Preface

First, we announce that Mitsubishi Shindoh Co., Ltd. merged with Mitsubishi Materials Corporation in April 2020. As a material maker, we believe that it is possible to use a lead-free copper alloy in many automobile applications for the following reasons:

Regarding "ECO BRASS", which is a lead-free copper alloy, over 40,000 tons was manufactured and sold in 2017 according to its track record of production and sales in Japan, Europe, and the United States. It is estimated that nearly 4% of leaded brass can be replaced with ECO BRASS. In 2019, the accumulated sales volume of ECO BRASS exceeded 300,000 tons. In terms of the amount of lead contained in CuZn39Pb3, which is a representative leaded brass, it is about 9,000 tons, which in turn means that a 9,000-ton reduction in the use of lead was made by using ECO BRASS. Approximately 20 years has passed since the large-scale production and distribution of ECO BRASS began, and now, ECO BRASS is used in various fields centered on drinking water-related field and auto parts field. ECO BRASS' reliability as a material has been sufficiently ascertained, and in the meantime, machining technology is being established. Further, in the future, environmental load is expected to be reduced by seeking a way to reduce component weight by utilizing ECO BRASS' characteristics such as high strength, excellent wear resistance, and corrosion resistance.

As we have previously presented ECO BRASS' characteristics, this report focuses on the alloy's further growth in its production and sales, examples of machining performed with the cooperation of several machining companies, and selection of cutting tools suitable for machining ECO BRASS. We disclose machining conditions in the sections where machining examples are presented. Also, we introduce you to characteristics of GloBrass, our newly developed, lead-free, free-cutting brass, and some examples of machining the alloy.

Summary

- ECO BRASS' Track Record of Use

- ECO BRASS' production and sales in 2017 in Japan, Europe, and the United States exceeded 40,000 tons. In 2019, the accumulated volume reached 300,000 tons.
- We report that, in most cases, ECO BRASS is used as a substitute of leaded brass (mostly CuZn39Pb3; hereinafter referred to as "C36000") and is scarcely substituting stainless steel.
- In Europe, production and sales of ECO BRASS exceeded 15,000 tons both in 2017 and 2018, and the accumulated sales volume through to the end of 2018 was approximately 90,000 tons. By use of ECO BRASS, the reduction in lead consumption is about 400 tons annually, and 2,500 tons cumulatively (assuming that C36000 was replaced by ECO BRASS) based on a calculation.
- In Europe, approximately 750 million pcs of ECO BRASS components are installed in products annually assuming that the weight of material used for one component is 20g, and altogether over 4.5 billion components have been installed in products and used in various environments.

- We report that there is no problem with ECO BRASS in terms of material supply, machining, performance, durability, and recycling, and replacement of C36000, a copper alloy containing about 3% Pb, with ECO BRASS has been proceeding smoothly.

– Practicability of replacement by ECO BRASS including adaptation of machining process

- We have confirmed with multiple customers that ECO BRASS has equivalent machinability and productivity to that of C36000.
- We have confirmed that products made of ECO BRASS exhibit equivalent surface quality and dimensional precision to those made of C36000 even though it depends on machining conditions.
- In component machining using a 6-spindle automatic lathe, which is a mass machining facility, performed with the cooperation of two machining companies, we confirmed that there was no problem to machine approximately 10,000 pcs of components continuously at both companies.
- In a test production of approximately 1000 pcs of components using commercial NC lathes performed with the cooperation of two machining companies, no quality issue was found in any of the machining methods used including turning, drilling, threading, knurling, and grooving. The tools incurred only minor damage, and there was no problem in disposal of chips.
- In test machining of eight kinds of small components weighing from 0.4 to 10 g performed with the cooperation of a machining company, it was ascertained that there was no quality issue in any of the machining methods used including turning, drilling small holes (ϕ 0.7 mm), inside/outside threading, and knurling.
- It was confirmed that ECO BRASS has no problem being machined on a commercial basis through production of 15 kinds of components by various machining methods made with the cooperation of five machining companies although we admit that not all the existing machining methods were used in the production.
- We have confirmed that, by using a cutting tool suitable for ECO BRASS, increase in the cutting resistance of ECO BRASS is capped at only 10 to 20% higher than that of C36000 and brittle chips are generated similar to C36000.

– Reliability

- ECO BRASS has earned high reliability from the market and customers since over half of the components made of ECO BRASS that have been sold to date have been in use for five years or longer.
- ECO BRASS has been used for various applications including drinking water-related components and automobile components, and such track record of use as a material for component production has demonstrated its excellent durability and corrosion resistance under various environments such as in water of varied qualities, in soil, under high temperature, extremely low temperature, or high humidity.

- In some important auto parts, ECO BRASS has demonstrated its superiority in performance and durability over C36000, which has contributed to high reliability. As a result, such parts made of ECO BRASS are now newly mounted on over one million automobiles every month, and to date over 100 million automobiles in Europe, the United States, and Japan have been mounted with them based on a calculation.

– For the future

- As ECO BRASS' reliability as a material has already been ascertained, it is now possible to aim at reducing weight of components by utilizing the alloy's characteristics such as high strength, excellent wear resistance, and corrosion resistance. A reduction in the weight of components allows improvement in fuel efficiency of automobiles and a decrease of the load imposed on the environment since the amount of raw material used will be reduced. In order to realize that, it is necessary to actively attempt to devise a way to reduce component weight beginning from the stage of designing components.
- Our company was able to develop a new, lead-free, free-cutting brass. We believe that by using this new alloy together with ECO BRASS, replacement of brass containing a large amount of Pb will be accelerated in many applications.

I Global Sales of ECO BRASS and its Track Record of Use

Fig. 1 shows records of ECO BRASS sales in Japan, Europe, and the U.S.

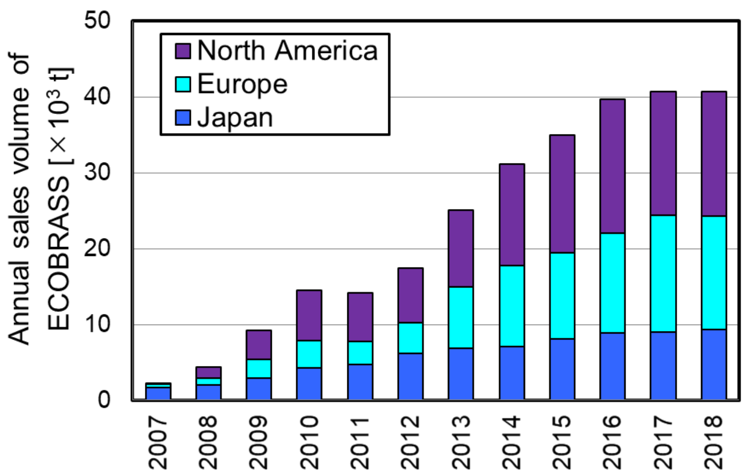


Fig. 1: Track Record of ECO BRASS' Global Sales

- With a strong demand to remove lead, which is a harmful substance, sales volume of ECO BRASS is increasing year by year. In 2017 and 2018, its production and sales volume in Japan, Europe, and the U.S. exceeded 40,000 tons. It is presumed that about 4% of leaded brass has been substituted by ECO BRASS already.

- We report that ECO BRASS has no serious supply-related or economical issue.
- We report that ECO BRASS is mostly substituting leaded brass, and there are only a few cases where stainless steel is substituted by ECO BRASS.
- By employing ECO BRASS, Pb use in materials is calculated to have been reduced by about 1,200 tons annually (assuming that C36000 is replaced with ECO BRASS).
- In April 2019, the accumulated global sales of ECO BRASS reached 300,000 tons. Based on a calculation, use of ECO BRASS has contributed to a reduction in use of lead by 9,000 tons.
- The production and sales of ECO BRASS in Europe rapidly increased particularly in 2013, and its production and sales volume reached 15,000 tons in 2017.
- We report that separation and re-melting of chips generated during production and used products are easy.
- We report that there is no problem recycling ECO BRASS as scraps are separated, managed, collected, and reused without confusion.
- ECO BRASS is used in various industrial fields and applications including auto parts, but mainly for drinking water-related components due to strengthened regulations on lead in drinking water-related parts and fittings. Through such uses, ECO BRASS has demonstrated its durability and corrosion resistance in various environments such as in water of varied qualities, in soils, under high temperature and high humidity, or extremely cold. Recently, ECO BRASS is used to make components of electric vehicles as well.
- Assuming that the amount of material required to make one component is 20 g, approximately 15 billion components made of ECO BRASS have been installed and put to use based on a calculation. Out of these components, about eight billion have been used for five or more years. ECO BRASS has earned high reliability as a material due to such records of use in products.
- It is presumed that the primary reasons for the sales growth of ECO BRASS are that the alloy excels as a material, performance of ECO BRASS-made components is excellent, its reliability is proven, and machining is not difficult, in addition to the world trend towards employment of lead-free materials.

Ⅱ Examples of ECO BRASS Applications – Auto Parts

We are introducing four types of auto parts below as representative applications of ECO BRASS.

1) Important Small Component A for Car Air-Conditioner – Check Valve

Fig. 2 shows an important small component for a car air-conditioner placed near the engine room of an automobile.

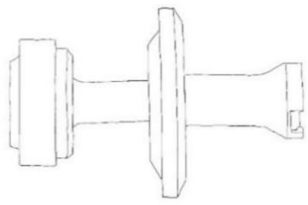


Fig. 2: Small Car Air-Conditioner Component A – Check Valve

- Small Component A consists of two parts which are made of ECO BRASS rod of ø10 mm (currently downsized to ø8 mm) and ø5 mm respectively. These parts weigh 0.42g and 0.66g respectively and are classified as small parts.

Fig. 3-1 shows records of sales volume of ECO BRASS for the component.

- The sales volume has been approximately 60 tons annually since 2014, and the accumulated sales volume through to the end of September 2020 reached 440 tons.

Fig. 3-2 shows records of estimated number of each part manufactured. For your information, this estimation is based on a calculation in which the weight of the material sold is divided by the weight of material required to make one piece of part figured out by a rough calculation from the component dimensions (calculated estimation of manufactured number).

- The number of components manufactured is increasing year by year. In 2019, approximately 34 million were installed in about 17 million automobiles. Based on these figures, it is presumed that over 100 million automobiles had this component installed by the end of the year.

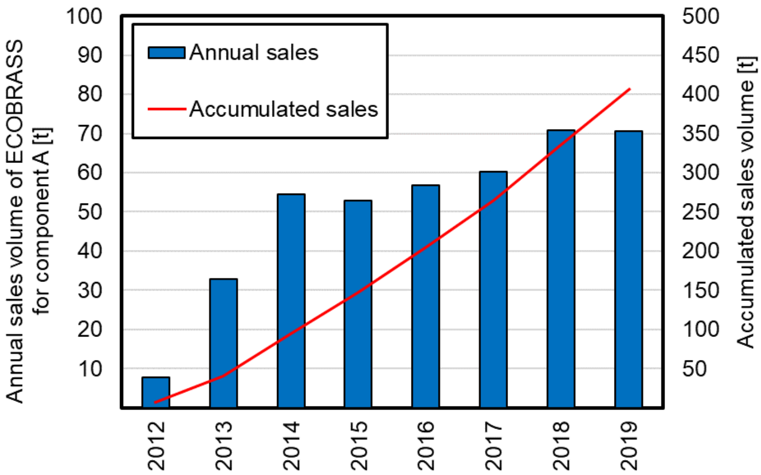


Fig. 3-1: Sales Volume of ECO BRASS for Small Car Air-Conditioner Component A

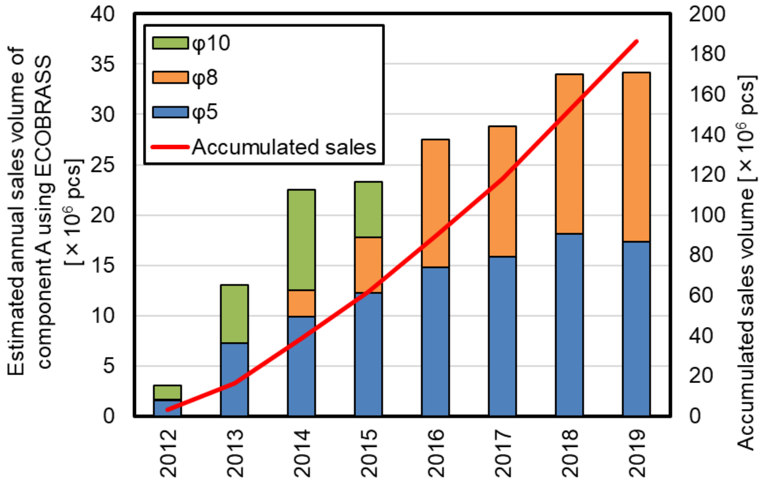


Fig. 3-2: Estimated Number of Small Car Air-Conditioner Component A Manufactured

2） Important Car Air-Conditioner Component B – Control Valve for Variable Capacity Compressor

Fig. 4 shows three types of another important car air-conditioner component B (weighing 36.8 g, 34.3g, and 23.7g respectively from left to right). These components require particularly high dimensional precision of 2 μm.

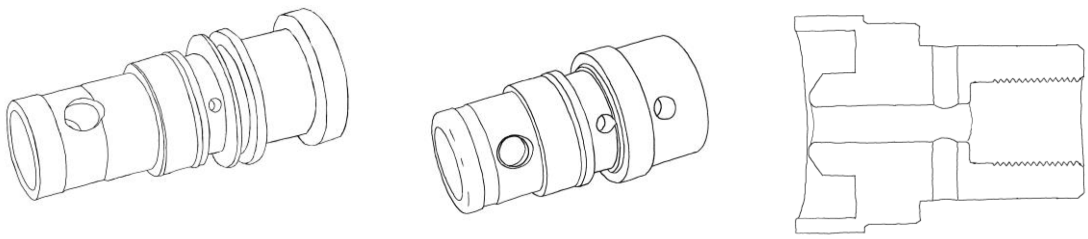


Fig. 4: Car Air-Conditioner Component B – Control Valve for Variable-Capacity Compressor

Fig. 5-1 shows records of sales volume of ECO BRASS. **Fig. 5-2** shows records of estimated number of components manufactured. For your information, this estimation is based on a calculation in which the weight of the material sold is divided by the weight of material required to make one piece of part figured out by a rough calculation from the component dimensions.

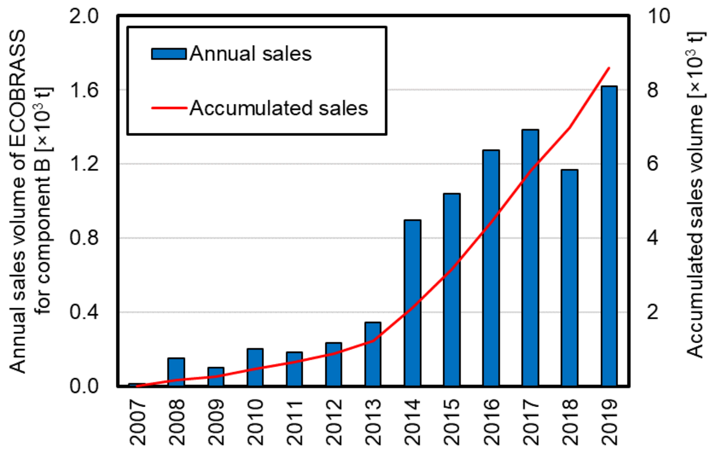


Fig. 5-1: Sales Volume of ECO BRASS for Important Car Air-Conditioner Component B

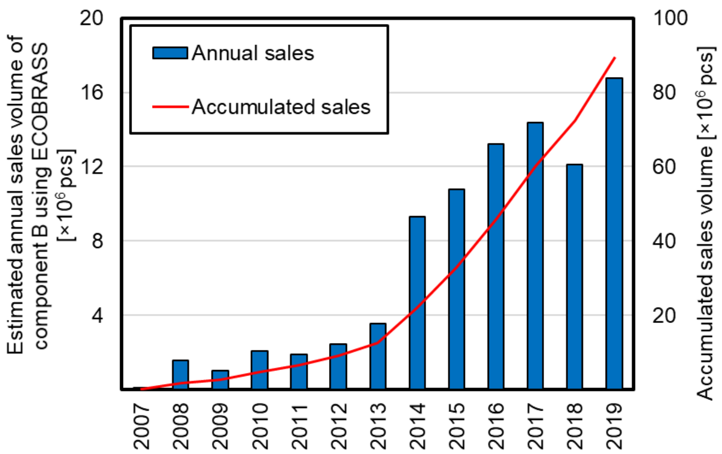


Fig. 5-2: Estimated Number of Important Car Air-Conditioner Component B Manufactured

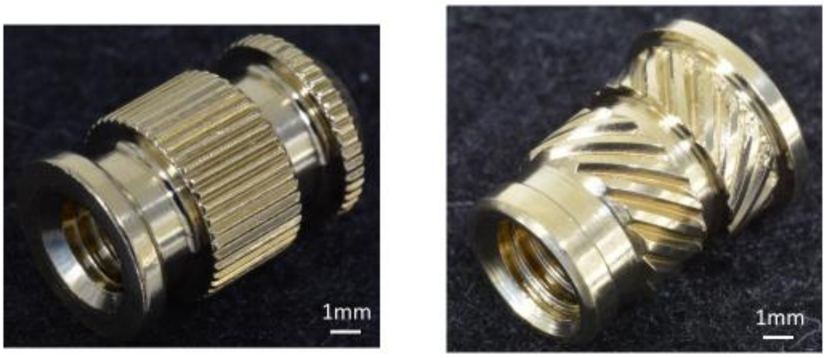
- Sales volume of ECO BRASS used for Important Car Air-Conditioner Component B began to increase rapidly from 2014, and its annual sales volume reached about 1,600 tons in 2019. Further, the accumulated volume of ECO BRASS sold to manufacture this component from January 2007 has reached about 8,600 tons.
- The estimated number of this component manufactured per year exceeds 10 million and the accumulated number of the component manufactured has exceeded 89 million. Approximately 89 million cars have been installed with this component.
- According to certain information obtained from machining companies on mass machining of this component, which requires high dimensional precision, for 2014, "in mass machining of ECO BRASS, productivity was at least 90% that of C36000 and tool life was at least 80% that of C36000".
- The volume of ECO BRASS sold to manufacture this component for the period between 2007 and 2012 is about 877 tons. The number of this component installed in automobiles for eight

or more years is approximately nine million based on a simple calculation demonstrating that there was no problem in their durability or reliability.

- This component is regarded as an important automobile component. In 2008, a full-scale mass production of 1.5 million pcs/year began. It is presumed that its sales volume jumped in 2014, six years after that, due to the reliability that the component established during the six years.
- It is presumed that the sales volume jumped in 2014, and from 2015 ongoing, Component Bs have been installed in over 10 million automobiles since ECO BRASS has better features, performance and durability than C36000., ECO BRASS' reliability has been ascertained and at the same time, its machinability is more or less the same as that of C36000.

3) Small Car Components C & D – Insert Nuts

Fig. 6 shows examples of mass-produced insert nuts C & D for automobiles.



Insert nut C (2.0g) Insert nut D (1.1g)

Fig. 6: Examples of Mass-Produced Insert Nuts for Automobiles

- Insert Nut C began to be manufactured in large quantities in 2016 using ϕ7 to 10-mm rods. By September 2020, a total of 50 tons of materials were used for mass production. Based on a calculation from component weight and yield, about five million pcs of Insert Nut C have been manufactured and used.
- At another maker, Insert Nut D has been manufactured since 2015 using ϕ7 to 9-mm rods, and 95 tons of such materials were used for the production of this component by August 2020. Based on a calculation from component weight and yield, over 20 million pcs of Insert Nut D have been manufactured and used.
- Surface quality of these components is good. In particular, no fibrous foreign matter or crack is observed on the product surface which is processed by rolling a knurl piece. The components' machined surface is in good condition showing that knurling conditions for mass production have been established.

III Machining Examples of ECO BRASS

Examples of machining about 1,000 pcs of parts are presented below. The test machining was performed with the cooperation of some machining companies using their machining facilities normally used for manufacturing commercial products. Details of the test machining are: 1) machining small diameter rods to produce parts assumed to be used as auto parts or electrical/electronic parts, 2) machining with an automatic 6-spindle lathe (a mass production facility), and 3) machining with a multi-purpose NC lathe.

1) Machining Example of Small Diameter Rod (Example 1)

At Machining Company A (capitalized at 3,000,000 yen; number of employees: 10), 100 to 200 pcs for each of the parts were test-produced.

Fig. 7 shows examples of machining small diameter rods of 3 to 12 mm in diameter. An NC lathe was used for the test production of eight kinds of small parts weighing from 0.4 to 10 g assumed to be used as auto parts or electrical/electronic parts.

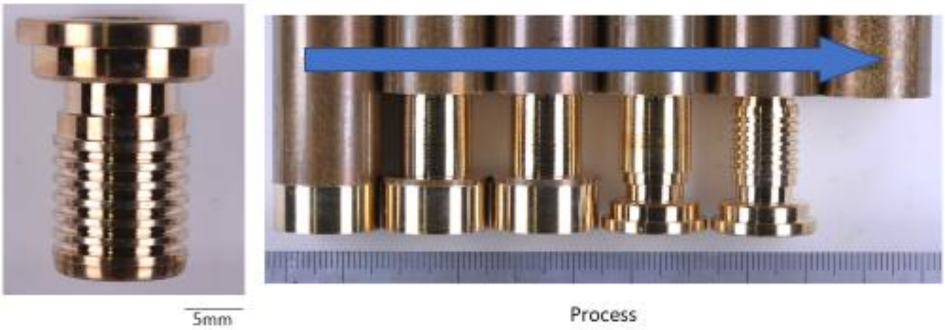
Fig. 7: Machining Example 1 – Machining Small-Diameter Rods for Production of Parts Assumed to Be Used As Auto Parts or Electrical/Electronic Parts [rod diameter / component weight]

- Turning, small hole drilling (drilling ϕ0.7-mm holes), side drilling, threading (inside and outside) , and knurling were well done, and product quality was equivalent to when C36000 was used. We applied the same machining conditions as those applied to C36000. Unfortunately, we are unable to disclose them though.
- Machining rods of small diameter went well, too, demonstrating that small parts can be manufactured with ECO BRASS rods.

2) Machining examples using 6-spindle lathe (Examples 2 & 3)

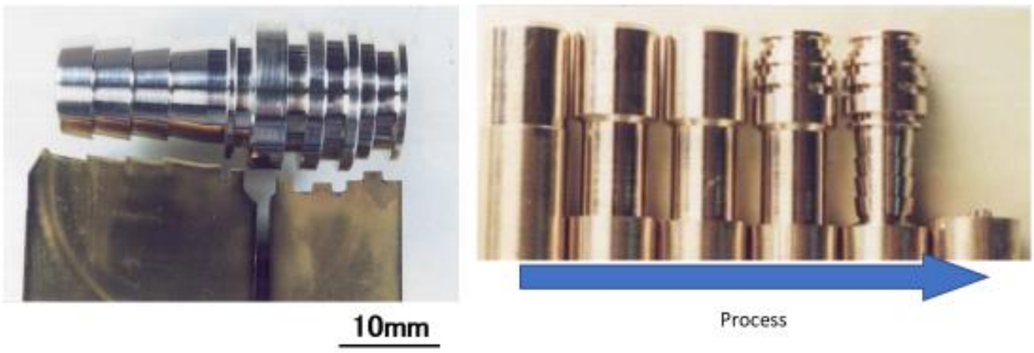
Automatic 6-spindle lathe is the most productive machine since it is possible to work on six different locations at the same time. However, the shapes of workpieces it can handle are limited, and dimensional precision is moderate. Using such mass production facilities, machinability of ECO BRASS in mass production was evaluated at Machining Companies B (number of employees: 240) and C (capitalized at 20 million yen; number of employees: 100).

Figs. 8 & 9 show examples of machining using automatic 6-spindle lathe. For the test machining, two kinds of parts actually mass-produced with C36000 by a process including drilling were selected. Then, 23,000 pcs and 12,000 pcs respectively of the selected parts were produced continuously by machining on the same conditions as when C36000 was used.



- Cycle : 10sec
- Condition : Wet
- Material : ϕ19 × 3000
- Pieces : 23,380

Fig. 8: Machining Example 2 – Machining with Automatic 6-Spindle Lathe



- Cycle : 10sec
- Condition : Wet
- Material : ϕ18 × 3000
- Pieces : 12,000
- Machining Condition :
  ϕ8.0 Drilling(2000rpm, 0.15mm/rev.), Forming tool(2000rpm, 0.03mm/rev.)

Fig. 9: Machining Example 3 – Machining with Automatic 6-Spindle Lathe

- It takes only a short period of time, about 10 seconds, to finish machining one component with a 6-spindle automatic lathe. As productivity is prioritized, the load imposed on cutting tools is heavy.
- Somewhere around 10,000 pcs of each part were able to be machined continuously.
- There were no irregularities such as chips getting bulky or tangling the tools. There were no problems like components' dimensions getting out of allowable tolerance or poor surface conditions.

As a result of machining products of different shapes at two machining companies using automatic 6-spindle automatic lathes, it is considered that ECO BRASS can be used for mass production without modifying the machining conditions applied to C36000 since no problem was found in machining productivity or quality during the test machining of ECO BRASS with the 6-spindle automatic lathes.

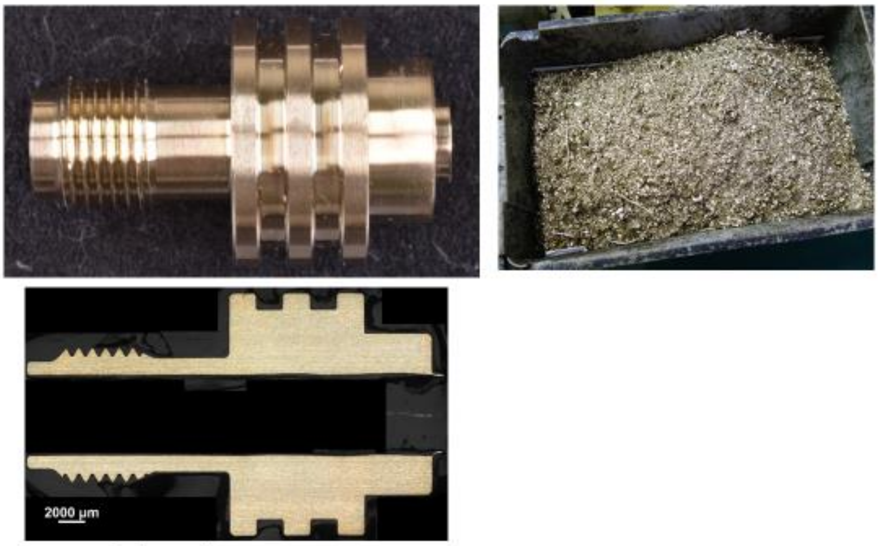
3) Examples of continuous machining using NC lathe (Examples 4 & 5)

Two examples of machining 1,000 pcs of components at Machining Companies D (capitalized at 12 million yen; number of employees: 25) and E (capitalized at 20 million yen; number of employees: 57) using NC lathes are presented below.

3) -1. Machining Example 4 – Valve Part

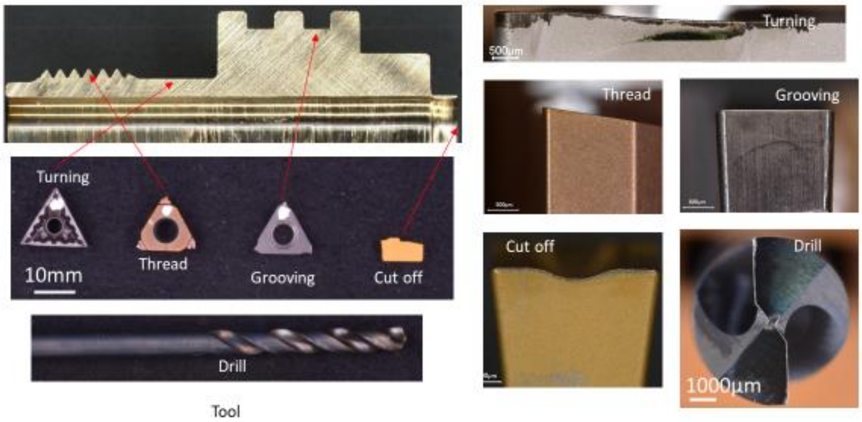
Continuous machining of 1,000 pcs of valve parts was performed at Machining Company D for four days in a row (during daytime operation hours only though) using ø20-mm ECO BRASS rods and an NC lathe which was normally used for mass production of commercial products.

Fig. 10-1 shows the appearances of a part after machining and generated chips. **Fig. 10-2** shows appearances of the cutting tools after machining 1,000 pcs.



- Process：
  End face→Centre hole→ϕ6.0 Drilling(1200rpm,0.12mm/rev.,4step)
  →Turning(100m/min,0.07mm/rev.)→Thread(1200rpm,1.0mm/rev.)
  →Turning(100m/min,0.07mm/rev.)→Grooving(120m/min,0.2mm/rev.)→Turning→Cut off
- Cycle：142sec
- Condition：Wet
- Machine： Star Micronics JNC25

Fig. 10-1: Machining Example of Valve Part 4-1



Tool

Flank wear after 1,000 pieces machining

Fig. 10-2: Machining Example of Valve Part 4-2

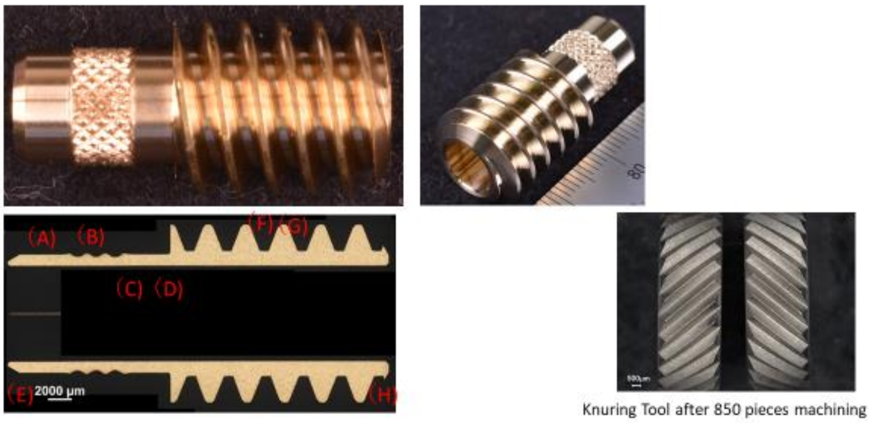
- After machining 1,000 pcs, no change in the quality of machined surface or product dimensions was observed. There was no occurrence of problem like product being tangled with chips and damaged. Fig. 10-1 indicates that the chips generated during the machining were easy to dispose of .
- Fig. 10-2 shows that no visible wear was observed in any of the tools used for turning, grooving, threading, or severing. It is considered that further continuation of machining was possible.
- Assuming that it takes 3 minutes to complete machining of one workpiece, 20 pcs/h, 480 pcs/day could be produced if operated around the clock. An alloy can be considered to have good machinability if it has machinability equivalent to that of C36000. Specifically, continuous machining is possible for 24 hours without human assistance or presence, quality

issue in the product, problem with disposal of the chips, or necessity of tool replacement. Therefore, it is true that the longer the tool life is, the better, but there would be no substantial problem if disposal of chips and replacement of tools could be done at a timing when the NC lathe is stopped to perform inspection or the like.

3)-2. Machining Example 5 – Component Similar to Worm Gear

Continuous machining of components similar to worm gears was performed at Machining Company E using a NC lathe usually used for commercial mass production and ϕ15-mm ECO BRASS rods.

Fig. 11 shows the appearances of the similar component to worm gear that was last machined and the knurl piece after completion of the machining of 850 pcs.



- Process：
  (A)Turning→(B)Knurling→(C)ϕ7.8Drilling(1600rpm,0.07mm/rev.,6step,27sec)
  →(D)Boring (1700rpm,0.05mm/rev.,56sec)
  →(E)Chamfering→(F)Threading(40sec)→(G)Chamfering→(H)Cut off
- Cycle：182sec
- Condition : Wet
- Machine : Citizen Machinery L-20Ⅷ
- Pieces : 850

Fig. 11: Machining Example 5 – Component Similar to Worm Gear

- Regarding component shape, as the front, oblique-view, and cross-sectional pictures show, a thin wall is constructed by precision machining and surface conditions are good. In addition, from the cross-section picture in Fig. 11, it is understood that most part of the material turns into chips.
- There is little difference in surface quality and component dimensions between the first and the last pieces of the 850 pcs.
- No tool wear was observed including the knurl piece after completion of machining the 850 pcs.
- Continuous chips or stuck chips that would affect the component's shape or machined surface were not observed.

From the evaluation of the 1000-piece machining using a mass production facility, we were able to ascertain that ECO BRASS is a material that can be used for mass production since quality of machined surface and dimensional precision were satisfactory, quality of machined products was steady, tool wear was little, and continuous machining was possible in a short period of time without trouble, which are more important than the results of cutting resistance in laboratory testing.. We will continue to review the machining conditions to see if the current process can be shortened. Incidentally, in the test machining, commercial wet machining facility for mass production was used, but we have also confirmed in a laboratory that there is no problem in dry machining (described in Chapter IV where selection of suitable tools is discussed).

4) Cycle Time

4)-1 Machining Example 6 – Machining with NC Lathes

Evaluation of machining including small-hole drilling was performed with the cooperation of Machining Company D using their NC lathes which are normally used for mass machining of commercial products and ø10-mm ECO BRASS rods.

<u>Fig. 12</u> shows an example of machining a component having a shape like a water temperature sensor.

- Process :
  - Outer : Turning→Threading→Deburring→Chamfering→Cut off
  - Inner : End face→Center hole→ϕ8.0 Drilling(2000rpm, 0.1mm/rev., 2step) →Center hole→ϕ4.0 Drilling(2000rpm, 0.07mm/rev., 3step)
- Cycle : 83sec (Outer-43sec, Inner-40sec)
- Condition : Wet
- Material : ϕ10 × 2500
- Machine : Outer-Star Micronics JNC25, Inner-Takamaz XC-100

Fig. 12: Machining Example 6 – Component Similar to Water Temperature Sensor

- After performing turning and threading, wall-thinning process and small and deep-hole drilling were performed using another NC lathe.
- Drilling can be performed without causing broken drill by introducing peck drilling.

- Swarf was flowing out without problem. There was no trouble such as workpiece damage caused by the tool tangling with swarf.

NC lathe is the most-commonly used machine when 1) dimensional precision is required, 2) the workpiece has a complicated shape, 3) several different machining methods such as drilling, threading, end-milling, and knurling need to be used, or 4) the quantity of workpieces to machine is small. Even when C36000 is used, it takes one to five minutes to finish machining one component depending on required dimensional precision, surface roughness, shape, the number of machining methods used, and machining quantity.

One of the main reasons C36000 is chosen for the manufacture of auto parts is that the alloy can be machined to form a complicated shape in a short period of time with dimensional precision. Few auto parts and electrical/electronic parts have a simple shape. Most of them require grooving, end-milling, threading, drilling, knurling and so on in addition to simple turning for their production. When dimensional precision of the inside is required, re-lathing is performed after drilling. Therefore, machining is generally performed in about ten steps total, which is time-consuming. Further, when high dimensional precision is required like the previously mentioned car air-conditioner component (e.g. precision of 2 μm), it is necessary to reduce the feed rate. Therefore, machining time varies depending on the quality and shape required by the product.

Many Japanese machining companies adopt peck drilling, a drilling method in which a hole is drilled at an intermittent feed for the sake of quality assurance and prevention of inflicting damage on the drill. ECO BRASS can be machined on the conditions equivalent to those applied to C36000, and fortunately, the same level of surface roughness can be obtained at a higher feed rate as described later, which leads to a reduction in machining time.

4)-2 Relation between Surface Roughness and Feed Rate

Fig. 13 shows relation between surface roughness and feed rate.

Regarding roughness of machined surface, ECO BRASS has the following advantages which are utilized for the reduction of machining time.

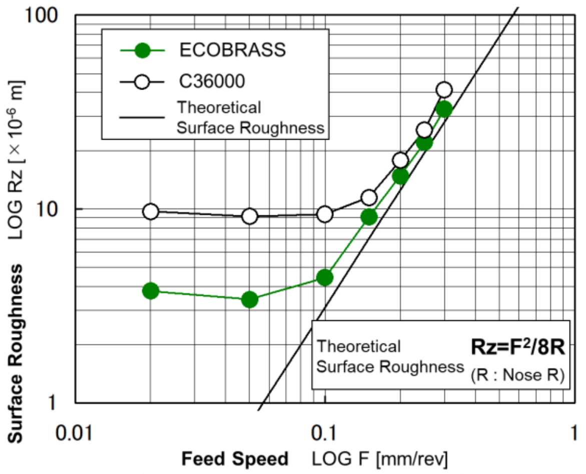


Fig. 13: Relation between Surface Roughness and Feed Rate

- Generally speaking, surface roughness is closely related to feed rate. The lower the feed rate, the rougher the surface gets than the theoretical surface roughness. If a very smooth surface is required, it is necessary to reduce the feed rate.
- When ECO BRASS is used, surface roughness close to the theoretical surface roughness can be obtained at a lower feed rate than when C36000 is used. In other words, when ECO BRASS is used, the same surface roughness can be obtained at a higher feed rate than when C36000 is used. By machining at a higher feed rate, it is possible to reduce machining time.

5) Summary of machining examples provided with the cooperation of machining companies

With the cooperation of five companies including four machining companies having several dozen employees and capitalized at somewhere around 100,000 euros, test machining of components having various shapes was performed using ECO BRASS at their commercial mass production facilities. The outcome was that the test machining went well and without problems at all of the companies. With the consent of the machining companies, we were able to disclose a lot of information such as component shape and surface quality on 15 kinds of machined items including mass produced auto parts. It became possible to disclose how much the tools wear, conditions of generated chips, and machining process although such disclosure is not complete.

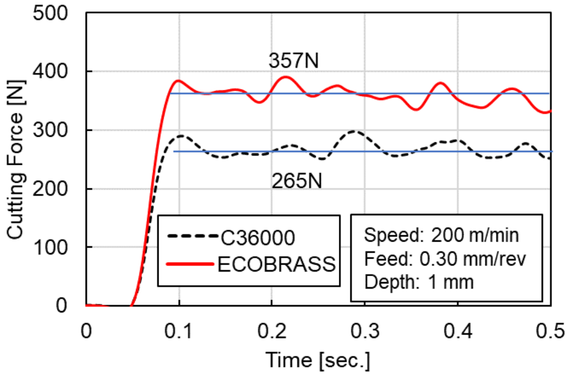
From the results of the test machining in which turning, grooving, all sorts of threading, knurling, wall-thinning, and drilling of various holes are included, there is generally no serious problem in machining ECO BRASS materials on a commercial scale although the 15 kinds of the test-machined items do not cover all the existing auto parts and electrical/electronic parts.

Ⅳ Selection of Cutting Tools Suitable for ECO BRASS

In order to select suitable cutting tools for ECO BRASS, machining tests were performed on wet and dry conditions in a laboratory using several cutting tools for the evaluation of cutting resistance and brittleness of chips. The results of the laboratory test presented below are a part of the entire results. We will disclose further technical information as necessary.

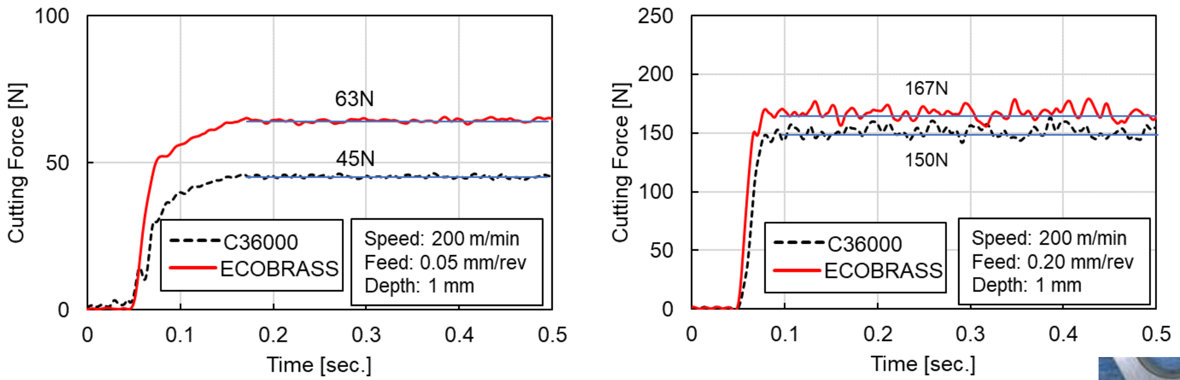
1) Wet Machining with NC Lathe

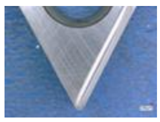
Cutting resistance was measured in a laboratory using an NC lathe attached with Inserts A and B. The chart indicating the cutting resistance is based on the measurements of cutting force of ECO BRASS in comparison with that of C36000, a free-cutting brass containing 3% Pb. For the laboratory evaluation, ø20-mm round rods were used both for ECO BRASS and C36000.



Insert A

Fig. 14: Cutting Resistance When Insert A Was Used (Wet Lathing)





Insert B

Fig. 15: Cutting Resistance When Insert B Was Used (Wet Lathing)

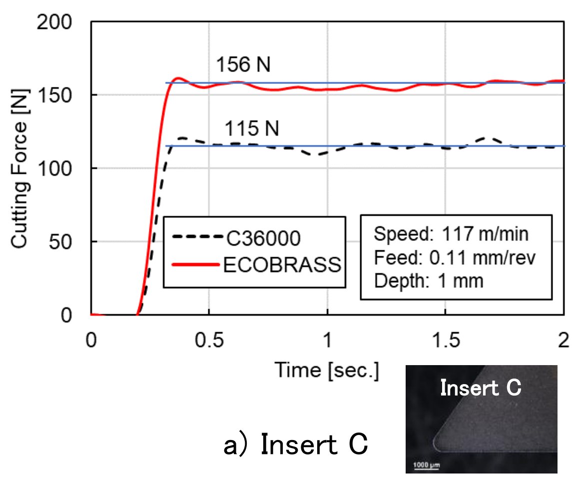
- ECO BRASS has about 1.4 times the strength of C36000. As cutting resistance depends on the strength of material, an increase in cutting resistance is inevitable.
- In other words, machinability of ECO BRASS can be considered good if its cutting resistance is less than 1.4 times that of C36000 (or the cutting resistance of C36000 is more than 0.71 times that of ECO BRASS).

- **Fig. 14** shows the results of lathing with Insert A attached at 200 m/min, which is a relatively high speed, and 0.3 mm/rev, which is relatively a high feed rate. ECO BRASS' cutting resistance is 1.35 times that of C36000. Considering the difference of strength between the two, it can be said that machinability of ECO BRASS is equivalent to that of C36000.
- **Fig. 15** shows the results of lathing with Insert B attached at a constant cutting speed of 200 m/min and feed rates of 0.05 mm/rev and 0.2 mm/rev. Compared with C36000, ECO BRASS' cutting resistance was 1.40 times and 1.11 times higher respectively.
- When ECO BRASS was lathed with Insert B attached at a higher feed rate of 0.2 mm/rev and 200 m/min, increase in the cutting resistance was capped to only 11% that of C36000. Considering the strength of ECO BRASS, this suggests that machining itself went better with ECO BRASS than C36000.

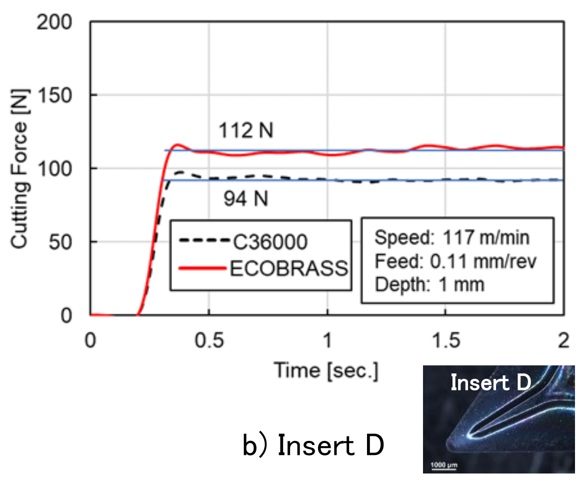
In summary of the results of wet lathing tests, it can be said that increase in cutting resistance is avoidable by selecting cutting tools and machining conditions that are suitable for ECO BRASS. As Fig. 13 shows, ECO BRASS can obtain surface roughness equivalent to that of C36000 at a higher feed rate, indicating that reduction of the cycle time (machining time) is possible.

2) Dry Machining with a Manual Lathe

Dry lathing was performed in the laboratory using a manual lathe attached with Inserts C and D to measure cutting resistance and evaluate the chips.



a) Insert C

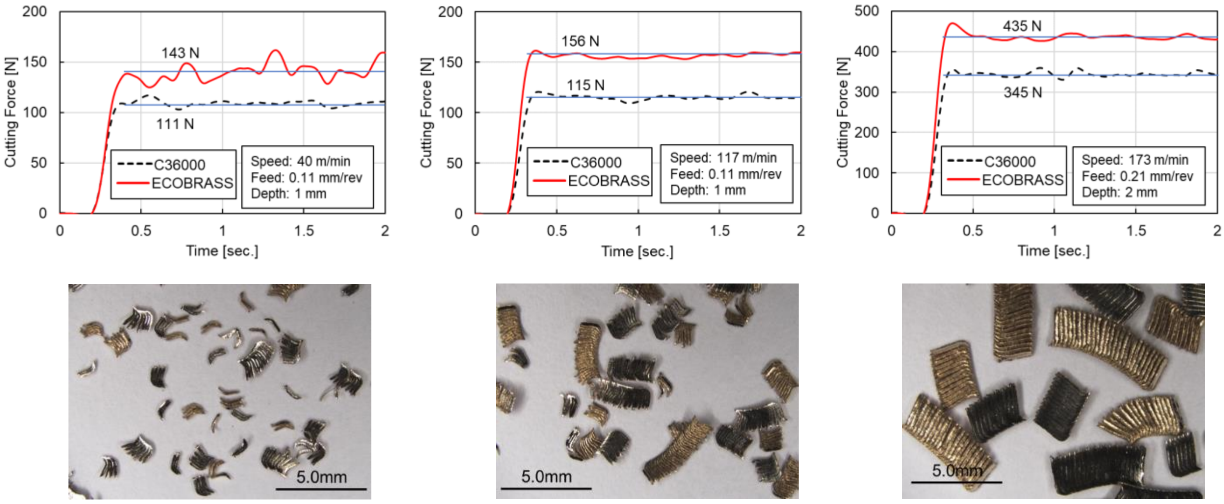


b) Insert D

Fig. 16: Influence of Insert on Cutting Resistance (in Dry Lathing)

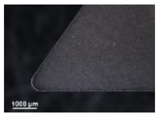
- **Fig. 16** shows a chart of cutting resistance when dry lathing was performed using Inserts C and D at a cutting speed of 117 m/min, a feed rate of 0.11 mm/rev and a cutting depth of 1.0 mm. These cutting conditions are close to those applied when the test machining of 1000 pcs was performed at Machining Companies D and E.
- When Insert C was used, the cutting resistance of ECO BRASS was 1.36 times that of C36000 whereas when Insert D was used, it was 1.19 times that of C36000 indicating that selection of

a suitable insert has an effect of suppressing the increase of ECO BRASS' cutting resistance. The absolute value of the cutting resistance also varies depending on the tools used.



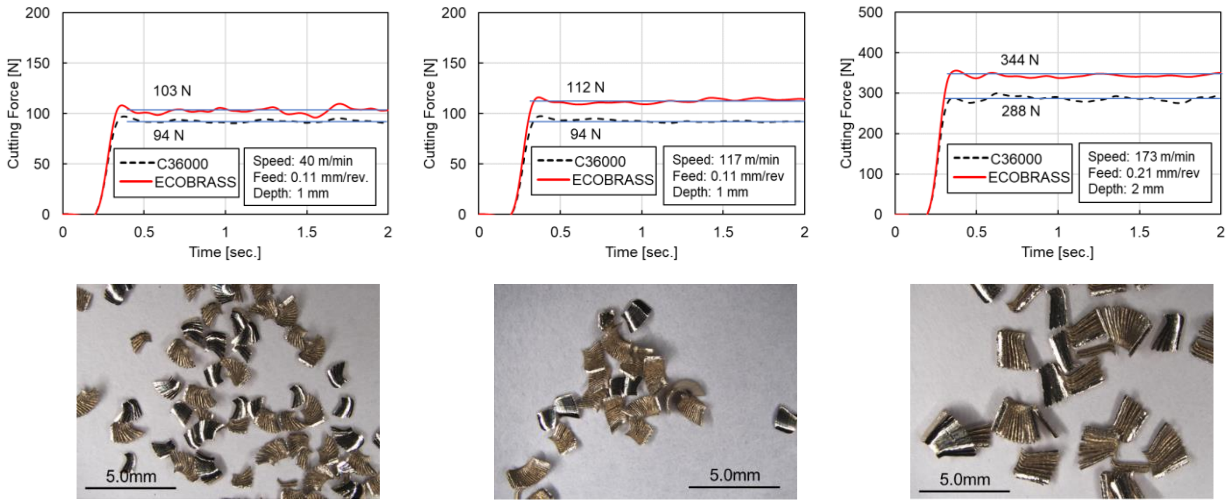
Conditions 1)　　Conditions 2)　　Conditions 3)

Fig. 17: Cutting Resistance and Appearances of Chips when Insert C was Used

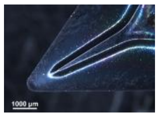


Insert C

- Fig. 17 shows charts of cutting resistance and the appearances of chips when lathing was performed using Insert C on the three combinations of conditions described below.
- The machining test was performed on dry conditions at varied cutting speeds of 40 m/min, 117 m/min, and 173 m/min, feed rates of 0.11 mm/rev and 0.21 mm/rev, and cutting depths of 1.0 mm and 2.0 mm mainly to see the influence of cutting speed. The three combinations of the conditions are: 1) 40 m/min, 0.11 mm/rev, 1.0 mm, 2) 117 m/min, 0.11 mm/rev, 1.0 mm, and 3)173 m/min, 0.21 mm/rev, 2.0 mm.
- When Insert C was used, regardless of the cutting conditions such as cutting speed, the cutting resistance was constant being approximately 1.3 times that of C36000, and with the increase of cutting speed, the length of chips became slightly longer.
- When Insert C was used, cutting resistance increased by about 30 percentage points compared with C36000 and as a result, brittleness of chips sometimes deteriorated a little.



Conditions 1) Conditions 2) Conditions 3)



Insert D

Fig. 18: Cutting Resistance and Appearances of Chips when Insert D was used

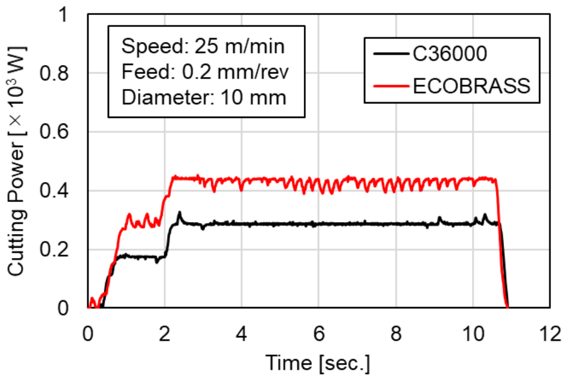
- **Fig. 18** shows charts of cutting resistance and the appearances of chips when lathing was performed with Insert D on the three combinations of conditions like when the test lathing was performed using Insert C.
- When Insert D was used, regardless of the cutting conditions, cutting resistance was more or less stable and 1.1 to 1.2 times that of C36000. The cutting resistance was lower than when Insert C was used. This means that when Insert D was used, increase in cutting resistance was capped to be only 10 to 20 percentage points compared with C36000. Thus, considering the strength of ECO BRASS, it is suggested that ECO BRASS excels over C36000 in machinability.
- It was ascertained that ECO BRASS had good machinability from the fact that no significant difference was observed in the shape of the chips among the three combinations of conditions and that they were finely broken.

In summary of the results of the test lathing on dry conditions, ECO BRASS demonstrated good machinability like the wet conditions. In addition, by selecting an appropriate insert, severe increase in cutting resistance could be avoided, specifically, the increase was limited to only 10–20% that of 36000, and brittle chips were generated like C36000.

3) Dry Drilling

Cutting resistance during drilling was evaluated by cutting power using a high-speed steel drill and a carbide drill.

High-speed steel drills are cheaper than carbide drills and are used for the production of commercial products with C36000 materials on many occasions. Drilling conditions recommended by a multiple number of tool makers, are described as about 30 m/min for drilling speed and about 0.2 mm/rev for feed rate. At all of the five machining companies cooperating in the test machining described in Chapter III, high-speed steel drills are used. Each company has its own set of machining conditions determined by their own know-how and required machining quality, characteristics and drill life. Therefore, the drilling is performed at a cutting speed of 23 to 50 m/min and a feed rate of 0.07 to 0.15 mm/rev.

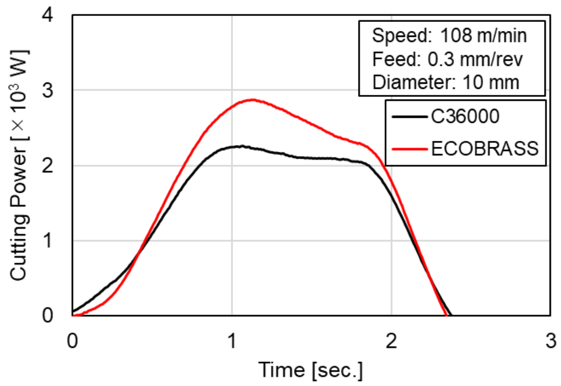


Drill A

Fig. 19: Cutting Power when High-Speed Steel Drill Was Used

- Fig. 19 shows the cutting power when drilling was performed on a ø20-mm ECO BRASS rod using an NC lathe with a ø10-mm high-speed steel drill attached.
- Dry drilling was performed on the conditions recommended by the drill manufacturer: at a cutting speed of 25 m/min, a feed rate of 0.2 mm/rev, and L (depth of hole) / D (diameter) = 3.0.
- What matters for cutting power during drilling is its maximum value which may cause the drill to be broken. The maximum value of cutting power was compared between ECO BRASS and C36000 (maximum value of ECO BRASS' cutting power/ maximum value of C36000's cutting power).
- Like in wet lathing described above, in drilling also, if ECO BRASS' cutting resistance is lower than 1.4 times that of C36000, its machinability can be considered good.
- In the case Drill A is used, the cutting power of ECO BRASS is 1.39 times that of C36000, which is proportionate to the difference in material strength between the two alloys. Therefore, it can be said that ECO BRASS' machinability is equivalent to that of C36000 in drilling.
- Pictures of the chips generated during the drilling are left out, but as described in Chapter III, the chips were easy to dispose.

As carbide drills are expensive compared with high-speed steel counterparts, they are used less frequently even though drilling can be performed at high revolution and high feed rate. A number of carbide drills are found in catalogues of tool makers because for other metallic materials, they are used on many occasions. In the case of carbide drills, the recommended drilling conditions by several tool makers are about 100 m/min as cutting speed, and about 0.3 mm/rev as feed rate. As improvement of productivity was expected by using carbide drill for ECO BRASS also, we have conducted the evaluation as presented below.



Drill B

Fig. 20: Cutting Power When Carbide Drill B Was Used

- **Fig. 20** shows the cutting power when drilling was performed on a ø20-mm ECO BRASS rod using an NC lathe attached with ø10-mm Drill B.
- Dry drilling was performed on the conditions recommended by the drill maker: at a cutting speed of 108m/min, a feed rate of 0.3mm/rev, and L (drill hole depth)/D(diameter)=3.0.
- In the case Drill B was used, ECO BRASS' cutting power was 1.27 times that of C36000, which is smaller than the difference in material strength between the two alloys. Therefore, it can be said that ECO BRASS has the same machinability as that of C36000 in drilling.
- The chips generated during the drilling were easy to dispose like those generated when C36000 material was used.

In this document, examples of drilling with a high-speed steel drill and carbide drill are presented only once for each, but in both examples, ECO BRASS' cutting resistance was slightly lower than 1.4 times that of C36000 - specifically, 1.39 times and 1.29 times respectively. This indicates that ECO BRASS has no problem in cutting resistance either.

4) Summary of Laboratory Test Machining

The results of the test machining presented above indicate that by selecting cutting tools (insert and drill) suitable for ECO BRASS and machining with appropriate conditions, increase in the cutting resistance can be contained to the level slightly higher than that of C36000, and brittle chips are generated. Since C36000 has superb machinability, there are only a few cutting tools devoted to machining the alloy, but there are many which are suitable for machining leaded and free-cutting steel, common carbon steel, stainless steel, etc. and readily available all over the world. It should not be so laborious to find ones that allow further reduction in cutting resistance, generation of more brittle chips, and longer tool life if selected from such cutting tools.

ECO BRASS is manufactured and sold worldwide, with the total quantity of 300,000 tons in Japan, Europe, and the U.S., which amounts to as many as about 15 billion pcs in terms of the number of components. At many machining companies, when they machine ECO BRASS material for the first time, it is done on the conditions applied to C36000 first, and then over time, they improve productivity through selection of cutting tools that are suitable for achieving the quality required for the product and the machining conditions. By doing so, ECO BRASS materials are machined on a commercial basis without trouble. The technical information disclosed in this document is only one example. We intend to disclose further if necessary.

V GloBrass

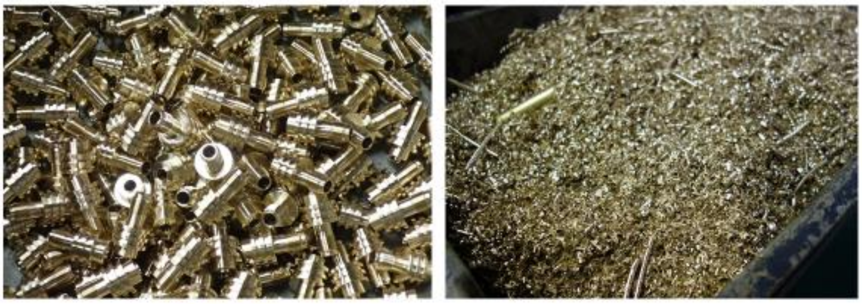
GloBrass is a lead-free, free-cutting brass developed by our company. Like ECO BRASS, it is a Cu-Zn-Si alloy and concentration of each of the remaining elements contained in the alloy is 0.1% or less (Cd: 0.01% or less). However, GloBrass contains 60 to 65% Cu whereas the concentration of Cu in ECO BRASS is approximately 76%. The metal structure of GloBrass resembles that of C36000, and differs from that of ECO BRASS. GloBrass has good machinability and mechanical properties, details of which can be disclosed as necessary. **Table 1** shows comparison of the properties of ECO BRASS and GloBrass. Incidentally, electrical conductivity of GloBrass is higher than that of phosphor bronze which is used for many auto parts as well as electrical/electronic parts and contains either 6% or 5% Sn. Therefore, it is considered that GloBrass can be used for components that require certain thermal conductivity and/or electrical conductivity. We are sure that the range of applications of Pb-free alloys will expand now that we have GloBrass in addition to ECO BRASS.

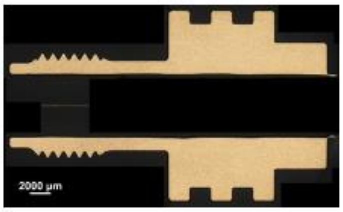
Table 1: Properties of GloBrass

	GloBrass	C36000	ECOBRASS
Tensile Strength	○	△	○
Wear Resistance	○	△	○
Corrosion Resistance	△	△	○
Machinability	○	○	○
Hot Forgeability	◎	-	○
Castability	○	-	○
Conductibity/%IACS	16	26	8

1) Machining Example of GloBrass

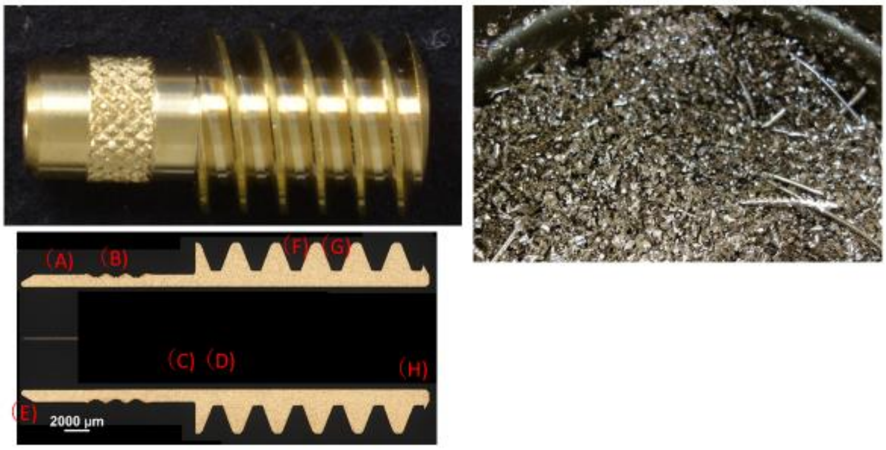
Like ECO BRASS, machinability of GloBrass in mass production was evaluated using NC lathes normally used for making commercial products with the cooperation of Machining Companies D and E.





- Process：
  End face→Centre hole
  →ϕ6.0 Drilling（1200rpm、0.12mm/rev.、4step）
  →Turning（100m/min、0.07mm/rev.）
  →Threading（1200rpm、1.0mm/rev.）
  →Turning（100m/min、0.07mm/rev.）
  →Grooving（120m/min、0.2mm/rev.）
  →Turning→Cut off
- Cycle：142sec
- Condition : Wet
- Machine : Star Micronics JNC25

Fig. 21: Machining Example 7 – Valve Part



- Process：
  (A)Turning→(B)Knurling→(C)ϕ7.8Drilling(1600rpm,0.07mm/rev.,6step,27sec)
  →(D)Boring (1700rpm,0.05mm/rev.,56sec)
  →(E)Chamfering→(F)Threading(40sec)→(G)Chamfering→(H)Cut off
- Cycle：182sec
- Condition : Wet
- Machine：Citizen Machinery L-20Ⅷ

Fig. 22: Machining Example 8 – Component Similar to Worm Gear

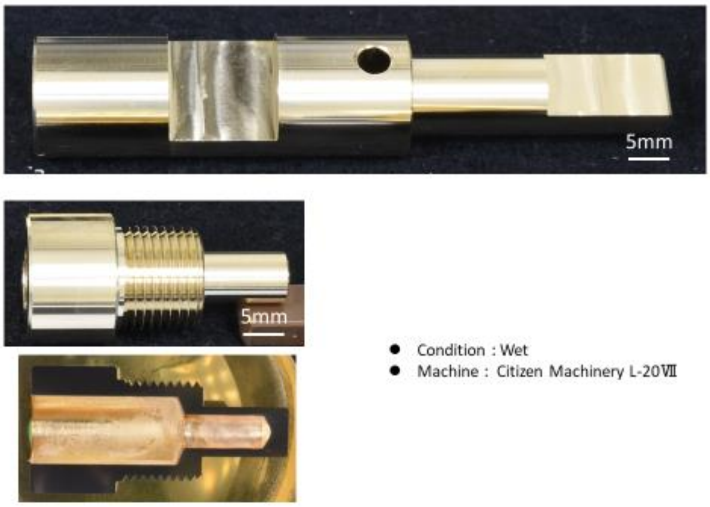


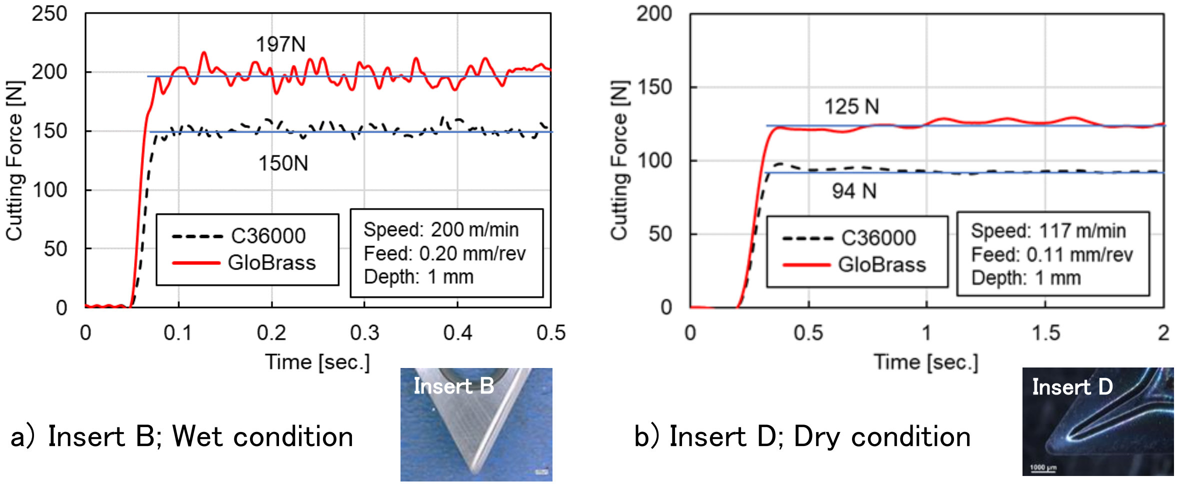
Fig. 23: Machining Example 9 –Component Requiring Milling and Component Similar to Temperature Sensor

- **Fig. 21** shows an example of machining 1000 pcs of valve part performed at Machining Company D. **Fig. 22** shows an example of machining 1000 pcs of components similar to worm gear performed at Machining Company E. **Fig. 23** shows an example of machining 100 pcs each of components which include milling in their manufacture and temperature sensor-like components performed at Machining Company E. The aforementioned test machining was performed on the cutting conditions applied to test machining of ECO BRASS.
- Figs. 21 to 23 show that turning, grooving, drilling, side drilling of small-holes, threading, severing, knurling, milling, and end-milling were able to be performed without problem. Both the valve parts and worm gear-like components exhibited good surface quality like when ECO BRASS was used, and no difference was observed in the surface quality between those machined at the beginning and the end of machining the 1,000 pcs. There was little dimensional difference between them. Quality of the machined surface was good like that of a product made of ECO BRASS.
- The chips generated during machining of the valve parts, worm gear-like components, components that include milling in their manufacture, and components having a shape similar to that of a temperature sensor were easy to dispose. No problem like chips tangling the cutting tool and causing damage on a workpiece occurred.
- After machining 1,000 pcs each of the valve parts and worm gear-like components, no visible damage was observed on any of the cutting tools used for turning, grooving, drilling, threading, severing, and knurling. It is therefore considered that further continuation of machining was possible.
- The evaluation of the test machining of GloBrass was more or less the same as that of ECO BRASS.

We were able to confirm that, like ECO BRASS, GloBrass has good machinability, can be machined to form thin walls and complicated shapes on a commercial basis, and can be processed by various machining methods, and quality of machined products made of GloBrass is good. We were able to confirm that GloBrass is a material that can be used for mass production from the fact that after machining 1,000 pcs, no decrease in machined product quality was observed and brittle chips were generated. In addition, we have received comments from an operator of one of the machining companies which offered cooperation in the test machining that GloBrass is a material having machinability close to that of C36000. Therefore, it is considered that GloBrass can be used for mass production.

2) Cutting Resistance of GloBrass

2)-1 Lathing on wet and dry conditions

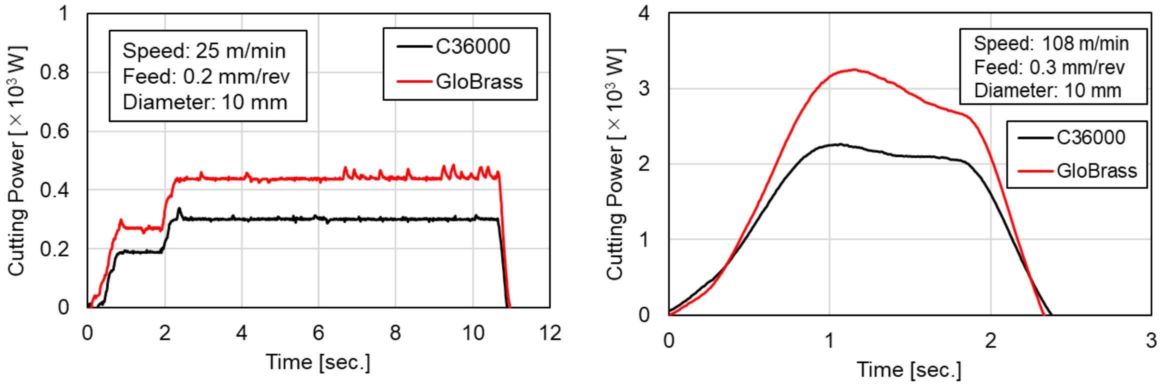


a) Insert B; Wet condition b) Insert D; Dry condition

Fig. 24: Cutting Resistance for Inserts B (Wet Condition) and D (Dry Condition)

- <u>Fig. 24</u> shows, as examples, the cutting resistance when wet lathing was performed in a laboratory using an NC lathe attached with Insert B at a cutting speed of 200 m/min, a feed rate of 0.20 mm/rev, and a cutting depth of 1 mm, and when dry lathing was performed using a manual lathe attached with Insert D at a cutting speed of 117 m/min, a feed rate of 0.11 mm/rev, and a cutting depth of 1 mm. For this evaluation, ø20-mm rods were used both for GloBrass and C36000.
- GloBrass has about 1.3 times the strength of C36000. This high strength is disadvantageous in cutting resistance, which is 1.31 times and 1.33 times that of C36000 in wet lathing and dry lathing respectively. Since the difference in cutting resistance is proportionate to that in the strength compared with C36000, it can be said that, all in all, GloBrass was able to be machined as well as C36000, like ECO BRASS.
- The chips generated during the lathing were finely broken and easy to dispose like those of C36000 as shown in Figs 21 and 22 depicting the chips produced during the test machining

performed with the cooperation of some machining companies.



a) Drill A (High-Speed Steel Drill) b) Drill B (Carbide Drill)

Fig. 25: Cutting Power When High-Speed Steel Drill A (Left) and Carbide Drill B (Right) Were Used

- Fig. 25 shows the cutting power when dry drilling was performed using an NC lathe with High-Speed Steel Drill A and Carbide Drill B attached at the cutting speeds and feed rates of 25 m/min and 0.2 mm/rev for Drill A, and 108 m/min and 0.3 mm/rev for Drill B with L (depth of drill hole)/D (diameter)=3.0 for both drills.
- The cutting resistance of GloBrass was about 1.4 times that of C36000 both when High-Speed Steel Drill A and Carbide Drill B were used, which is slightly higher than the difference by ratio in material strength compared with C36000. Compared with ECO BRASS, GloBrass' cutting resistance was found to be 10% higher
- The chips generated during the drilling were easy to dispose.

3) Summary of GloBrass

Considering the fact that GloBrass has about 1.3 times the strength of C36000, it can be said that GloBrass can be machined well with a lathe or a drill. At present, various evaluations are ongoing for GloBrass and ECO BRASS in order to find suitable cutting tools and cutting conditions. Practical machining evaluations are being performed, too. The technical information disclosed in this document is an example, and we intend to disclose more as necessary.

VI Conclusion

The knowledge and technical information we now have can be summarized as follows:

- The following matters have been confirmed regarding ECO BRASS.
  1) ECO BRASS has been processed into approximately 15 billion components by now, and about a half of them have been used for five or more years under various environments allowing ECO BRASS to earn high reliability as a material.
  2) ECO BRASS has earned high reliability in terms of strength, corrosion resistance, durability and some other characteristics.
  3) By selecting appropriate machining methods and conditions, ECO BRASS can provide almost the same level of productivity, tool life, dimensional precision, and surface quality as C36000.
  4) ECO BRASS scraps are separated and managed, then collected for recycling without confusion.
  5) In the area of auto parts, there exists a multiple number of ECO BRASS parts that have been installed in approximately 100 million cars by now. ECO BRASS has earned high reliability due to such records of use in products.
  6) There are several auto parts which include knurling in their production process. Each of them has been installed in over five million automobiles. They are meeting customers' quality-related demands such as forming a complicated shape or high dimensional precision.
- With the cooperation of five machining companies including four having several dozen employees, we have confirmed that ECO BRASS can be machined on a commercial basis without problem at all of the five companies using their commercial facilities that are normally used for machining C36000 materials.
- It has been ascertained that ECO BRASS can be machined on a commercial basis without serious problem based on the results of test-machining of 15 kinds of components performed using various methods with the cooperation of some machining companies although there exist auto parts that require other machining methods for their production than those used for the production of the 15 kinds of components.
- In one example, when test machining was performed using a cutting tool suitable for ECO BRASS, cutting resistance was capped to be only 10 to 20% higher than that of C36000, and brittle chips were generated.
- There are not many cutting tools that are devoted to machining C36000 since its cutting resistance is low which prolongs tool life. However, there are many which are suited for machining leaded and free-cutting steel, stainless steel, etc. which are readily available all over the world. It is considered that productivity can be improved further by selecting cutting tools suitable for ECO BRASS and GloBrass. If necessary, we will disclose our proprietary information on machining these alloys.
- ECO BRASS is an alloy having higher strength, better wear resistance, creep properties, and corrosion resistance than those of the conventional material containing 3% Pb. Therefore, it

is presumed that, thickness and weight of components can be reduced if ECO BRASS is used instead. We believe that lead-free and lighter components can reduce various loads imposed on the environment.

- We have successfully developed, a new, lead-free, and free-cutting brass called GloBrass which has different composition, metal structure, and properties from those of ECO BRASS. We are certain that the range of applications of Pb-free alloys will expand now that GloBrass is available in addition to ECO BRASS.