# Developments and Future Trends in Aluminum Products with Improved Surface Functions

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*Functional surface treated aluminum products are presented in this article. The key function of printing plates is a highly efficient electrochemical grainability. The superior surface quality of OPC drum is achieved by a newly developed electrolytic grinding. K.PRAS® is developed for manufacturing semiconductor device tools that provide superior resistance under corrosive gas and plasma through a unique anodizing process. Tailored surface functions of pre-coated fin-stock include hydrophilicity, corrosion resistance and lubricity. Pre-coated sheets for electrical devices are characterized by a number of key properties including electrical conductivity, lubricity and scratch resistance.*

## Introduction

Aluminum and its alloys have superior characteristics of lightness, specific strength, machinability and surface treatability including anodization. We manufacture a variety of aluminum products utilizing those characteristics.

Printing plates have been manufactured domestically from the 1970s. Due to higher performance, the graining method was changed from brush graining to electro-graining in the 1980s. In electro-graining, surface morphology is largely affected by metallurgical structure and minor constituents of aluminum. By continuous investigation we have developed "high current efficiency aluminum alloy", which has high current efficiency and uniform surface morphology in electro-graining, and is highly appreciated by our customers.

OPC (Organic Photo Conductor) drums began to be machined from extruded pipes in around 1980. We manufactured the highest quality drums with the development of a scratch-less alloy. In around 1990 low cost extruded pipes (ED pipes), which do not require machining, were developed. We, on the other hand, developed a manufacturing technology for electrolytically grinding pipes, which enabled the production of high-precision high-function OPC drums. The grinding technology is originally ours and has gained high evaluation from customers.

Due to higher integration of semiconductor devices, higher gas and plasma corrosion resistance is required for manufacturing parts. We started developing a surface modification technology used for the parts in 1993. In 1995 we developed a unique anodizing technology which controls cracks at high temperatures above 300℃ and has higher corrosion resistance when exposed to gas and plasma. In addition, we have developed technology which has higher physical plasma impact resistance. These technologies called "K.PRAS" are highly appreciated by customers since they significantly reduces contaminations and particles in manufacturing process of semiconductor devices.

We started the development of surface treated fin stocks in the 1980s and established basic technologies on hydrophilicity treatments with silica, used for exterior units of air-conditioners, in the early 1980s, and also developed resin based hydrophilicity treatment used for interior units in the late 1980s. We have commercialized a variety of "high function, surface treated, fin stocks" including corrosion resistant stocks used in brine damaging environment, and pollution resistant stocks having long lasting hydrophilicity.

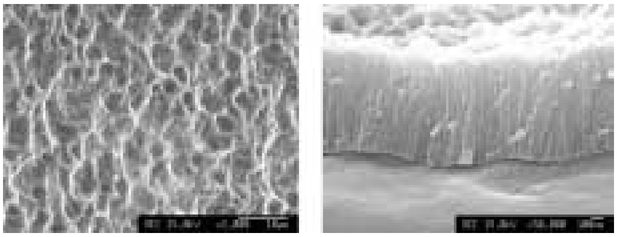
Rising environmental concerns in the 1990s required elimination of press oil degreasing using chlorine-based solvents. In response to this, we developed and commercialized pre-coated aluminum sheets having high lubricity. Also, we have been developing "functional pre-coated aluminum sheet" having such functions as electrical conductivity and heat release. The products are now used for casings, including a CD-ROM drive cover for notebook computers, and their applications are expanding.

The following describes the technical trend and development status of each product.

## 1. High current efficiency aluminum alloy

### 1.1 Technical trend and required qualities

Newspapers and magazines are printed by off-set printing machines with printing plates. Aluminum sheet is widely used as the substrate of printing



a) Grained surface b) Cross-section of anodized film

**Photo 1** SEM observation of electrochemical grained surface and cross-section of anodized film

plates having photosensitive layers. Printing plates are being converted from PS (Pre-sensitized) plates to CTP (Computer To Plate) plates on which document images are provided directly from computers.

The manufacturing process of printing plates (JIS A 1050-H18, approx. 0.3 mm thick is applied) includes steps of pre-treatment, graining, anodization, hydrophilization and photo-sensitive layer coating.[1)] For good printing performance (run length, water retention, scum resistance), aluminum alloy sheet has appropriate quality in flatness and electro-grainability. **Photo 1** shows electrochemical-grained surface and cross- section of anodized film. The aim of the development of aluminum alloy is to obtain suitable surface morphology for printing and to obtain high current efficiency in electro-graining process, and to obtain anodized layers with suitable hardness and structures.

### 1.2 Development of aluminum alloy for printing plates

#### 1.2.1 Flatness and dimensional accuracy of aluminum alloy sheet

The plates for automatized printing machines are required to have high qualities including strength for handling, flatness and dimensional accuracy for mounting, thermal stability during burning treatment for longer run length, and scratch-free surfaces to prevent printing smear.

To increase strength and thermal stability, aluminum alloy is subject to intermediate annealing with rapid heating and cooling cycle and cold rolling during the manufacturing process.[2)] The flatness and dimensional accuracy are improved by profile control during hot rolling, and thickness and flatness control during cold rolling. The flatness is further adjusted by tension leveling. Small foreign compounds have been reduced by the cleaning of manufacturing environment and automatization of the process. Other improvements include dynamic-recrystallization control during hot-rolling process[3)] and dedicated use of the final cold rollers and the tension leveling line.

#### 1.2.2 Material quality

Surface qualities of the aluminum substrates are also important to ensure printing quality. As shown in Photo 1, the surface of the substrate consists of macroscopic pits, made either by brush graining or electro-graining, and of an anodized layer which has microscopic pits.

The substrate surface, which consists of uniformly distributed pits, has a grained average surface roughness (Ra) of approx. 0.5 μm to ensure print-run length and water retention.[1)] The electro-grainability is optimized by controlling minor constituents of Cu and Ti[4)], and addition of Ni.[5)]

An anodized layer of approx. 1 μm thickness is formed on the surface for water retention, hardness and run length. Chemical compositions and homogenization treatment have been adjusted for optimum properties.[2)]

### 1.3 Future development

Mergers of companies are progressing also in the print industry. Currently the three groups, Agfa, Kodak Polychrome Graphics and Fuji Film, occupy 78% of the world market share. Shift toward CTP is accelerating and the market in China is expanding. We will continue development to improve plate qualities and electrolytic characteristics.

## 2. High-function OPC drums

### 2.1 Technical trend and market needs

The market for OPC is expected to grow annually by 10% and demands in China and Asia are expected to increase rapidly.

The OPC drums are required to have dimensional accuracies and surface characteristics for higher printing qualities and more rapid printing time by printers and copiers. Cost reduction is also pursued by making the drum materials thinner and longer.

### 2.2 Development of high precision process

Lathe turning assures high precision; however, it

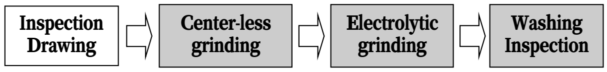



**Fig. 1** Production process for new grinding pipe of OPC drum

requires personal skills and tends to be costly for longer drums because the turning tools contact the work piece surface by points. Precision drawn pipes (ED pipe) are less expensive; however, they are hard to finish with high precision due to remaining dents and bends.

We have developed a processing technology for aluminum alloy OPC drums based on electrolytic grinding, which assures high dimensional precision, low cost and excellent surface characteristics with minimum grinding burrs.[6]

**Figure 1** shows the manufacturing process. The main process steps are center-less grinding[7] and electrolytic grinding. The center-less grinding removes the surface scratches and oxide film on the raw pipe, and improves dimensional accuracies including ripples. Subsequently, the electrolytic grinding improves the surface roughness and removes burrs. The properties of OPC drums made by this process are:

① High precision unobtainable by machining for longer pipes,
ripples < 20 μm, straightness < 25 μm
② Surface roughness close to mirror finish
$R_{max}$ = approx. 0.5 μm
③ Superior imaging characteristics due to reduced burr[8]
④ Superior surface cleanliness due to electrical degreasing effect

### 2.3 Features of the developed OPC drum

Surface morphology: **Photo 2** shows SEM micrographs of drums. The electrolytic grinding results in a smoother surface compared to the ED pipe, which shows a number of deep pits. The average roughness values (Ra) for both the surfaces are almost the same at 0.8 μm, while the maximum roughness value ($R_{max}$) of the ED pipe is 1.5 μm and is almost twice the roughness of electrolytically ground surface. This is caused by the deep pits shown in Photo 2.

Surface cleanliness: **Table 1** shows the results of quantitative analyses on drum surfaces by ESCA (Electron Spectroscopy for Chemical Analysis). The ED pipe indicates a larger amount of C caused by organic contaminants for both the inner and outer surfaces. The result confirms the cleanliness of the electrolytic grinding process.

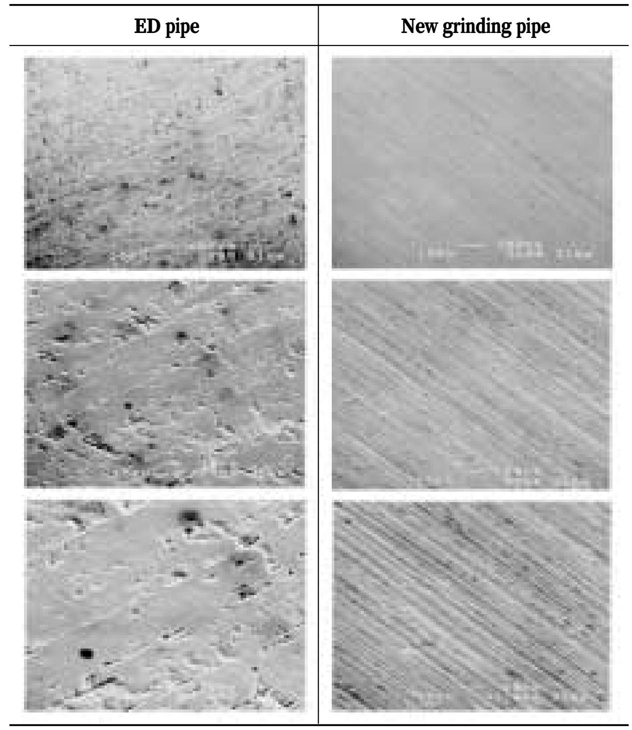



**Photo 2** Surface morphology of drums by SEM

**Table 1** Quantitative analysis of drum surface by ESCA

(at%)

| | Element | C | | | O | | | Al | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Etching time(s) | 0 | 30 | 60 | 0 | 30 | 60 | 0 | 30 | 60 |
| Pipe | New grinding | 28 | 7 | 7 | 44 | 52 | 53 | 26 | 39 | 39 |
| | ED | 46 | 14 | 11 | 35 | 49 | 50 | 18 | 35 | 38 |

### 2.4 Future development

The OPC drums produced by the newly developed electrolytic grinding process have superior surface characteristics with no residue of grease, which can eliminate the degreasing process steps in customers' manufacturing lines. We will further pursue higher accuracies, more functions and lower cost.

## 3. Plasma resistant, surface treated, aluminum products

### 3.1 Technical trends in manufacturing parts for semiconductor devices and liquid crystal displays (LCDs)

Aluminum alloys are widely used for manufacturing parts of semiconductor devices and LCDs because aluminum has unique characteristics such as light weight, good machinability and low out-gassing. Anodization is performed to aluminum products in order to obtain gas and plasma corrosion resistance; however, conventional anodizing technology can not provide sufficient corrosion resistance and causes contaminations and particles due to fluctuation of base materials, and fracture of anodic oxide films occurs in manufacturing process.

We have developed a special anodizing technology, K.PRAS, which drastically improves gas and plasma corrosion resistance by controlling microstructures of both base aluminum alloy and the anodic oxide film.[9), 10)]

### 3.2 Features of K.PRAS

① The K.PRAS has gas and plasma corrosion resistances at elevated temperatures as high as 450℃ because K.PRAS can reduce cracks in the film by controlling microstructures of the base aluminum alloy and the anodic oxide film (**Photo 3**). As a result, contaminations and particles in manufacturing processes are reduced significantly (**Figure 2**).

② The K.PRAS can be applied to several processes such as dry etching and plasma CVD by optimizing chemical solution and conditions during anodization. This feature has been realized through years of our accumulated experience in designing and developing the best suitable anodizing technology for customers by utilizing our unique analytical technique.

③ By taking advantage of our strength as a material manufacturer who can control all the process from raw material, machining, anodization to quality control, we can constantly provide high performance products to customers.

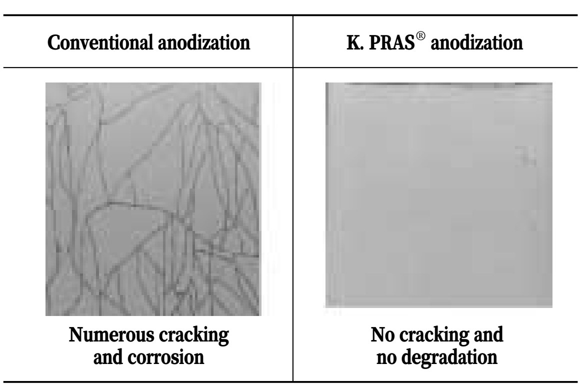



**Photo 3** Appearance of anodized coupons after exposure to $Cl_2$ gas

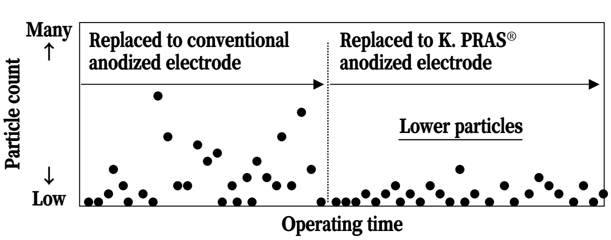



**Fig. 2** Schematic diagram of particle trend in plasma CVD processing

### 3.3 Applications to products

Upper and lower electrodes used in plasma process under halogen gas are exposed to a severe corrosion environment at high temperatures and close to the substrate during the process. Therefore high and stable corrosion resistances are required.

Since the K.PRAS is designed for outstanding performance under this environment, it is highly appreciated by customers.

The K.PRAS is also applied to reactor chambers, liners and ion doping antennas that require high corrosion resistance.

### 3.4 Future development

The semiconductor device industry will move toward nano-process, in which the required design rule becomes less than 100 nm, and toward higher integration. Therefore, more sophisticated and complicated processes will be developed. As for equipment parts, more advanced technology will be required to reduce contamination and particles and to realize stable performance. Since the K.PRAS meets all those needs, it will be applied widely in the future.

## 4. High functional coated fin stocks

### 4.1 Technical trend and market needs

Aluminum fins used for air-conditioners are required to have corrosion resistance and hydrophilicity for lower energy consumption and environmental protection. They also are required to have lubricity for forming. We have developed various surface coatings that add these functions to the surface.

### 4.2 Development of high functional surface treatment

**Table 2** shows the milestones of the pre-coated aluminum fin-stocks.

① Development of high functional coatings

The fins for air-conditioners require more hydrophilicity, as energy saving is required from heat exchangers with higher functions and down-sizing. Hydrophilicity sheds dew-condensation water and reduces ventilation resistance by

**Table 2** Progress of pre-coated aluminum fin-stock in Kobe Steel

| Type | 1980~ | 1985~ | 1990~ | 1995~ | 2000~ |
|---|---|---|---|---|---|
| Silicate layer<br>Aluminum<br>KS202 | ▶ Corrosion resistance<br>▶ Hydrophilicity | | | | |
| Hydrophilic silicate layer<br>Silicate layer<br>Aluminum<br>KS203 | | ▶ Improved hydrophilicity | | | |
| Lubricant resin layer<br>Hydrophilic silicate layer<br>Corrosion resistant layer<br>Aluminum<br>KS635 | | | ▶ Good formability with evaporative lubricants<br>▶ Decreased wear of forming tool | | ▶ Out-door use only |
| Hydrophilic resin layer<br>Corrosion resistant layer<br>Aluminum<br>KS173 | | | ▶ Resin type hydrophilic layer | | |
| Lubricant resin layer<br>Hydrophilic resin layer<br>(Optimized type)<br>Corrosion resistant layer<br>Aluminum<br>KS175, KS176 | | | | ▶ Anti-hydrophilicity decline by indoor pollutants (VOC) | |

preventing bridge formation between the fins. KS203 has improved hydrophilicity with addition of fine roughness feature to the silica coating of KS202. The roughness feature was created by addition of water soluble resin having low compatibility with silica which separates the phases at the time of baking.[11)]

The silica-based, hydrophilic coating wears the tool significantly at the time of pressing because of its hardness. In addition, elimination of solvent-cleaning process for environmental regulation made a requirement for the lubricant to be more volatile and less viscous, causing various forming defects.[12)] KS635 was developed in response to those issues. The material has a lubricant resin coating on top of the silica-based hydrophilic coating with the surface roughness feature.[13)] KS635 has been accepted widely by air-conditioner manufacturers with its lubricant coating eliminating forming failures, improving tool lives and preventing disarray of fin pitches (so-called 'avec') which occurred frequently at the time of the copper tube expansion process.[14)]

② Development of functional coating including pollution resistance (**Photo 4**)

The VOC (Volatile Organic Compound) in general atmospheres is absorbed to the fin surfaces, converts the surfaces from hydrophilic to hydrophobic, and causes dew condensation water to be blown out of air conditioners. This phenomenon of "water blow-out" became obvious in VOC-rich environments such as newly built houses.

The KS175 and KS176 were developed with pollution resistances which prevent deterioration of hydrophilicity at the time of VOC absorption.[15)]

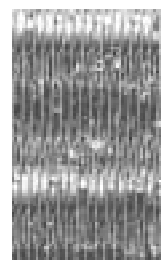
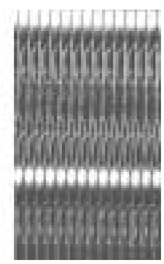
| | | |
|---|---|---|
| Appearance |  |  |
| Hydrophilicity (under the atmosphere with VOC) | Poor (Many " Bridges ") | Good (No " Bridge ") |
| Specimen | Conventional surface coat | Developed surface coat (KS176) |

**Photo 4** Appearance of aluminum fins at cooling mode under atmosphere with VOC

Those fins have rough resin-based coatings with hydrophilicity and lubricant resin layers on top. The resin-based hydrophilic layer was made rough to add sufficient hydrophilicity and has optimized chemical composition and baking conditions to prevent the absorption of VOC. The development has improved the pollution resistance[16)] and reduced the "water blow-out" significantly. The KS175 and KS176 are widely used in the interior heat exchangers of air-conditioners.

### 4.3 Future development

Our surface coated fin-stocks are based on highly advanced fundamental technologies resulting from continuous development and response to a variety of needs from air-conditioner manufacturers. We will continue development further to advance the functions of air-conditioners and to respond to the needs for environmental burden reduction.

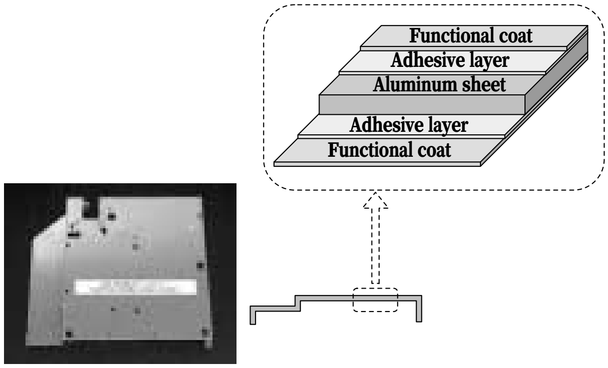



**Fig. 3** Formed application example (CD-ROM cover) and composition of functional pre-coated aluminum

## 5. Functional pre-coated aluminum

### 5.1 Technical trends and features

Electronics devices have been developed by expanding their applications into areas including personal computers, DVD recorders and flat panel displays. We have developed functional pre-coated aluminum sheets "KS700 series" for those applications.[17] Examples of applications and compositional structures are shown in **Figure 3**. A significant characteristic of the pre-coated aluminum is that the optimum functions are added to the coating layer depending on applications.

### 5.2 Design technology of functional coating

Lubricity is an important characteristic of pre-coated aluminum sheets since most of them are press-formed. The fundamental base of the technology is an appropriate mixing of lubricants into the base matrix resin.

Lubricants have the functions of either improving lubricity or adding scratch resistance, and combined use of those functions is preferable.[17] PTFE (polytetrafluoroethylene) particles are added for those functions and especially for scratch resistance and also for appearance. The addition ratio for PTFE has been optimized for maximum scratch resistance.[18]

In addition to lubricant, various additives are mixed for functions required by the applications.

### 5.3 Milestones of functional coating development

**Table 3** summarizes the developmental milestones of KS700 series.

KS701 has a high lubricity which enables press-forming without oil or with quick drying oil, and eliminates oil decreasing process after pressing. Other products developed from KS701 are KS702, which has higher scratch resistances, and K730, which is designed for food sanitation purposes. They are used for floppy disk shutters and refrigerator trays.

The slim-type CD-ROM and liquid crystal displays for notebook computers require lightness. In those applications, electrical grounding is required to make the electrical potentials of devices equal and to prevent malfunction by static charge. KS720 has electrical conductivity and lubricity in the coating, which allows grounding on to the coating. The product is now used for the CD-ROM casings. In order to respond to various other grounding requirements, KS724 and KS724K were developed and are used in a variety of electronics devices.

New functions are required of aluminum coating with the advancement of electronics equipment. The latest developments are KS750 (KOBEHONETSU aluminum) which has a superior heat release characteristic and KS760 which enables easy removal of adhesives and smudges.

### 5.4 Future development

Functions of surface can be further developed by accumulated knowledge on the coating selection and coating design. We will continue to develop products with added designed surface functions that satisfy a variety of market needs.

**Table 3** Progress of functional pre-coated aluminum in Kobe Steel

| Type | 1996～ | 1998～ | 2000～ | 2002～ | 2004～ |
|---|---|---|---|---|---|
| Lubricating | Standard (KS701)<br>Hard coat (KS702) | For food sanitation use (KS730) | | | |
| Electrical conductive | | Conductive (KS720) | Excellent conductive (KS724) | Excellent conductive & Anti-scratched (KS724K) | |
| Various functions | | | | Heat release (KS750) | Anti-stick adhesive tape (KS760) |

| Surface functions | Lubricating | Electrical conductive | Various functions |
|---|---|---|---|
| Target | Formability improvement<br>Promotion of process omission (cost cut) | Grounding for electrical use<br>Good appearance (Anti-scratch) | For high performance electrical use<br>For high performance automobile use |

## Conclusions

Aluminum products with improved surface functions are widely used in our daily appliances even though they are scarcely recognized. We will continue to develop products with higher functions, expand the applications and respond to the market needs.

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