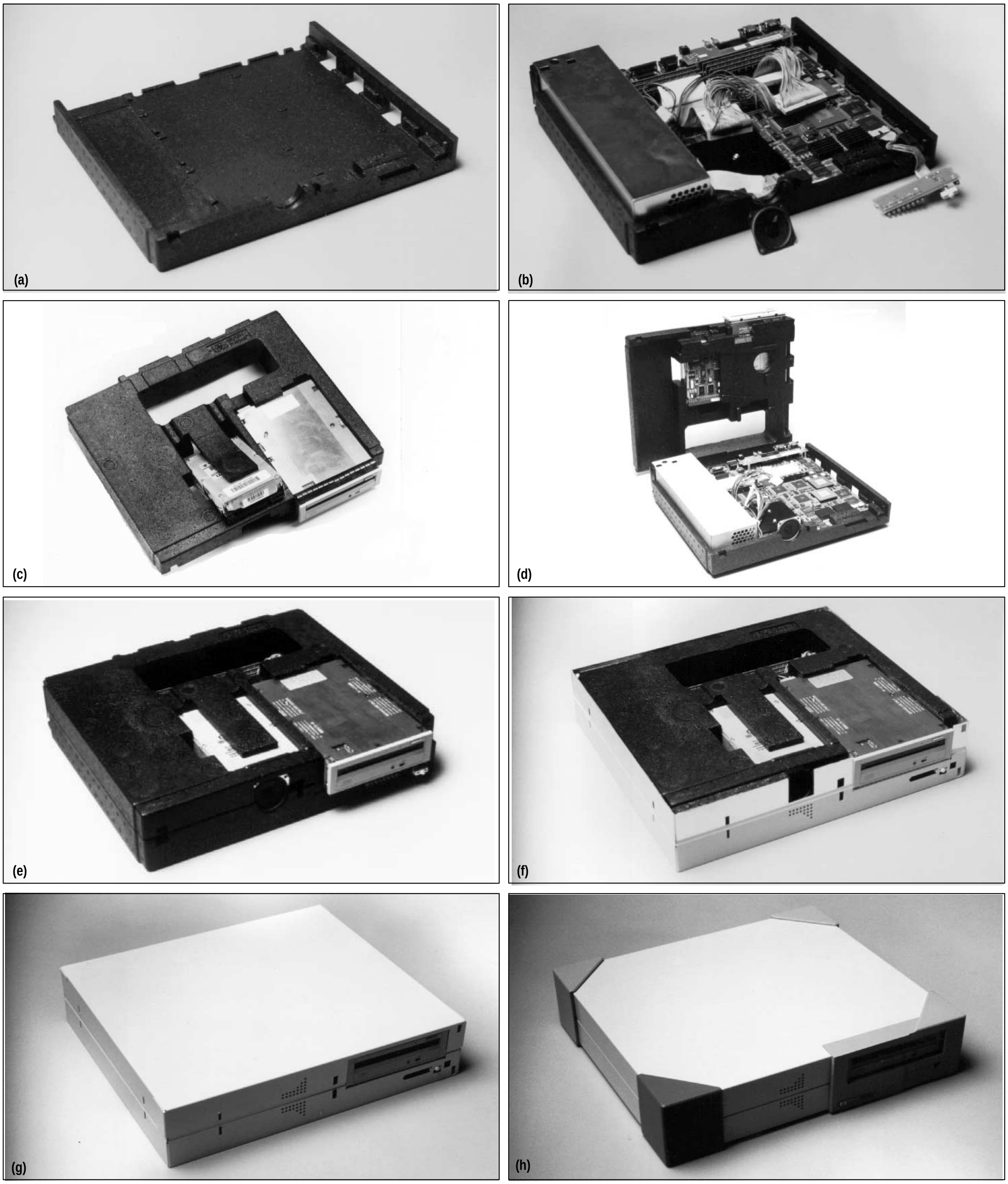


Fig. 5. HP-PAC workstation assembly sequence. (a) Foam bottom chassis. (b) Loaded bottom chassis. (c) Partially loaded foam top chassis. (d) Open loaded chassis. (e) Assembled loaded chassis. (f) Lower enclosure added. (g) Upper enclosure added. (h) Enclosure completed.

Development of a chassis only means spatially arranging components within a molded part and adhering to certain construction guidelines (function- and production-specific). The external enclosure is developed separately after definition of the interfaces. There are hardly any tolerance problems as a result of material flexibility. Changes are simple to perform by cutting, gluing, and additional grinding so an optimal solution can be reached quickly.

It is possible to perform all relevant environmental tests on the first prototype. Prototypes can also be used for the first functional tests. It is relatively simple to make changes during the tests, since industrial design and functionality are clearly separated and changes on the molded part can be performed in the lab. Once the design is complete, manufacturing of the molding tool is fast and cost-effective, and tool changes are not required.

The result is a short, cost-effective chassis development phase.

Material Development

HP-PAC places high demands, some of which are new, on the material used. Expanded polypropylene meets these demands in almost all ways.

So far EPP has been mainly used in reusable packaging and to an increasing extent in the automobile industry, where bumper inlays and side impact cushions for car doors are typical applications. Traditionally the automobile business has placed high demands on the quality of components. In terms of precision and long-term behavior these demands are identical to those of HP-PAC.

However, the situation is somewhat different for two new HP-PAC-specific material requirements: ESD (electrostatic discharge) suitability and flame retardant properties. We are working with raw material manufacturers in the U.S.A., Japan, and Germany to develop optimum raw material for HP-PAC in the medium and long term. For the short term, procedures had to be found and checked to meet these demands. In terms of ESD suitability this meant spraying or dipping parts in an antistatic solution. A suitable flame retardant was developed and patented together with a company specializing in flame retardants. Like plastic molding, treatment with flame retardant places an additional burden on the environment and impairs recyclability. However, a good product design renders flame retardants unnecessary. Three prototype HP-PAC products without flame retardant already have UL/CSA and TÜV approval.

We expect that the incentive for suppliers to develop suitable raw materials will steadily increase as the number of products using HP-PAC grows. Thus, in the future we hope to have custom-made materials available that will allow further improvements in quality at reduced cost.

EPP and Its Properties

EPP raw material is available on a worldwide basis. Some EPP manufacturers and their trade names for EPP are JSP ARPRO, BASF NEOPOLEN P, and Kaneka EPERAN PP. EPP comes in the form of foam polypropylene beads. Its chemical classification is an organic polymer, one of the class of ethylene polypropylene copolymers.

EPP contains no softeners and is free of CFCs. The product does not emit any pollution. Compressed air, steam, and water are used during the molding process. According to one EPP manufacturer, no chemical reactions take place during this process.

The specifications quoted here are for the JSP raw material we used. EPP from other manufacturers should vary only a little or not at all from these specifications.

Mechanical Properties. The following list shows the relevant mechanical properties of parts made of expanded polypropylene foam with a density of 60 g/l.

Density: 60 g/l
Tensile strength: 785 kPa
Compressive strength at 25% deformation: 350 kPa
Residual deformation after 24 hours at 25% deformation: 9%
Deformation under static pressure load (20 kPa): 1.2%
    After 2 days: 1.3%
    After 14 days: 1.4%

Thermal Properties. After the molding process, the parts are tempered so that the dimensions become consistent. Any further temperature influences will not result in significant contraction, expansion, or changes of mechanical properties between −40°C and 110°C. The coefficient of thermal expansion is 4.2×10^{-5}/°C from −40°C to 20°C and 7.5×10^{-5}/°C from 20°C to 80°C. Thus, a 100-mm length of foam at 20°C will be 100.375 mm long at 70°C.

The material changes state above 140°C. Thermal dissolution occurs at 200°C and the ignition point is 315°C.

There was no permanent deformation in a temperature loop test consisting of:
4 hours at 90°C
0.5 hour at 23°C
1.5 hours at −40°C
0.5 hour at 23°C
3 hours at 70°C and 95% humidity
0.5 hour at 23°C
1.5 hours at −40°C
0.5 hour at 23°C

Electrical Properties. EPP has good electrical insulation properties. This means that the foam parts can easily acquire an electrical charge. Consequently, methods are being developed to produce antistatic EPP. There is no noticeable interference between EPP material and high-frequency circuits with square-wave signals up to 100 MHz. Tests at very high frequencies ($>$100 MHz) have not yet been conducted.

We can infer from solid polypropylene some of the electrical properties of expanded polypropylene:

- Dissipation factor of injection-molded EPP at 1 MHz: tan $<5\times10^{-4}$
- Breakdown voltage of injection molded EPP: 500 kV/cm
- Surface resistance at 23°C and 49% relative humidity, untreated: 10^{11} to 10^{12} ohms.

Chemical Resistance. EPP has good chemical resistance because of its nonpolar qualities. It is resistant to diluted salt, acid, and alkaline solutions. EPP can resist lye solutions, solvents at concentrations up to 60%, and alcohol. Aromatic and halogenated hydrocarbons found at high temperatures in grease, oil, and wax cause it to swell. When EPP is mixed with other substances, dangerous chemical reactions do not take place.

Reaction to Light. In general, EPP is sufficiently resistant to radiation at the wavelengths of visible light.

Reaction to Humidity and Water. Humidity has little or no effect on the mechanical properties of EPP. Water absorption is 0.1% to 0.3% by volume after one day and 0.6% after seven days. No changes are visible after 24 hours in water at 40°C.

Manufacturing Process

The raw material beads are injected in a precombustion chamber at a pressure of approximately 5 bar which reduces the pellet volume. The beads are then injected into the mold at a pressure of approximately 4 bar until a particular filling ratio is reached. The pressure is then reduced to normal so that the beads can reexpand and fill the mold. Once the mold is filled, steam at 180°C is injected into the mold through nozzles, warming the surface of the beads and fusing them together. This defines the foam part, which is left to cool down and then removed from the mold. Subsequently, by means of specified temperature cycles, controlled maturing and dimensional changes are induced in the part, resulting in its final form. This form remains constant within a specified temperature range.

Recycling of EPP

Polypropylene foam material can be recycled and used for manufacturing of other products. Manufacturers of polypropylene take back EPP waste free of charge.

EPP can be melted and fed back into source material polypropylene in thermoplastic form. Compression, melting, and granulation take place in gas extruders. The extruded recycled material can be used for polypropylene injection molded or extruded products. Recycling trials with a bumper system made out of short glass fiber (approximately 20% of weight), EP rubber (approximately 20% of weight) and polypropylene produced a granule that can be used for complex injection molding.

Conclusions

To protect the HP-PAC technology in an appropriate manner we have filed for a patent under European patent application number 0546211.

It goes without saying that we will continue to develop the technology further. Efforts in which we are currently engaging are material development, prototype manufacturing, quality assurance, and marketing of HP-PAC.

We have not yet set any specific limits on user distribution. Possible areas for user application range from the electronics and electromechanical industries to home electronic equipment and transportation. At the Mechanical Technology Center, we offer various services ranging from consulting to complete solutions, not only for HP-PAC but also for sheet-metal and plastic parts. We have experience in the computer, analytical, and instrument businesses and are in contact with others.

Acknowledgments

We would like to thank the Novaplast Company and the following HP entities: Böblingen Computer Manufacturing Operation, Exeter Computer Manufacturing Operation, Böblingen Manufacturing Operation Mechanical Technology Center, Böblingen Manufacturing Operation environmental test laboratory, Workstation Systems Group quality department.