

Cover Glass for Mobile Phone Display

1. Background of cover glass use

A variety of cover materials are used on panels for mobile phones. Such covers are used for the main display, sub display and camera display. Conventionally scratch resistant acrylic or polycarbonate with hard coating on one or both sides is used for the cover materials. Although more expensive than acrylic, polycarbonate has greater mechanical strength and the pieces are less likely to be sharp when broken. Cover glass that had been used in watches was first adopted as the glass material for displays. The first adopted glass material was somewhat chemically strong with molten alkaline salt (potassium nitrate), for which the basic plate size was 160 x 500 mm. (The 160mm width of the basic plate was relatively narrow and needed to go through the process flow from rough grind to final polish.) To chemically strengthen the glass, sodium on the glass surface was often exchanged with potassium ions to enhance the density, for which ionic radius was larger. In this way, by processing raw materials or using processing solvent, a chemically strengthened cover glass was developed.

2.Characteristics of cover glass

Motorola started to use glass covers in their mobile phones around 2004 and 2005, which had an impact in the industry. The main purpose of this adoption was to reduce the thickness of the enclosure. Meanwhile the demand for sub-display started to increase.

Since 2007, cover glass has been increasingly adopted by terminal manufacturers such as Apple using the glass covers for iphone, Toshiba, Sharp and Hitachi (CHMC: Casio Hitachi Mobile Communications). In general glass is fragile. The problem manufacturers initially faced was how to make glass less fragile for such special use.

(1) How to create surface strength

Theoretically the strength of glass is valued numerically at close to 10^3kg/mm^2 . However, the strength of glass practically used is 3 to 5kg/mm^2 , which is quite low due to slight scratches or cracks generated on the surface. To increase the strength of glass, a method that creates a layer of compressive stress on the surface of glass was invented. Two approaches are physical strengthening and chemical strengthening.

(2) Physical strengthening: quenching method

In this process, after heating the glass close to the softening point, it is uniformly quenched. Through quenching, a temperature difference between the internal and external surfaces is generated. The difference generates thermal stress. Taking advantage of the thermal stress, a layer of compressive stress can be left on the solidified surface. Air jet can be used for cooling the surface. Generally this physical approach requires 3mm or more of glass plate thickness.

(3) Chemical strengthening

The basic principle of chemical strengthening is to increase glass strength by chemically changing the composition or characteristics of the glass surface. One method is chemical etching which can eliminate fine cracks, the so called Griffith cracks, on the glass surface. The other method is ion exchange.

(4) Chemical etching

There have been several methods such as dealcalizing to increase strength by heating after glass contact with potassium pyrosulfate or using hydrofluoric acid solution to increase the adhesive strength of sealing glass for cathode ray tubes. The application of these methods was limited.

(5) Ion exchange

Immersing glass into molten salt causes counter diffusion exchange of alkali ions in glass and in molten salt. Compressive stress is generated in the exchange layer, which strengthens the glass. There are two types of ion-exchange methods as described below.

(5-1) Ion exchange at high temperature

Glass that contains Na_2O or K_2O is immersed in Li salt within the range from transmission temperature to softening temperature to cause ion exchange of Na^+ or K^+ in glass with Li^+ . Next the glass is cooled to room temperature. The difference of expansion coefficient between the glass surface layer that contains Li^+ and the internal glass that contains Na^+ or K^+ generates compressive stress on the surface, which strengthens the glass.

If the glass contains Al_2O_3 or TiO_2 , β -spodumene ($\text{Li}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2$), crystals that have very low expansion coefficient are created during the ion exchange.

This can generate very strong compressive stress on the glass surface after it cools down. The strength could be close to $70\text{kg}/\text{mm}^2$. Applicable glass types are SiO_2 57 - 66, Al_2O_3 13.5 - 22, Na_2O 8 - 11, and Li_2O 10 - 13. Immersing the glass in Li, Na or Ag salt at 600 to 750°C to cause ion exchange with Na^+ , Ag^+ or Li^+ creates two layers of ion exchange. This generates two crystallized glass layers: β -eucryptite for outside and Li- metasilicate for inside. This process significantly increases the strength of the glass. However, the problem with this method is glass deformation that can happen during the strengthening process.

(5-2) Ion exchange at low temperature

Glass is immersed in molten alkali salt, in which the ion radius is larger than the alkali ion contained in the glass in the transition temperature. The Li^+ ions in the glass, for example, are exchanged with Na^+ or Na^+ with K^+ . After cooling down, compressive stress is generated on the glass surface due to the difference of volume occupied by alkali ions and the strength is accordingly increased. Compared with the method of ion exchange at high temperature, the exchange rate is low but there is minimal glass deformation. Therefore, this method is rather practically applied.

(6) Comparison of physical (air cooling) and chemical strengthening (ion exchange)

Table 1 shows the comparison of strengthening methods: air cooling and ion exchange.

Table 1. Comparison of methods

	Physical strengthening	Chemical strengthening
Compressive stress value	Low (10 to 15kg/mm ²)	High (30 to 80kg/mm ²)
Depth of compressive stress layer	Thick (approx. 1/6 of plate thickness)	Thin (10 to 300µm in general)
Modulus	High (approx. 1/2 of the compressive stress)	Low
Treatment time frame	Short (5 to 10 min.)	Long (30 min. to one week)
Form and thickness of glass	Limited	No limitation except for ultra thin material

Table 1 shows the comparison of strengthening methods: air cooling and ion exchange. The ion exchange method takes considerable time to create a compressive stress layer sufficient for practical use. Therefore, the cost is higher than air cooling. However, the ion exchange method should be applied to meet the following requirements: 1) high strength is required, 2) thin glass, sheet glass or complicated shape, and 3) strict dimensional precision is required.

(7) Trend of ion exchange method

The ion exchange methods discussed in section 2 are the basic ones. Another strengthening method has been invented: Ceramic glass that developed crystals with heat treatment is immersed in melt to create a surface layer with various crystals by exchanging the alkali ions in the ceramic glass with the alkali ions in the melt. In addition, various types of glass materials, which are suitable for the ion exchange method, have been invented.

(8) Glass materials suitable for ion exchange

Glass materials that have shown practical results or have potential to be suitable glass material are as follows: time-proven glass material used for watches as cover glass, soda or lithium glass that have been used for, or will be used for display, glass used for window glass for airplanes and for hard disks. When considering the cost and performance balance after the chemical strengthening, soda glass could be generally applicable. The users themselves can decide the optimum use. Comparison data by glass material type is shown in Table 2 below.

(8-1) Comparison of characteristics (by glass type, each with the same dimension and measured after chemical processing)

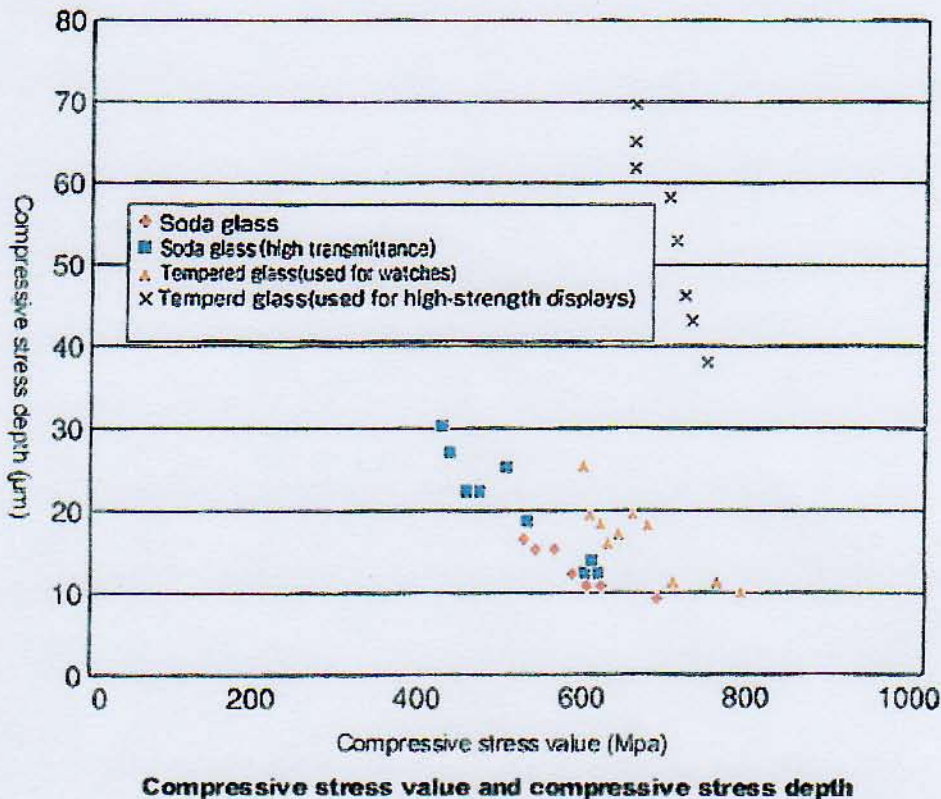
Table 2. Comparison of glass types

	Glass 1 for strengthening	Glass 2 for strengthening	Soda glass	High transmittance soda glass
Vickers hardness (Hv)	640	700	570	570
Surface compressive stress value (MPa)	785	750	549	588
Surface compressive stress depth (μm)	20	60	15	15

(8-2) Compressive stress value and compressive stress depth

Figure 1 shows the tendency of glass materials under different conditions for chemical strengthening

Fig. 1. Compressive stress value and compressive stress depth



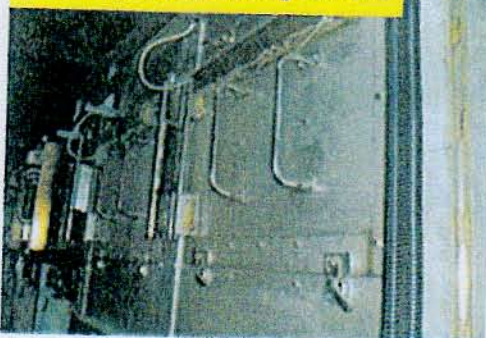
The finding is that there are types of glass with a significantly thicker layer of surface compressive stress such as Glass 2 for strengthening. The finding was obtained under optimum conditions of chemical strengthening for physical property comparison.

(8-3) Facility for chemical strengthening and product evaluation

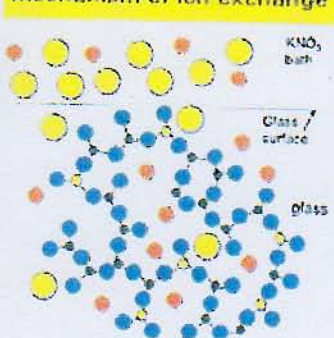
Matsunami Glass Ind., Ltd. facility for chemical strengthening and testing methods adopted for product evaluation.

Dipping glass into a salt bath using a chemical-strengthening furnace causes counter diffusion exchange of sodium ions and potassium ions to generate compressive stress. This is the method Matsunami Glass Ind., Ltd. uses.

Chemical-strengthening furnace



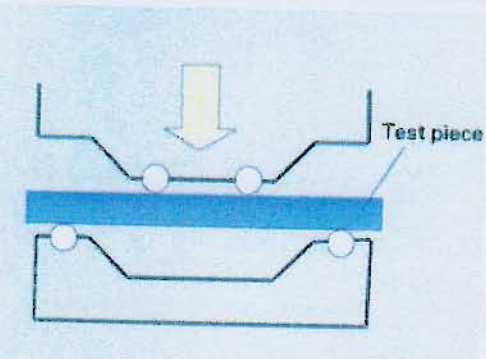
Mechanism of ion exchange



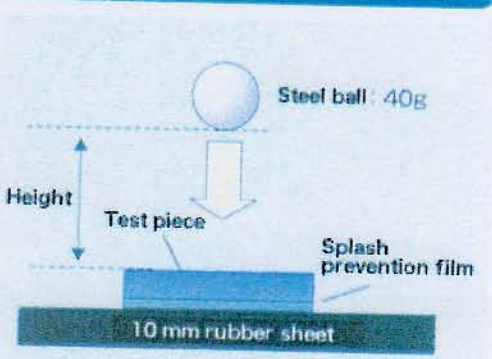
- O₂
- Si
- Al
- Na:0.97 Å
- K:1.33 Å

Typical evaluation method

Four-point bending test



Falling ball impact test



3. Production process for cover glass

The process flow for cover glass is as follows:

Flat glass → cut/boring/notch/polish/slight chamfer → chemical strengthening → coating → printing → attaching shatterproof film → users

(1) Selection of raw materials

Suitable material for chemical strengthening should be selected, considering cost efficiency. Soda glass is the first selection. When it comes to thinning the glass, glass plates manufactured for strengthening could be an option. In this case, the viewpoint of selection is the characteristics; glass with high compressive strength and less stress depth or glass with thicker stress depth assuming there could be fine scratches.

If processing is the focus as a factor for selection, materials that cost less in polishing are advantageous. Therefore, materials produced by the float or fusion process is suitable due to the process flow and for the variety of plate thickness. Still the float process is suitable for mass production but not for small-lot or custom-made production.

(2) Cut / boring / notch / slight chamfer / polish

Outline machining that includes slight chamfer is indispensable for this type of cover glass. Chemical strengthening is performed after polishing. Out of five global glass producing companies, two inaugurated their businesses with processing cover glass for watches. These global companies have production capacity in which more than 50 billion pieces (on the assumption of three-inch glass plates) are produced each month. However, if the process flow is based on the processes of cover glass for watches, the boring process is performed separately in many cases (supersonic processing). The boring process should preferably be performed by CNC for outline machining as well as slight chamfer.

(2-1) Cut / boring / notch

Still only a limited number of manufacturers currently use the integrated process flow with water jet machining. In the future the majority of manufacturers will possibly adopt this process flow. Originally, water jet machining was adopted for glass processing in only a few cases. In general this method is for cutting raw materials such as metals, stones, plastic, composite, glass, ceramics and rubber. This machining is applicable to glass plates of t0.2 to 200mm. The thickness of cover glass plates for mobile phones is generally t0.5 to 1.0mm. In addition, there should be an opening for the loud-speaker in many products at the upper side. Therefore, an integrated process flow that includes outline machining and boring is desirable.

(2-2) Slight chamfer

A wet system with swing mechanism is used to polish the end face of slight chamfer of the mobile phone cover glass plate. The polishing wheel polishes up to the set point and the wheel section automatically moves. The process points, such as the end face of chamfering, squeezing pattern of polishing wheel and pressure intensity, can be set in advance. The mechanism allows end face polishing and finishing even if cutting precision is insufficient. The CNC processing system for cutting and slight chamfer with water jet machining mentioned above is applicable to R-processing of display panel or larger sized crystal that is used as part of a single lens reflex camera.

(2-3) Coating

AR coating by deposition is widely adopted for resin covers to control the reflectance of cover material surface. Glass covers are widely applied to LCD for digital cameras. Currently the major coating type is AR coating. AR coating has been examined to see if decorative print of the frame around the cover glass is possible. That is, the coating is examined for high grade appearance on the deposition side.

(2-4) Printing / attaching shatterproof film

In general decorative print is provided on the surface of the mobile phone cover. For upgrading cover glass strength, materials have been studied and processing has been improved, showing some positive results. However, in most cases, shatterproof film is attached to provide the strength. Besides the method of printing on the glass itself, attaching decorative film that is shatterproof has been also introduced. The aim is a processing technique that makes the difference between the display and the enclosure inconspicuous.

Fig. 4. Cover glass for mobile phone use ... finish machining

Fig. 4. Cover glass for mobile phone use ... finish machining

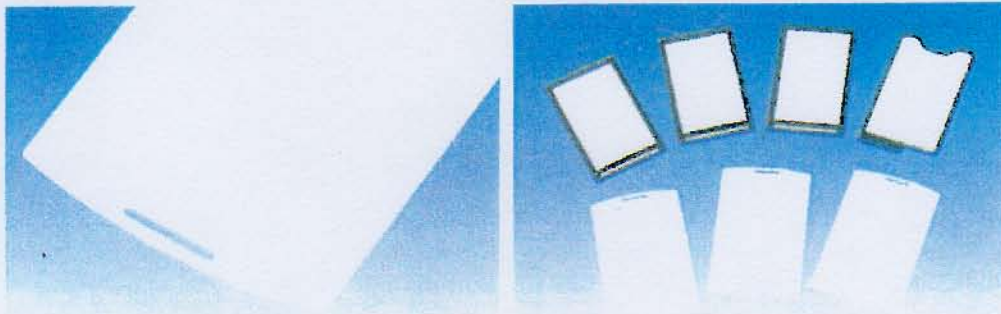


Figure 4 shows a sample specification for a water jet machining system. However, customized specifications should be applied in accordance with individual requirements.

CNC Table Condition

Cutting Area	X(mm) 3,100 Y(mm) 1,600 Z(mm) 200(Automatic)+100(Hand operated)
Transfer Speed (mm/min)	15,000
TransferMethod	[X,Y] Ball Screw Nut Drive [Z] Ball Screw Drive
DivingMethod	AC SERVO MOTOR
CNC Control Unit	SENTROL 2-1
Minimum Driving Unit	0.001

4. Future trends for cover glass materials

The challenges are thinning the mobile phone, upgrading the display quality and developing low cost process flow for expanding demand. Thus far processing is mainly performed abroad. However, due to the declining yield rate for products with specifications that are difficult to meet, costs are higher. There should be a limitation in the integrated outline machining by specially designed cam as before. For the cutting process, water jet machining by CNC that allows power savings could be more popular and the same applies to the slight chamfer. For the surface decoration technique, besides popular gravure and silk printing, there is a demand for coloring by deposition. More technological improvement for the cover glass and for peripheral materials can be expected.

[References]

1. S. Tsuchiya, Physical Chemistry of Glass Surface, Kodansha Ltd.
2. S. Tsuchiya, Chemistry of Glass, Kodansha Ltd.
3. Ishizuka Glass Co., Ltd, CRYSTERNA
4. CORNING [Corning® Gorilla™ Glass]
5. Nissha Printing Co., Ltd., Lamina Glass

Cover Glass for Mobile Phone Display

1. Background of cover glass use

A variety of cover materials are used on panels for mobile phones. Such covers are used for the main display, sub display and camera display. Conventionally scratch resistant acrylic or polycarbonate with hard coating on one or both sides is used for the cover materials. Although more expensive than acrylic, polycarbonate has greater mechanical strength and the pieces are less likely to be sharp when broken. Cover glass that had been used in watches was first adopted as the glass material for displays. The first adopted glass material was somewhat chemically strong with molten alkaline salt (potassium nitrate), for which the basic plate size was 160 x 500 mm. (The 160mm width of the basic plate was relatively narrow and needed to go through the process flow from rough grind to final polish.) To chemically strengthen the glass, sodium on the glass surface was often exchanged with potassium ions to enhance the density, for which ionic radius was larger. In this way, by processing raw materials or using processing solvent, a chemically strengthened cover glass was developed.

2.Characteristics of cover glass

Motorola started to use glass covers in their mobile phones around 2004 and 2005, which had an impact in the industry. The main purpose of this adoption was to reduce the thickness of the enclosure. Meanwhile the demand for sub-display started to increase.

Since 2007, cover glass has been increasingly adopted by terminal manufacturers such as Apple using the glass covers for iPhone, Toshiba, Sharp and Hitachi (CHMC: Casio Hitachi Mobile Communications). In general glass is fragile. The problem manufacturers initially faced was how to make glass less fragile for such special use.

(1) How to create surface strength

Theoretically the strength of glass is valued numerically at close to 10^3kg/mm^2 . However, the strength of glass practically used is 3 to 5 kg/mm^2 , which is quite low due to slight scratches or cracks generated on the surface. To increase the strength of glass, a method that creates a layer of compressive stress on the surface of glass was invented. Two approaches are physical strengthening and chemical strengthening.

(2) Physical strengthening: quenching method

In this process, after heating the glass close to the softening point, it is uniformly quenched. Through quenching, a temperature difference between the internal and external surfaces is generated. The difference generates thermal stress. Taking advantage of the thermal stress, a layer of compressive stress can be left on the solidified surface. Air jet can be used for cooling the surface. Generally this physical approach requires 3mm or more of glass plate thickness.

(3) Chemical strengthening

The basic principle of chemical strengthening is to increase glass strength by chemically changing the composition or characteristics of the glass surface. One method is chemical etching which can eliminate fine cracks, the so called Griffith cracks, on the glass surface. The other method is ion exchange.

(4) Chemical etching

There have been several methods such as dealcalizing to increase strength by heating after glass contact with potassium pyrosulfate or using hydrofluoric acid solution to increase the adhesive strength of sealing glass for cathode ray tubes. The application of these methods was limited.

(5) Ion exchange

Immersing glass into molten salt causes counter diffusion exchange of alkali ions in glass and in molten salt. Compressive stress is generated in the exchange layer, which strengthens the glass. There are two types of ion-exchange methods as described below.

(5-1) Ion exchange at high temperature

Glass that contains Na_2O or K_2O is immersed in Li salt within the range from transmission temperature to softening temperature to cause ion exchange of Na^+ or K^+ in glass with Li^+ . Next the glass is cooled to room temperature. The difference of expansion coefficient between the glass surface layer that contains Li^+ and the internal glass that contains Na^+ or K^+ generates compressive stress on the surface, which strengthens the glass.

If the glass contains Al_2O_3 or TiO_2 , β -spodumene ($\text{Li}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2$), crystals that have very low expansion coefficient are created during the ion exchange.

This can generate very strong compressive stress on the glass surface after it cools down. The strength could be close to 70kg/mm^2 . Applicable glass types are SiO_2 57 - 66, Al_2O_3 13.5 - 22, Na_2O 8 - 11, and Li_2O 10 - 13. Immersing the glass in Li, Na or Ag salt at 600 to 750°C to cause ion exchange with Na^+ , Ag^+ or Li^+ creates two layers of ion exchange. This generates two crystallized glass layers: β -eucryptite for outside and Li- metasilicate

for inside. This process significantly increases the strength of the glass. However, the problem with this method is glass deformation that can happen during the strengthening process.

(5-2) Ion exchange at low temperature

Glass is immersed in molten alkali salt, in which the ion radius is larger than the alkali ion contained in the glass in the transition temperature. The Li^+ ions in the glass, for example, are exchanged with Na^+ or Na^+ with K^+ . After cooling down, compressive stress is generated on the glass surface due to the difference of volume occupied by alkali ions and the strength is accordingly increased. Compared with the method of ion exchange at high temperature, the exchange rate is low but there is minimal glass deformation. Therefore, this method is rather practically applied.

(6) Comparison of physical (air cooling) and chemical strengthening (ion exchange)

Table 1 shows the comparison of strengthening methods: air cooling and ion exchange.

Table 1. Comparison of methods

	Physical strengthening	Chemical strengthening
Compressive stress value	Low (10 to 15kg/mm^2)	High (30 to 80kg/mm^2)
Depth of compressive stress layer	Thick (approx. 1/6 of plate thickness)	Thin (10 to $300\mu\text{m}$ in general)
Modulus	High (approx. 1/2 of the compressive stress)	Low
Treatment time frame	Short (5 to 10 min.)	Long (30 min. to one week)
Form and thickness of glass	Limited	No limitation except for ultra thin material

Table 1 shows the comparison of strengthening methods: air cooling and ion exchange. The ion exchange method takes considerable time to create a compressive stress layer sufficient for practical use. Therefore, the cost is higher than air cooling. However, the ion exchange method should be applied to meet the following requirements: 1) high strength is required, 2) thin glass, sheet glass or complicated shape, and 3) strict dimensional precision is required.

(7) Trend of ion exchange method

The ion exchange methods discussed in section 2 are the basic ones. Another strengthening method has been invented: Ceramic glass that developed crystals with heat treatment is immersed in melt to create a surface layer with various crystals by exchanging the alkali ions in the ceramic glass with the alkali ions in the melt. In addition, various types of glass materials, which are suitable for the ion exchange method, have been invented.

(8) Glass materials suitable for ion exchange

Glass materials that have shown practical results or have potential to be suitable glass material are as follows: time-proven glass material used for watches as cover glass, soda or lithium glass that have been used for, or will be used for display, glass used for window glass for airplanes and for hard disks. When considering the cost and performance balance after the chemical strengthening, soda glass could be generally applicable. The users themselves can decide the optimum use. Comparison data by glass material type is shown in Table 2 below.

(8-1) Comparison of characteristics (by glass type, each with the same dimension and measured after chemical processing)

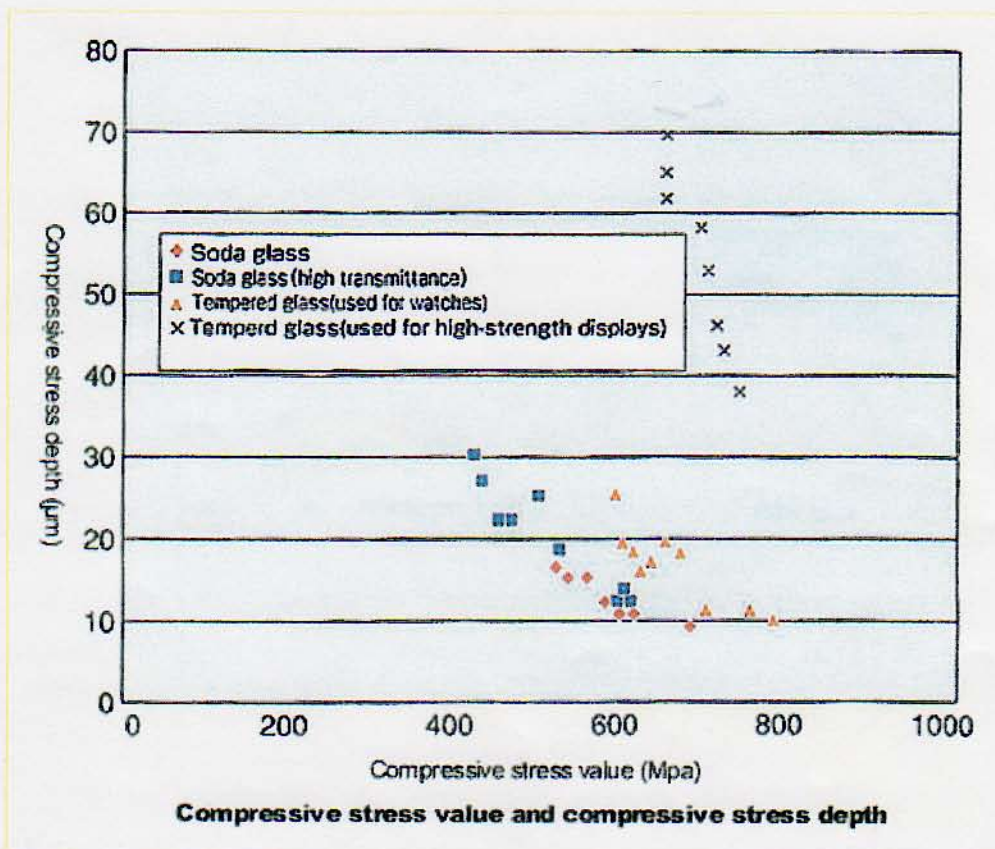
Table 2. Comparison of glass types

	Glass 1 for strengthening	Glass 2 for strengthening	Soda glass	High transmittance soda glass
Vickers hardness (Hv)	640	700	570	570
Surface compressive stress value (MPa)	785	750	549	588
Surface compressive stress depth (μm)	20	60	15	15

(8-2) Compressive stress value and compressive stress depth

Figure 1 shows the tendency of glass materials under different conditions for chemical strengthening

Fig. 1. Compressive stress value and compressive stress depth



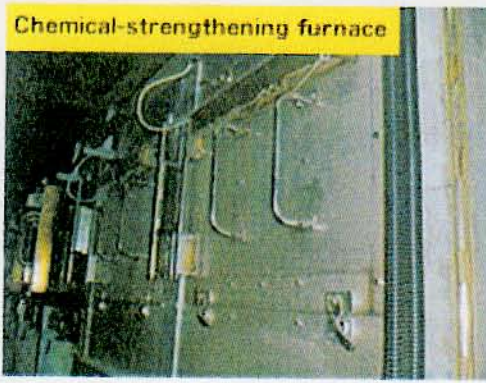
The finding is that there are types of glass with a significantly thicker layer of surface compressive stress such as Glass 2 for strengthening. The finding was obtained under optimum conditions of chemical strengthening for physical property comparison.

(8-3) Facility for chemical strengthening and product evaluation

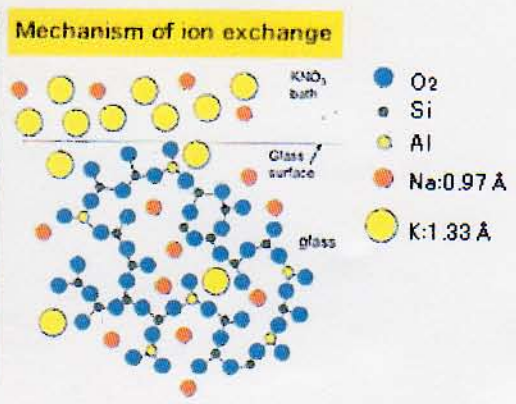
Matsunami Glass Ind., Ltd. facility for chemical strengthening and testing methods adopted for product evaluation.

Dipping glass into a salt bath using a chemical-strengthening furnace causes counter diffusion exchange of sodium ions and potassium ions to generate compressive stress. This is the method Matsunami Glass Ind., Ltd. uses.

Chemical-strengthening furnace



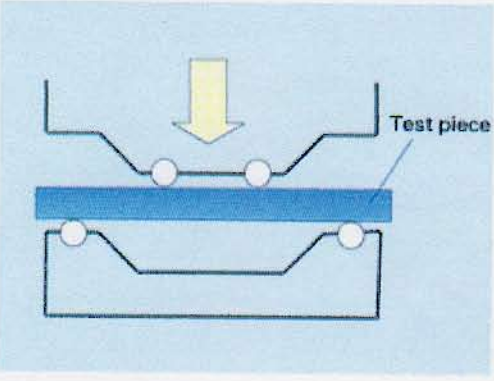
Mechanism of ion exchange



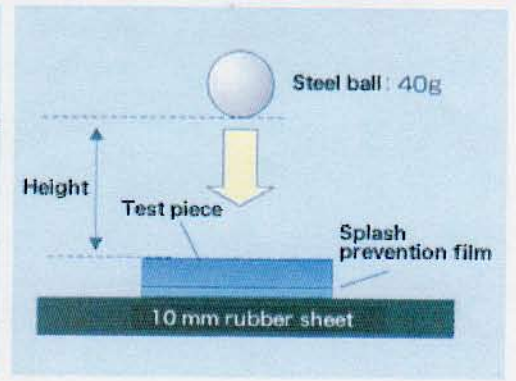
- O₂
- Si
- Al
- Na:0.97 Å
- K:1.33 Å

Typical evaluation method

Four-point bending test



Falling ball impact test



3. Production process for cover glass

The process flow for cover glass is as follows:

Flat glass → cut/boring/notch/polish/slight chamfer → chemical strengthening → coating → printing → attaching shatterproof film → users

(1) Selection of raw materials

Suitable material for chemical strengthening should be selected, considering cost efficiency. Soda glass is the first selection. When it comes to thinning the glass, glass plates manufactured for strengthening could be an option. In this case, the viewpoint of selection is the characteristics; glass with high compressive strength and less stress depth or glass with thicker stress depth assuming there could be fine scratches.

If processing is the focus as a factor for selection, materials that cost less in polishing are advantageous. Therefore, materials produced by the float or fusion process is suitable due to the process flow and for the variety of plate thickness. Still the float process is suitable for mass production but not for small-lot or custom-made production.

(2) Cut / boring / notch / slight chamfer / polish

Outline machining that includes slight chamfer is indispensable for this type of cover glass. Chemical strengthening is performed after polishing. Out of five global glass producing companies, two inaugurated their businesses with processing cover glass for watches. These global companies have production capacity in which more than 50 billion pieces (on the assumption of three-inch glass plates) are produced each month. However, if the process flow is based on the processes of cover glass for watches, the boring process is performed separately in many cases (supersonic processing). The boring process should preferably be performed by CNC for outline machining as well as slight chamfer.

(2-1) Cut / boring / notch

Still only a limited number of manufacturers currently use the integrated process flow with water jet machining. In the future the majority of manufacturers will possibly adopt this process flow. Originally, water jet machining was adopted for glass processing in only a few cases. In general this method is for cutting raw materials such as metals, stones, plastic, composite, glass, ceramics and rubber. This machining is applicable to glass plates of t0.2 to 200mm. The thickness of cover glass plates for mobile phones is generally t0.5 to 1.0mm. In addition, there should be an opening for the loud-speaker in many products at the upper side. Therefore, an integrated process flow that includes outline machining and boring is desirable.

(2-2) Slight chamfer

A wet system with swing mechanism is used to polish the end face of slight chamfer of the mobile phone cover glass plate. The polishing wheel polishes up to the set point and the wheel section automatically moves. The process points, such as the end face of chamfering, squeezing pattern of polishing wheel and pressure intensity, can be set in advance. The mechanism allows end face polishing and finishing even if cutting precision is insufficient. The CNC processing system for cutting and slight chamfer with water jet machining mentioned above is applicable to R-processing of display panel or larger sized crystal that is used as part of a single lens reflex camera.

(2-3) Coating

AR coating by deposition is widely adopted for resin covers to control the reflectance of cover material surface. Glass covers are widely applied to LCD for digital cameras. Currently the major coating type is AR coating. AR coating has been examined to see if decorative print of the frame around the cover glass is possible. That is, the coating is examined for high grade appearance on the deposition side.

(2-4) Printing / attaching shatterproof film

In general decorative print is provided on the surface of the mobile phone cover. For upgrading cover glass strength, materials have been studied and processing has been improved, showing some positive results. However, in most cases, shatterproof film is attached to provide the strength. Besides the method of printing on the glass itself, attaching decorative film that is shatterproof has been also introduced. The aim is a processing technique that makes the difference between the display and the enclosure inconspicuous.

Fig. 4. Cover glass for mobile phone use ... finish machining

Fig. 4. Cover glass for mobile phone use ... finish machining

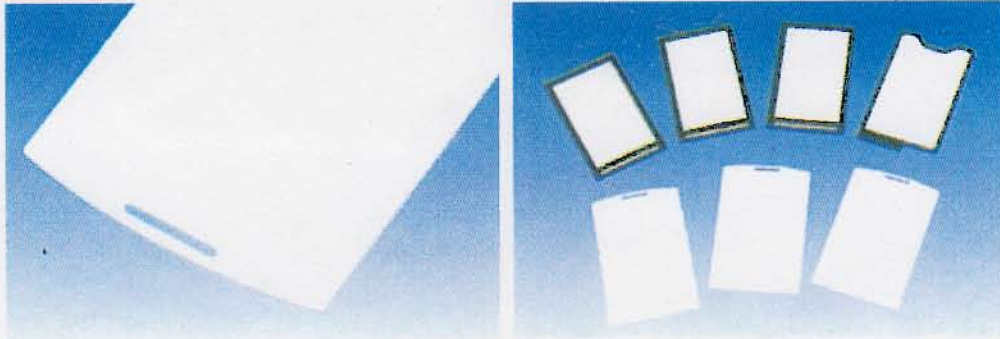


Figure 4 shows a sample specification for a water jet machining system. However, customized specifications should be applied in accordance with individual requirements.

CNC Table Condition

Cutting Area	X(mm) 3,100 Y(mm) 1,600 Z(mm) 200(Automatic)+100(Hand operated)
Transfer Speed (mm/min)	15,000
TransferMethod	[X,Y] Ball Screw Nut Drive [Z] Ball Screw Drive
DivingMethod	AC SERVO MOTOR
CNC Control Unit	SENTROL 2-1
Minimum Driving Unit	0.001

4. Future trends for cover glass materials

The challenges are thinning the mobile phone, upgrading the display quality and developing low cost process flow for expanding demand. Thus far processing is mainly performed abroad. However, due to the declining yield rate for products with specifications that are difficult to meet, costs are higher. There should be a limitation in the integrated outline machining by specially designed cam as before. For the cutting process, water jet machining by CNC that allows power savings could be more popular and the same applies to the slight chamfer. For the surface decoration technique, besides popular gravure and silk printing, there is a demand for coloring by deposition. More technological improvement for the cover glass and for peripheral materials can be expected.

[References]

1. S. Tsuchiya, Physical Chemistry of Glass Surface, Kodansha Ltd.
2. S. Tsuchiya, Chemistry of Glass, Kodansha Ltd.
3. Ishizuka Glass Co., Ltd, CRYSTERNA
4. CORNING [Corning® Gorilla™ Glass]
5. Nissha Printing Co., Ltd., Lamina Glass