Building a Solution to the Plastic Waste Problem With Paper Fibre Reinforcement Technology

*Hidekazu Hara**

ABSTRACT Multilayer films used for food packaging, etc. are not recycled, but are instead incinerated, landfilled, or leaked into the environment causing a plastic waste problem. By applying a unique fibre reinforcement technology using paper (APFU: Advanced Paper Fibre Upcycling) technology developed by our company, we have succeeded in upcycling multilayer films into high-strength plastic materials. Using these materials, our products including ballpoint pens can be injection moulded, bottles can be multilayer blow moulded, and these materials can also be used as a material for 3D printers. The life cycle assessment calculation commissioned by us confirms that greenhouse gas emissions can be significantly reduced incineration. To contribute to the prevention of marine pollution caused by plastic waste and the control of climate change, we are currently conducting demonstration experiments and feasibility studies in collaboration with Japanese and European companies, local governments, and alliance organizations toward the practical application of this APFU technology.

1. INTRODUCTION

1.1 The Plastic Waste Problem

There are many plastic products around us. As plastics have many excellent features such as light weight, durability, anti-rust, anti-corrosion and low cost, we can no longer imagine a life without plastics.

In fact, the world's plastic production has been increasing in recent years, and half of the cumulative production from 1950, when industrial production began, to 2020, was produced only in the last 15 years. The production volume in 2020 has reached 367 Mton[1]. Disposable plastics (Single-Use Plastics) represented by containers and packaging for food and toiletry products account for approximately 40% of plastic products, which accounts for the highest percentage[2), 3]. Plastic containers and packaging for food have excellent functions such as maintaining safety and sanitation, maintaining the quality of food inside, and a high transportation efficiency, which greatly contributes towards the reduction of food wastage.

However, due to the increase in the amount of the use of such disposable plastics, the amount of waste is also increasing. Only 14% of plastic containers and packaging waste is recycled (2015)[2], and the rest is disposed of by landfill, incineration, or leaked into the environment. This has caused environmental problems such as an increase in greenhouse gas (GHG) emissions, soil and water pollution, and marine pollution due to the outflow of plastic waste which is particularly serious. It is estimated that it will take hundreds of years for plastics to completely decompose in the natural environment, and it is predicted that the weight of plastics present in the ocean will exceed the volume of fish by 2050[4]. As animals living in the ocean mistakenly swallow small pieces of plastic as food, and they are taken up by land fauna and humans who eat them, there are concerns about the destruction of the ecosystem of land fauna as well as the ocean fauna. As stated above, while plastic containers and packaging have great merits, they cause major problems due to improper disposal of the large volume of waste generated.

1.2 The Situation Surrounding the Plastic Waste

In response to this plastic waste problem, there are active movements around the world to establish policies and ordinances. Following China's embargo on waste plastics in 2018 and the revision of the Basel Convention in 2019 (enforced in 2021), developing countries such as Southeast Asia will also ban imports of waste plastics in the future, and waste plastics will be required to be treated in a discharge area. In Europe, the European Union (EU) Plastics Strategy was announced in 2018, and the plastics tax was introduced in 2021. The items subjected to the plastics tax are plastic containers and packaging that are not recycled. In such a situation, if we continue to use plastic containers and packaging in the future, the recycling solutions will become even more important.

* Plastic Waste Recycling Project Team,
Social Design & New Business Development Department,
Global Marketing Sales Division

1.3 The Recycling of Plastic Containers and Packaging

One of the reasons for the low recycling rate of plastic containers and packaging is that most of them are multi-layer films. Layers are difficult to separate as they are made by laminating different materials having different chemical properties and melting points, and their compositions vary depending on the contents. This makes recycling as a material difficult (detailed in 3.1), and even if they are collected, there is no choice but to incinerate or landfill. There is a gap between Japan and Europe as to whether "energy recovery" that uses the heat energy generated during incineration is called recycling. However, in a situation where the conversion from fossil fuels to renewable energies is being required to control greenhouse gas emissions, it would be difficult to truly call this recycling.

On the other hand, in recent years, for polyethylene terephthalate (PET) bottles made of a single material, practical use of chemical recycling, that restores PET bottles to raw materials by depolymerization (Decomposing a polymer into a monomer), repolymerizes them, and recycles them into PET bottles, has begun. Although chemical recycling such as pyrolysis and gasification by thermal decomposition is being considered for multilayer films made of dissimilar materials, the technology is still under development and it is necessary to accumulate further data on its impact to the environment[5), 6)].

As stated above, one of the factors causing the plastic waste problem is the difficulty in recycling multilayer films.

2. FIBRE REINFORCED TECHNOLOGY USING PAPER (WASTE PAPER)

Furukawa Electric has been developing a technology to reinforce plastics with fibre utilising paper[7)]. Paper is made of entangled cellulose fibres. When paper and plastics are melt-kneaded, normally the paper is crushed to some extent, but as the cellulose fibres are still entangled with each other, the paper ends up existing as a contaminant in the plastic. On the other hand, with our technology, paper is disentangled into cellulose fibres and the cellulose fibres are dispersed in the plastic to produce a cellulose fibre reinforced plastic in one single process. Furukawa Electric has named this technology 'APFU' (Advanced Paper Fibre Upcycling) (Figure. 1). Figure 2 shows the outline of the APFU process. The paper used in APFU can be either new or used/recycled. Furthermore, laminated paper with aluminum (Al-laminated paper) used for beverage cartons of alcoholic beverages or vegetable juices can also be used. Although such laminated paper is classified as paper, it has an aspect of becoming plastic waste, as the residue left behind after the recycling process of paper consists mainly of polyethylene films.

The tensile strengths of the materials in which low-density polyethylene (LDPE, laminate grade), high-density polyethylene (HDPE, injection-moulded grade), and polypropylene (PP, block polypropylene, injection-moulded grade) are reinforced with Al-laminated paper by APFU is shown in Figure 3 to 5. Test pieces were prepared by injection moulding. In all cases, the tensile strength increases as the amount of paper added increases, up to two to three times the strength of the original plastic. At this time, the aluminium foil is finely crushed and dispersed in the plastic. In addition, if an HDPE is strengthened by using office paper instead of Al-laminated paper, the strength is further increased. This is because office paper does not contain LDPE or aluminium foil like Al-laminated paper. Figure 6 shows the tensile strength. The tensile strength reaches a maximum of approximately 80 MPa, which is comparable to that of glass fibre reinforced plastic.

As stated above, the APFU, the paper fibre reinforcing technology developed by Furukawa Electric can increase the strength of all the polyolefins.

Figure 1 APFU logo.

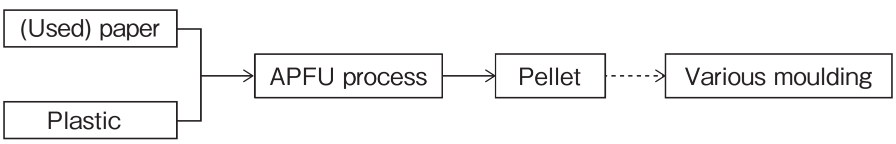

Figure 2 Process flow of the APFU.

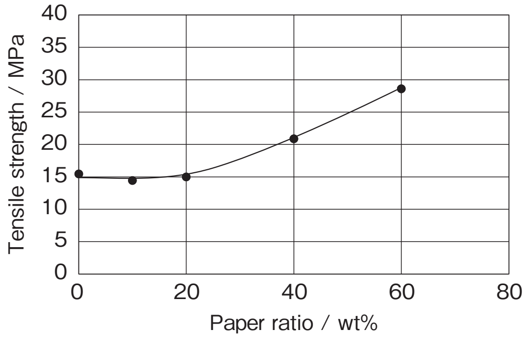

Figure 3 Tensile strength of LDPE when reinforced with Al-laminated paper.

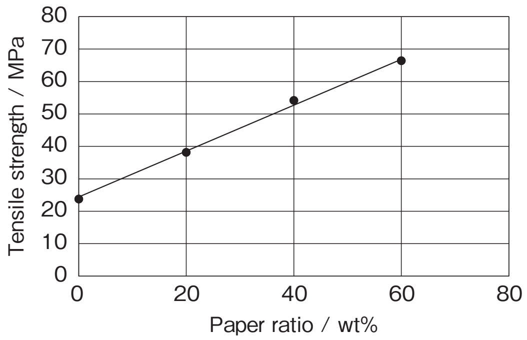

Figure 4 Tensile strength of HDPE when reinforced with Al-laminated paper.

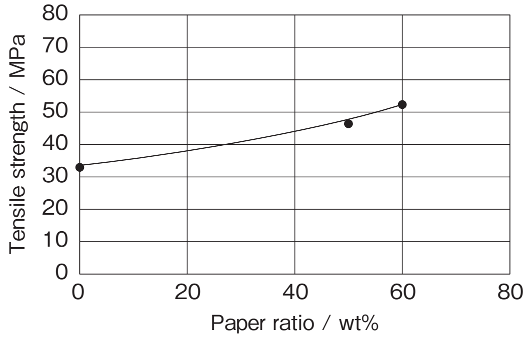

Figure 5 Tensile strength of PP when reinforced with Al-laminated paper.

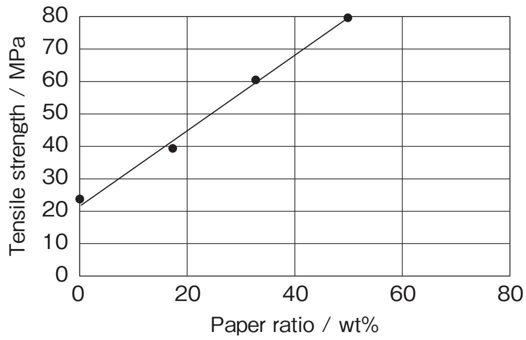

Figure 6 Tensile strength of HDPE when reinforced with office paper.

3. RECYCLING OF MULTILAYER FILMS USING APFU

3.1 Difficulty in Recycling Multilayer Films

The multilayer film is generally composed mainly of polyolefins such as LDPE or PP, and different materials such as PET, polyamide (PA), ethylene vinyl alcohol copolymer (EVOH), aluminium (Al) foil and paper are laminated. To recycle this as a material for films, it is necessary to completely remove foreign substances such as PET and PA other than the main component, which is challenging technically. In addition, the removed PET etc. becomes a residue, and eventually ends up as plastic waste. On the other hand, the strength is insufficient when recycled to be used as a material for moulded products having certain thicknesses. This is because many of the polyolefins for films have low strength and contain different materials which act as foreign substances. For those reasons, it is difficult to recycle multilayer films as materials.

3.2 The Application of APFU to Multilayer Films

We believe that if APFU could be applied to multilayer films to increase the strength, the multilayer films could be recycled as a material for moulding applications. To prove this, we experimented with various multilayer films using Al-laminated paper as a reinforcement source and evaluated the material's tensile strength. As in the previous section, the evaluation was performed using injection-moulded test pieces. Table 1 shows the applications and the compositions (analysis and estimation from manufacturer information) of each multilayer film used, and Figure 7 shows the evaluation results. The ratios of the Al-laminated paper added to the multilayer films are different because they were determined based on the ratio of polyolefin contained in the films. As Figure 7 shows, it was possible to increase the strength of the multilayer film having any composition using APFU. At this time, in order to suppress the decomposition of cellulose fibres, kneading and moulding was performed within a range of temperature not exceeding 200˚C approximately. Due to this, in the evaluation test pieces created, high melting point plastics such as PET and PA are included as foreign substances, but the increase in the strength was not affected.

Table 1 Applications and compositions of the multilayer films used for the evaluation.

Film applications	Compositions (estimated)
Hand soap refill	LLDPE/Al/PA
Softener refill	LLDPE/VMPET/PA
Chocolate sweets	PET/VMCPP
Potato chips	PP/PE/VMPET/PE/PP
Frozen food	OPP/VMCPP

LLDPE: Linear low-density polyethylene
VMPET: Vacuum metalizing PET
VMCPP: Vacuum metalizing CPP
OPP: Biaxially oriented PP

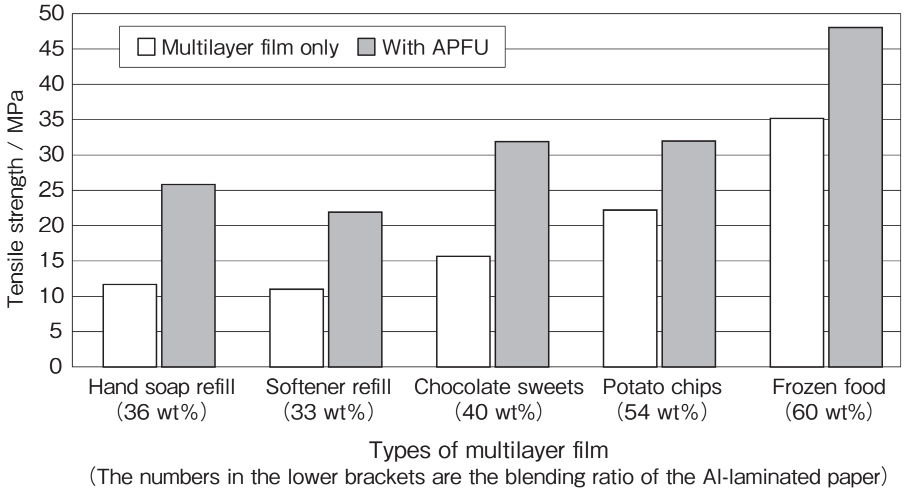

Figure 7 Tensile strength of multilayer plastic films with and without APFU.

3.3 The Moulding of Fibre-Reinforced Material With Paper

Fibre-reinforced materials with paper can be moulded by various moulding methods such as injection moulding. Examples of the moulded products are shown in Figure 8 to 13. The moulding method of each moulded product and the raw material used are described in parentheses in the explanation of the figure. Examples of injection moulding includes not only our cable related products such as Green Trough (Figure 8) and Bell mouth (Figure 9) which is an accessory for EFLEX cable conduit, but also ballpoint pens (Figure 10) and pen trays (Figure 11). Other product samples are wiring covers for office desks and chairs, which are used in our office. In addition, we have succeeded in making bottles by multilayer blow moulding (Figure 12) and 3D printed products (Figure 13), showing that various types of moulding methods can be applied.

Figure 8 Green Trough (Injection moulded; Poly-Al and beverage carton. Poly-Al is the residue from the recycling process of beverage cartons).

Figure 9 Bell mouth (Injection moulded; Multilayer film waste from Furukawa Electric and beverage cartons).

Figure 10 Ball point pen (Injection moulded; Multilayer film waste from Furukawa Electric and beverage cartons).

Figure 11 Pen tray (Injection moulded; Multilayer film waste from chocolate confectionery and paper box).

Figure 12 Multilayer bottle (Blow moulded; Outer layer is made from multilayer film waste from Furukawa Electric and beverage cartons. Inner layer is made of PE).

Figure 13 Vase (3D-Printed; Multilayer film waste from Furukawa Electric and beverage cartons).

APFU is a technology which can recycle multilayer films, that were previously difficult to recycle, into high-strength materials, and enables recycling those materials into parts and structural products that require high mechanical strength.

4. ESTIMATING AVOIDED EMISSIONS OF GREENHOUSE GAS BY LIFE-CYCLE ASSESSMENT (LCA) CALCULATION

So far, we have shown that multilayer films can be recycled into high-strength materials using APFU.

Next, an LCA calculation was performed to determine the effect of recycling multilayer films using this technology from the perspective of greenhouse gas (GHG) emissions.

Here, taking the ballpoint pen as a specific example, the case where a recycled material in which the multilayer film is reinforced with paper is used as the material for the ballpoint pen shaft (system No. 1), and the case where the multilayer film is incinerated and virgin PP is used as the material for the body of the ballpoint pen (system No. 2) were compared (Figure 14).

More specifically, it was assumed that PET/cast polypropylene (CPP) multilayer films and paper boxes are discharged as loss materials at a confectionery factory, and recycled materials are generated using APFU. The system No. 1 (Figure 14, top) is to manufacture a ballpoint pen using that material, and system No. 2 (Figure 14, bottom) was to incinerate the multilayer films, recycle the paper boxes as pulp, and then manufacture the shaft of the ballpoint pens with virgin PP. Then, the two systems were compared.

In this condition, the required material volume, the function of the ballpoint pen, and its lifetime were set the same for both materials. The GHG emissions for the ballpoint pen moulding and use were also set the same for both materials. In addition, since the recycling of the mul-

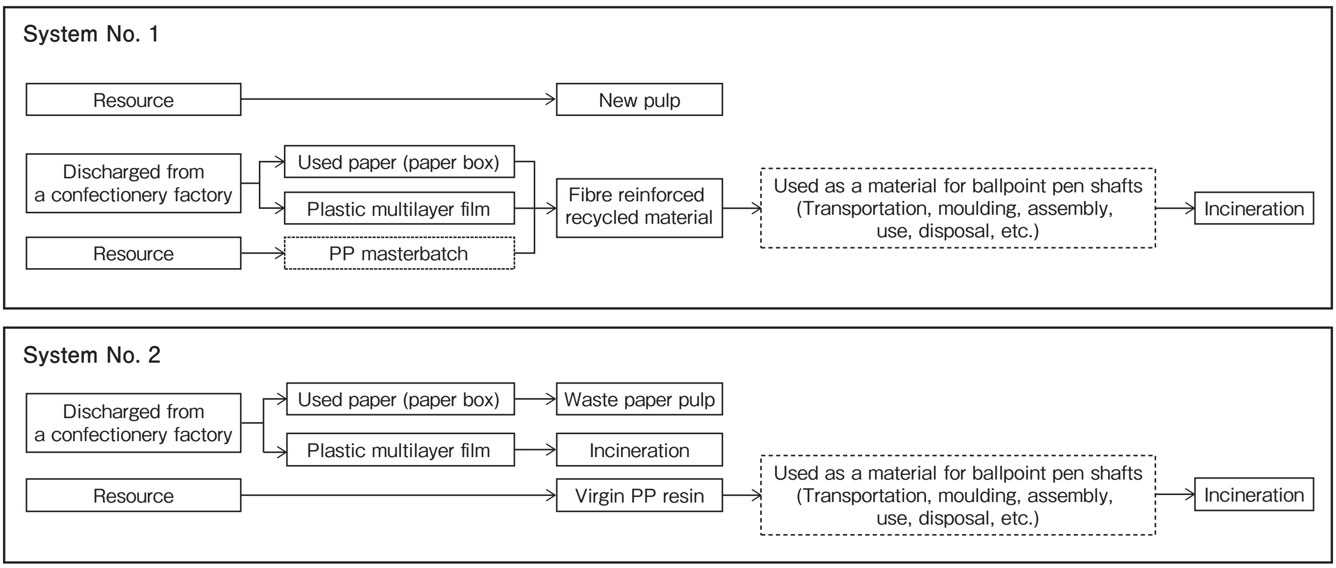

Figure 14 System boundaries of system No. 1 and No. 2.

tilayer film is not operated in mass scale, the estimated value from the prototype operation was used for the amount of GHG discharged in the recycling process. The used ballpoint pen at the end of its life, was set to be simply incinerated. As a result, by recycling and using the multilayer films, 2.5 CO_2-ekg was expected to contribute to GHG emission control per 200 ballpoint pens (equivalent to 1 kg of fibre-reinforced recycled material consisting of multilayer films and paper boxes) (Each basic unit used in the calculation is based on Inventory Database for Environmental Analysis (IDEA) ver.3.1).

Please contact us for details on this LCA calculation.

In this way, if multilayer films that have been incinerated are recycled into high-strength materials using APFU to replace virgin plastics, it is possible to contribute to a significant reduction in GHG emission.

5. APPROACHES TO RELATED ORGANIZATIONS

Furukawa Electric believes that by making multilayer films recyclable with the new technology ‘APFU’, it will be possible to contribute towards solving the plastic waste problem. However, as it is difficult to achieve this just by ourselves, a social innovation in collaboration with companies and organizations in the recycling value chain, such as manufacturers of plastic containers and packaging, manufacturers of products such as foods that use them, retailers who sell the products, us consumers, local governments that collect waste, recycling companies and plastic product manufacturers, is essential.

To achieve this, we believe that it is important to let as many people as possible to know about the potential value of this technology. In order to do so, we have introduced our technology at European exhibitions, joined the Clean Ocean Material Alliance (CLOMA), The Circular Economy for Flexible Packaging (CEFLEX), etc., and are now working with local governments and industry groups to create examples of recycling disposable plastics with APFU.

For example, in the activity conducted with Lion Corporation, low-strength toothpaste tube scraps were reinforced with paper waste generated by Lion Corporation and recycled into ballpoint pens (materials for the body). These ballpoint pens were used and exhibited at the EcoPro 2021 exhibition held in December 2021 by Lion Corporation. In addition, we have entered a Sustainable Development Goals (SDGs) partnership alliance with Kamikatsu Town, Tokushima Prefecture, and KISEKIREI Co., Ltd., which have pledged a “zero waste declaration”, and are working to recycle the materials of plastic waste generated in the town.

On top of that, we are proceeding a feasibility study of multilayer film recycling utilising APFU together with a European company who has a very high awareness of the plastic waste issue and the global climate change.

6. CONCLUSION

By implementing the fibre-reinforcement technology using paper (APFU), multilayer films can be recycled as a material, and it was further confirmed by the LCA calculation that GHG emissions can be reduced when substituting virgin plastic with APFU material.

Furukawa Electric believes that APFU is a technology that enables the recycling of multilayer films and can contribute to solving the plastic waste problem. Therefore, to actively provide APFU as a technology license, Furukawa Electric has registered with WIPO GREEN (a matching platform specializing in environmental technology operated by the United Nations’ World Intellectual Property Organization (WIPO)), and is looking for companies interested in partnering with us.

As mentioned in the previous section, cooperation with each stakeholder is indispensable for realizing a society in which multilayer films, which are usually incinerated or landfilled, are upcycled into usable materials.

Furukawa Electric will continue to solicit partner companies and work together to solve the plastic waste problem.

REFERENCES

1) Statista > Chemicals & Resources > Plastic & Rubber > Annual production of plastics worldwide from 1950 to 2020 (reference date December 20, 2021).
https://www.statista.com/statistics/282732/global-production-of-plastics-since-1950/
2) United Nations Environment Programme “SINGLE-USE PLASTICS: A Roadmap for Sustainability”(2018).
3) PLASTICS EUROPE “Plastics - the Facts 2021: An analysis of European plastics production, demand and waste data” (2021).
4) WORLD ECONOMIC FORUM “The New Plastics Economy: Rethinking the future of plastics” (2016).
5) ZERO WASTE EUROPE “Understanding the Environmental Impacts of Chemical Recycling: Ten concerns with existing life cycle assessments” (2020).
6) Camila Távora de Mello Soares, Monica Ek, Emma Östmark, Mikael Gällstedt, Sigbritt Karlsson: “Rrecycling of multimaterial multilayer plastic packaging; Current trends and future scenarios”, Resources, Conservation and Recycling, 176, (2022) 105905.
7) Hidekazu Hara, Masato Ikeuchi, Kentaro Yabunaka “Recycling Technology for Disposable Plastics Using Paper and a Fibre Reinforcement”, PLASTICS AGE 11 (2019) 80.