Introduction

ECO BRASS is a lead-free (Pb-free) high performance copper alloy with superior properties to currently used alloys. ECO BRASS has high strength, excellent machinability, exceptional wear resistance, good creep properties, and superior corrosion resistance. These properties allow fabricators to decrease component thickness and reduce product weight. Lead-free, lighter and stronger parts can reduce the environmental burden on society. About 1,000 tonnes of lead (Pb) per year has been eliminated by manufacturers who switched to ECO BRASS. ECO BRASS is widely used for drinking water fixtures and components and also it is selected by the automotive, electrical and electronic industries. The typical leaded copper alloy is CuZn39Pb3 but tens of leaded copper alloys are used for many purposes. Although it is not possible for ECO BRASS to replace all leaded copper alloys, ECO BRASS can be a substitute material for many components especially where high electrical conductivity is not critical.

Please note our technical input is solely as a material maker.

Responses

Responses to questions 4 and 5.

1. Trends in Sales of ECO BRASS

Fig.1 shows the growth of sales of ECO BRASS in Japan, North America and Europe.

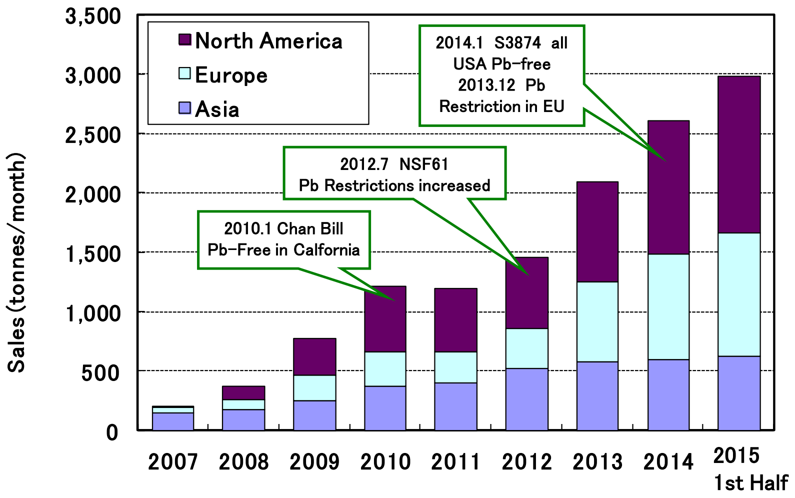


Fig.1 Growth of Sales.

- In the first half of 2015 global sales achieved 3,000 mt/mo (36,000 mt/yr) which is a 4 times increase compared to 2009. We estimate that using ECO BRASS at current consumption levels results in a reduction of about 1,000 tonnes of lead a year in the material stage.

- It is estimated that the total accumulative global sales of ECO BRASS reached over 150,000 tonnes in August 2015 since it was introduced into practical use in the early 21^{st} century.
- Breakdown of the 3,000 mt/mo world sales - Rod: 2,300 mt/mo, Casting: 700 mt/mo.
- Of rod (2,300 mt/mo) - North America: 1,050 mt/mo, Europe: 1,000 mt/mo, Japan: 250 mt/mo.
- Worldwide sales of ECO BRASS have increased rapidly with the tightening of U.S. lead regulations AB1953(2010.1) and S3874(2014.1). Conventional copper alloys used in fixtures or components for drinking water are being smoothly replaced with ECO BRASS without any problems in performance, usability, material supply or manufacturing.
- We understand from the market that scrap generated during the production of finished product, is easily segregated and recycled.
- ECO BRASS rods are used mostly as replacement material for free-cutting brass rod CuZn38Pb3 suggesting that there is no difference in productivity from leaded brass. Substitution of stainless steel by ECO BRASS still remains minimal.
- ECO BRASS has been used for water meters, valves, fittings and vehicle components since the early 21^{st} century, and the durability and corrosion resistance in various environments such as in soil or hot-humid conditions have been validated.

2. Examples of Applications

Below are examples of applications of ECO BRASS sold in Japan.

- ECO BRASS is often selected for fixtures or components for drinking water such as water meters, valves and fittings.
- According to surveys of water meter manufacturers about the machining characteristics, the productivity of ECO BRASS is equivalent to C83600 alloy (Cu85Zn5Sn5Pb5) under appropriate machining conditions and the drill life is about 80% of that of C83600.
- Five different components, each in over one million vehicles are confirmed to be using ECO BRASS.
- ECO BRASS has been adopted for the sliding component of vehicle air conditioner replacing C36000 (JIS H 3250 C3604) and the number of vehicles using ECO BRASS totals more than twenty million since 2007. According to surveys of manufacturers about machining of ECO BRASS compared to C36000, productivity is 90% or more under appropriate machining conditions and the drill life during mass production is more than 80%.
- It can be infered that the machining example of vehicle components is a model case for substituting small electrical and electronic components.
- Examples of ECO BRASS application for electrical and electronic components are gears, terminals, medical devices and valves for electrical water heater.
- RoHS categories lists large electrical home appliances (refrigerators, freezers, washing

machines, dishwashing machines, air-conditioners or air-conditioning facilities, etc.) and vending machines also as target products for evaluation.

- The shapes of components used in large electrical home appliances or vending machines are similar to that of fixtures or components for drinking water (valves, fittings or nuts etc.) as shown in **Fig.2**.

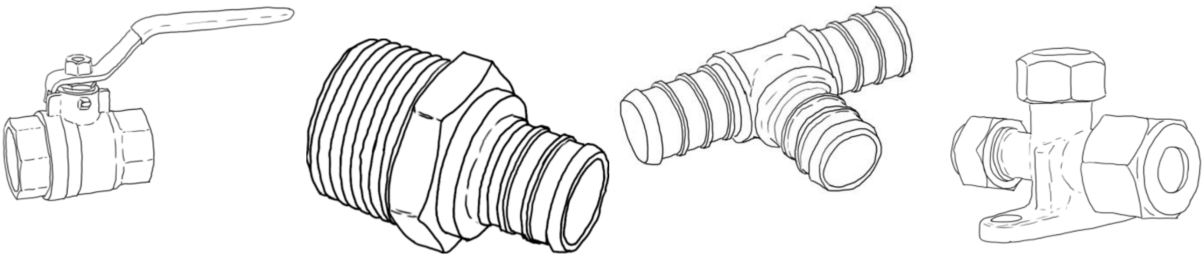


Fig.2 Examples of applications in fixtures or components for drinking water.

- The shapes of components which contain liquid or gas in electrical and electronic applications are similar to that of drinking water where material change from C36000 to ECO BRASS is now smoothly progressing, as such, we can presume that conventional materials for electrical and electronic applications could be replaced with ECO BRASS.
- High electrical conductivity is not critical for many electrical and electronic components made from leaded brass such as valves, fittings, insert nuts, planetary and worm gears, bushes and bearings. When lead-free copper alloys with high electrical conductivity are needed, copper alloys such as C18625 are available.

3. Properties

3-1. Basic Properties of ECO BRASS

Table1 shows the properties of ECO BRASS compared to C36000 (equivalent JIS H3250 C3604(CuZn38Pb3)).

Table1 Comparison in each property (representative value).

	Properties		ECO BRASS	C36000	C36000 ratio
Physical Properties	Specific Gravity		8.30	8.50	0.98
	Melting Point – Liquidus	℃	890	895	0.99
	Melting Point – Solidus	℃	855	880	0.97
	Specific Heat	J/kg・K	480	450	1.07
	Thermal Conductivity	W/m・K	45	133	0.34
	Electrical Conductivity	%IACS	8	26	0.31
	Coefficient of Thermal Expansion	10^{-6}/K	19.9	20.5	0.97
	Modulus of Longitudinal Elasticity	GPa	98	85	1.15
	Modulus of Transverse Elasticity	GPa	34	35	0.97
Mechanical Properties	Tensile Strength(φ 20)	MPa	670	475	1.41
	0.2% Proof Stress(φ 20)	MPa	510	355	1.44
	Elongation(φ 20)	%	30	20	1.50
	Vickers Hardness(φ 20)	5kg	190	145	1.31
	Poisson's Ratio		0.33	0.32	1.03
	Cold Compressive Stress	MPa	700	515	1.36
	Cold Compressive Proof Stress	MPa	435	290	1.50
	Cold Limit Compressibility	%	29	45	0.64
	Bending Stress	MPa	1230	785	1.57
	Fatigue Limit(10^7)	MPa	205	125	1.64
	Creep Strength, Stress at 0.5% Creep Strain(MPa)	100h at 90℃	–	about 330	–
		100h at 120℃	≦570	about 260	–
		100h at 150℃	about 490	about 200	–
Machining	Tool Life(Frank Wear–Turning)	pieces	4400	6300	0.70
	Tool Life(Frank Wear–Drilling)	pieces	4200	5900	0.71
	Surface Roughness Ra(JIS B 0601)	μ m	0.4	1.1	0.36
	Surface Roughness Rz(JIS B 0601)	μ m	4.4	9.4	0.47
Wear Resistance	Friction Coefficient(Non–Lubrication)		0.27	0.21	1.29
	Wear Loss(Non–Lubrication)	mg	5.0	91.5	0.05
	Wear Loss(Lubrication)	g	0.3	13.3	0.02
Corrosion Resistance	Potential Difference between Al	mV	397	403	0.99
	Mixed Potential Difference between Al	mV	417	373	1.12
	Cavitation Erosion Loss	mg	1.7	20.2	0.08
	Mean Cavitation Erosion Rate	μ m/h	2.8	30.5	0.09
	Max Corrosion Depth(ISO6509)	μ m	5	1000	0.01
	Max Corrosion Depth(JBMA T-303)	μ m	5	160	0.03
	Stress Corrosion Cracking Sensitivity		0.005	1.0	0.01

Fig.3 shows the stress-strain curve of extruded rods, **Fig.4** shows the creep properties.

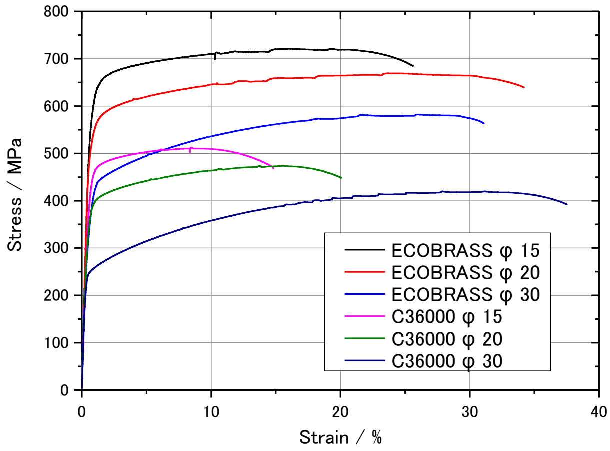


Fig.3 Stress-Strain Curve of Extruded Rods.

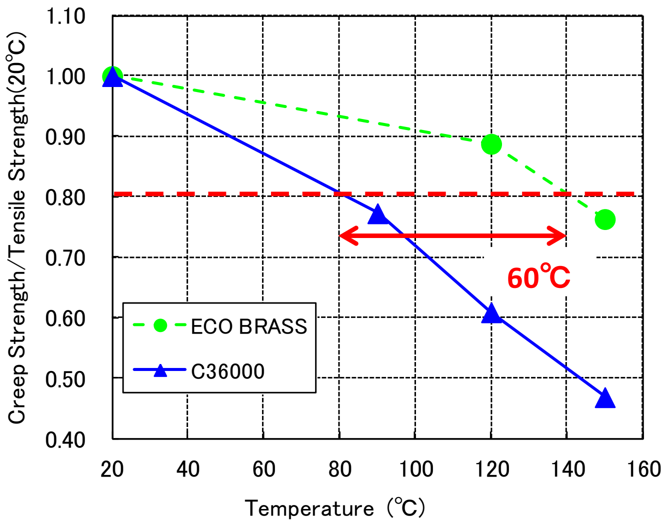


Fig.4 Relation between Temperature and Creep Strength/Tensile strength (20°C).

- ECO BRASS rod has 1.4 times higher tensile strength than leaded brass C36000.
- The elongation of ECO BRASS rod is equal to leaded brass C36000.
- Cold compression strength, bending stress, and fatigue limit of ECO BRASS are 1.4 - 1.6 times greater than those for leaded brass C36000.
- Electrical conductivity and thermal conductivity of ECO BRASS is equal to 1/3 of those for leaded brass C36000.
- We evaluate high-temperature creep by checking creep strength ratio after holding 100 hours at each temperature setting tensile strength 1 at normal temperature. Setting tensile strength 0.8 as limit of creep strength, ECO BRASS has the same strength as leaded brass C36000 but at temperatures 60°C or higher.
- In other words, creep strength at 80℃ of C36000 is equivalent to creep strength at 140℃ of ECO BRASS and a stress-relaxation property of ECO BRASS is superior to that of C36000

because the stress-relaxation property is similar to creep resistance property.

3-2. Wear Resistance

Fig.5 shows wear resistance of Cu-Zn-Si alloy and Cu-Zn-Pb alloy which was evaluated by wear loss applying a ball-on-disk method under non-lubrication and an Amsler method under lubrication.[1), 2)]

a) Non-lubricated

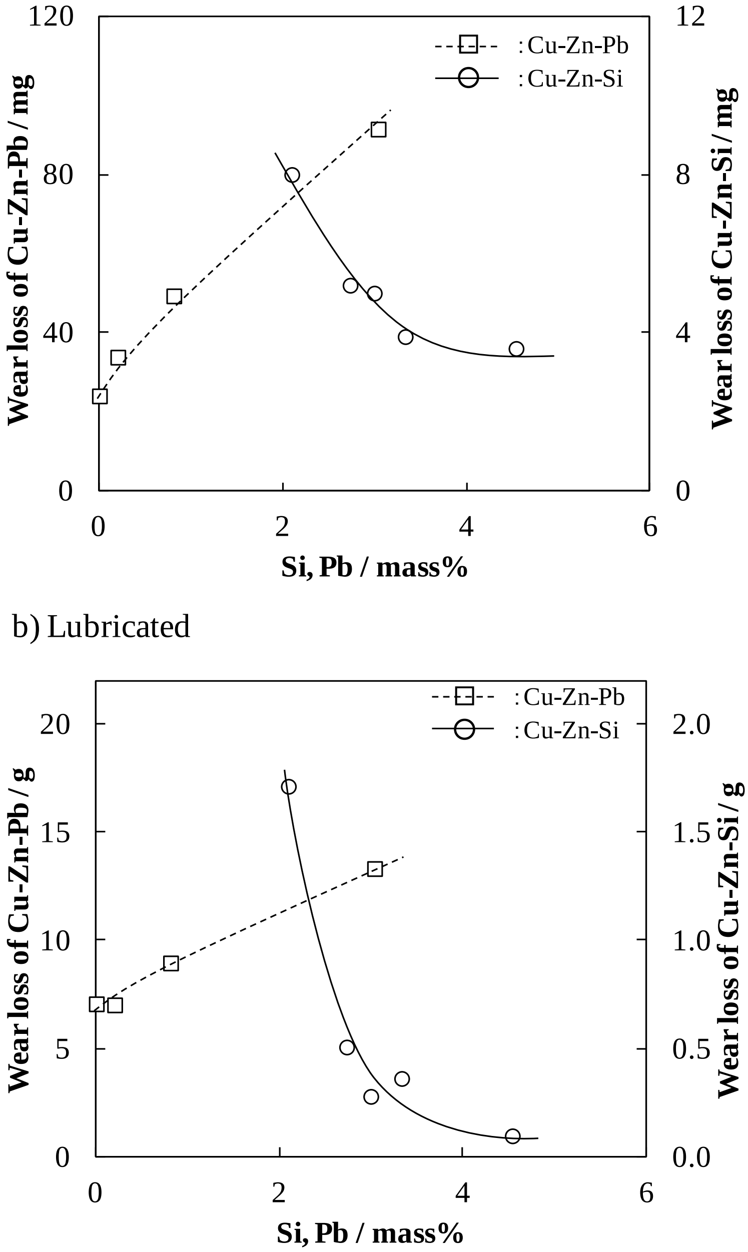


Fig.5 Wear Loss as a Function of Si or Pb. a)Non-Lubricated, B)Lubricated.

- Wear loss increases linearly with an increase in the amount of Pb for non-lubricated and lubricated Cu-Zn-Pb alloy.
- With Cu-Zn-Si materials wear loss greatly decreases with an increase of Si up to about 3% after

which wear loss decreases at a lower rate.

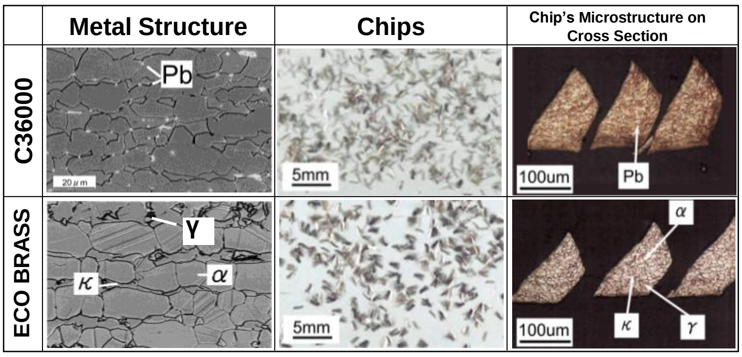
- Comparing wear loss of ECO BRASS containing 3% Si and C36000 containing 3% Pb, we can see the considerable reduction in wear loss for ECO BRASS, 1/18 (non-lubricated) of C36000 and 1/44 (lubricated) of C36000 showing that ECO BRASS has strong wear resistance.

3-3. Machinability

Fig.6 shows the chip breakup mechanism of ECO BRASS in comparison to C36000.[3)]

Chip Breakup Mechanism

Material	Chip Breakup Mechanism				
C36000	**Dispersed Pb (low melting point and soft)**	→	**Melting Pb by machining heat**	⇒	**Breakup**
ECO BRASS	**Separating hard γ and κ phases**	→	**Stress concentrating points for machining**		



Chips by working of γ and κ phases as stress concentrating point.

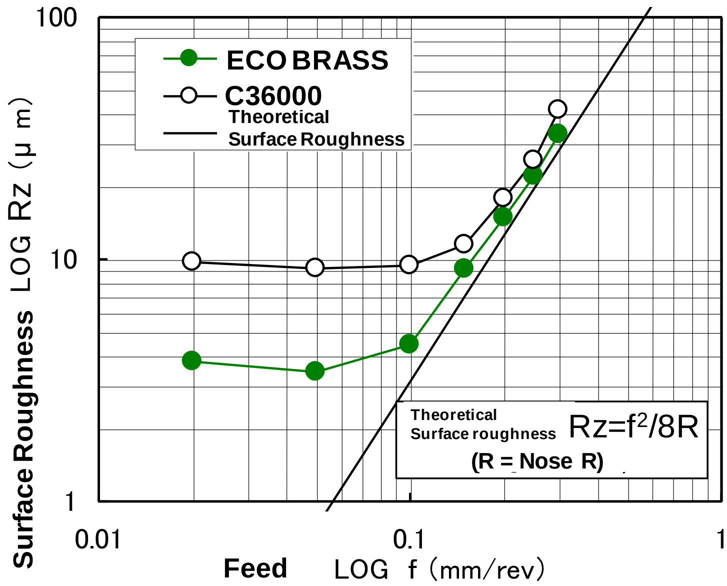
Fig.6 Chip Breakup Mechanism.

- The chip breakup mechanism of ECO BRASS is different from C36000. In the case of ECO BRASS, stress is concentrated on the hard phases of κ and γ and chips are broken.
- The thickness of ECO BRASS chips and the cross sectional shapes are near equal to those of C36000.
- Cutting force depends largely on the cross sectional shape of chips and the strength of the material (shear stress).
- The cutting force of ECO BRASS is almost 1.4 times of that of C36000 because the cross sectional shape of chips is almost the same and the strength of ECO BRASS is almost 1.4 times of that of C36000.
- Machinability rating is calculated from the reciprocal cutting force and so the machinability rating of ECO BRASS is about 70-75%.
- Cutting force is one criterion for machinability and cannot necessarily be linked to productivity, tool life, or ease in handling chips from mass production.

- Productivity of ECO BRASS will improve by adjusting the machining conditions because a cross sectional shape of break-up chips is same as C36000.

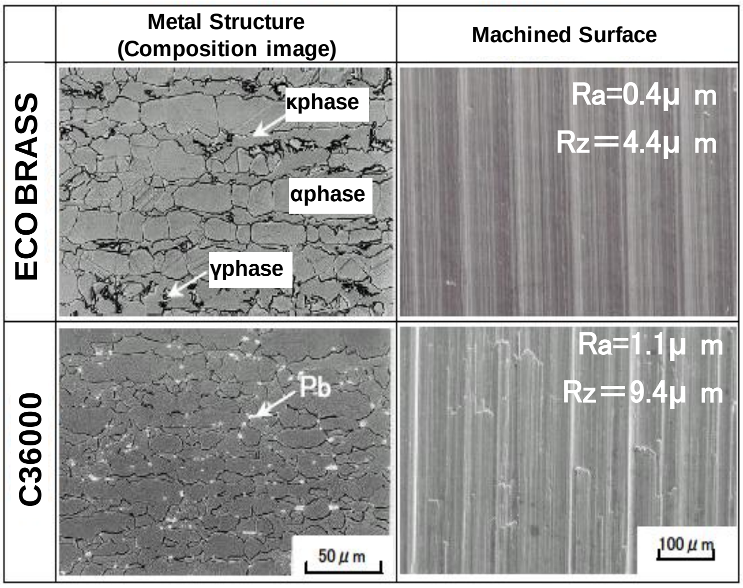
3-4. Machined Surface Roughness

Fig.7 shows relationships between feed and surface roughness. **Fig.8** shows the metal structure and machined surface.[4)]



Dry method, Cutting Speed 150m/min., Depth of cut 1.5mm, Nose R 0.4mm

Fig.7 Influence on Surface Roughness by Feed.



Dry method, Cutting Speed 150m/min., Depth of cut 1.5mm, Feed 0.1mm/rev., Nose R 0.4mm

Fig.8 Metal Structure and Machined Surface.

- We evaluate machined surface roughness through Ra (arithmetical mean deviation of the assessed profile) value and Rz (maximum height of profile) value regulated in standard JIS B 0601 (2013).
- We evaluate state of the machined surface with a secondary electron image.
- Relationship between feed and surface roughness approaches theoretical surface roughness as feed gets higher.
- With ECO BRASS, theoretical surface roughness can be obtained with a smaller feed than C36000.
- ECO BRASS does not contain soft particles that tear during machining resulting in a smoother machined surface compared to C36000.
- The machined surface of C36000 is rough and appears torn by the soft lead particle.
- Surface roughness of ECO BRASS is less than half of C36000 if the machining conditions listed in Fig. 8 are applied.

3-5. Machinability of Micro Drill

Fig.9 shows drilling condition and result of continuous machining on ECO BRASS for hole with size of φ1.0×10mm, **Table2** shows comparison of drilling result of ECO BRASS and C36000.[5)]

Φ1.0 Micro Drill

Machine	KITAMURA MyCenter-3XiH
Work Piece	ECO BRASS ⌀60×30t (HV 152)
Coolant	Soluble Cutting Fluid

Size	⌀1.0
Depth	10mm
Drill	RYOCO SEIKI ZH380-ViO
Material	Carbide
Drilling Speed	47m/min.
Feed	0.10mm/rev.
Drilling Time	4.9 sec

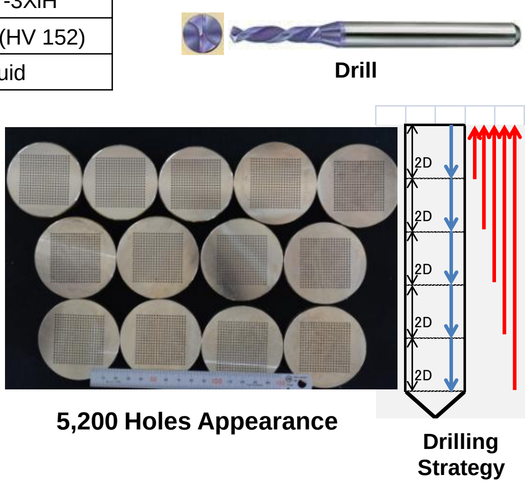


Fig.9 Drilling Condition and Result.

Table2 Comparison of Drilling Result.

Material	C36000	ECO BRASS	ECO BRASS	ECO BRASS
Name	Deutsches Kupferinstitut	Deutsches Kupferinstitut	A	B
Drill diameter / mm	1.0	1.0	1.0	0.99
Depth / mm	10	10	10	10
Machine	Excello XHC 241	Excello XHC 241	KITAMURA MC-3XiH	DMG MORI SEIKI NV5000α
Drill	Gühring DIN 338 R-N	Gühring DIN 338 R-N	RYOCO SEIKI ZH380-ViO	MMC MWS0099XB VP15TF
Drill Material	HSS	HSS	Carbide	Carbide
Coolant	Soluble	Soluble	Soluble	Soluble
Oil Holes	×	×	×	○
Drilling Speed / m/min.	40	40	47	40
Feed mm/rev.	0.02	0.02	0.1	0.1
Drilling step	1	10	5	1
Drilling time / sec	3	13	5	2
Pieces	≧1000	200→break	≧5200	≧1000

- We selected tools and machining conditions to implement the test considering the difference in machining mechanism and machining resistance which is 1.4 times higher than that of C36000 due to material strength as mentioned above.
- With conditions under A in Table 2, we confirmed the continuous processing of 5,200 holes is possible with; 1. Use of carbide drill, 2. Introduce 5 steps drilling, 3. Feed at 0.1mm/rev. Drilling time is about 5 seconds per hole even though we do not use special tool and/or equipment. Thus, we judge productivity issues are minimal.
- With conditions under B in Table 2, we confirmed the processing of 1,000 holes is possible by using carbide drill with internal coolant supply and without drilling step.
- Micro drilling of ECO BRASS has commercially required drill life and productivity is almost equal to C36000 with appropriate machining conditions.
- The study by Kato[6)] demonstrated that the continuous processing of 8,000 or more holes is possible in testing the micro drilling of ECO BRASS with size of φ0.2×2.0mm with appropriate machining conditions and drill selection.

3-6. Machining Examples of ECO BRASS

Fig. 10 shows machining examples of valve stem and vehicle component (total length of 21mm).
Fig. 11 shows machining example of ECO BRASS product with a small hole of φ1.5× 8mm and a side hole of φ3×8.4mm (total length of 40mm).

- These are just a few examples of machining conditions which we believe are informative in mass production machining of small components.

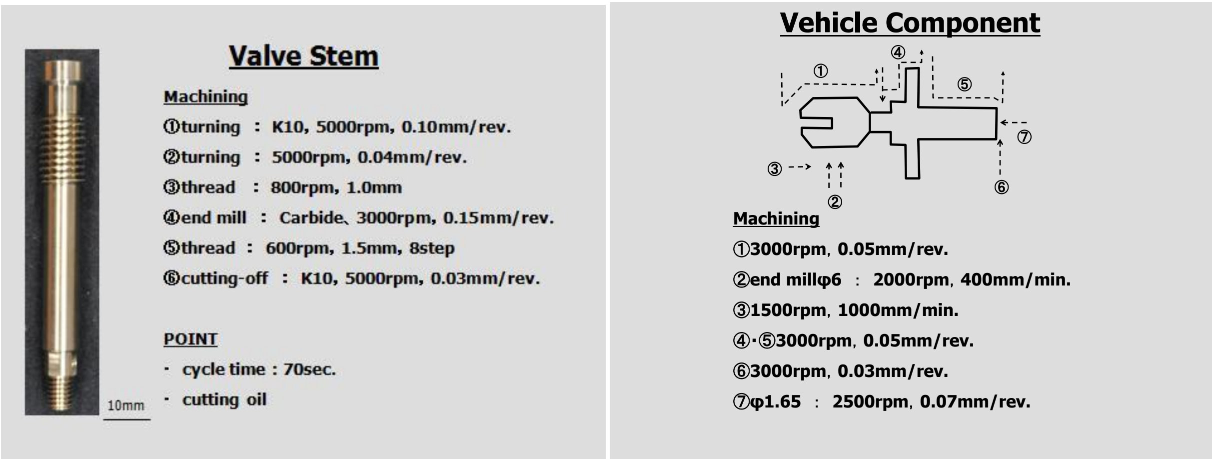
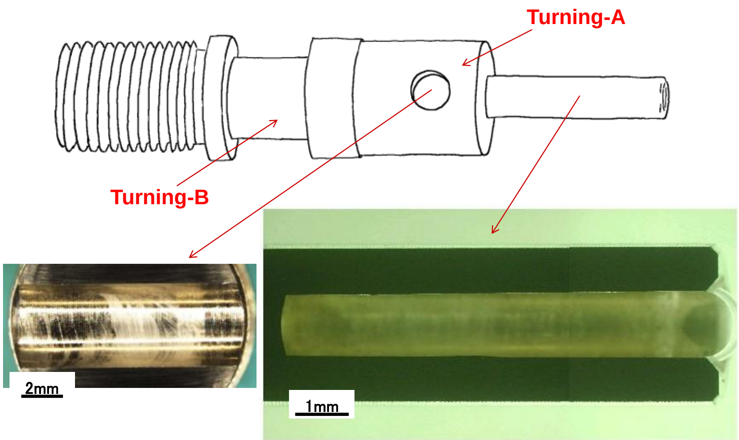


Fig.10 Machining Examples.

Machining example



No damage found with φ1.5 drill after machining 200 times.

Machining condition（Lubricated）

1. Turning-A： 3,800rpm, 0.07mm/rev. ,ISO K-10
2. Turning-B： 3,000rpm, 0.03mm/rev. ,ISO K-10
3. Thread： 3,000rpm, 4 step
4. φ3.0 drill： 4,000rpm, 0.075mm/rev.
5. φ1.5 drill： 5,000rpm, 0.04mm/rev., OSG(EX-SUS-GDS)
6. Cutting off： 3,000rpm, 0.02mm/rev. ,ISO K-10

Fig.11 Machining example.

Fig.12 shows the inside surface of sliding components of a vehicle air conditioner. In both examples, finish cutting has been carried out.

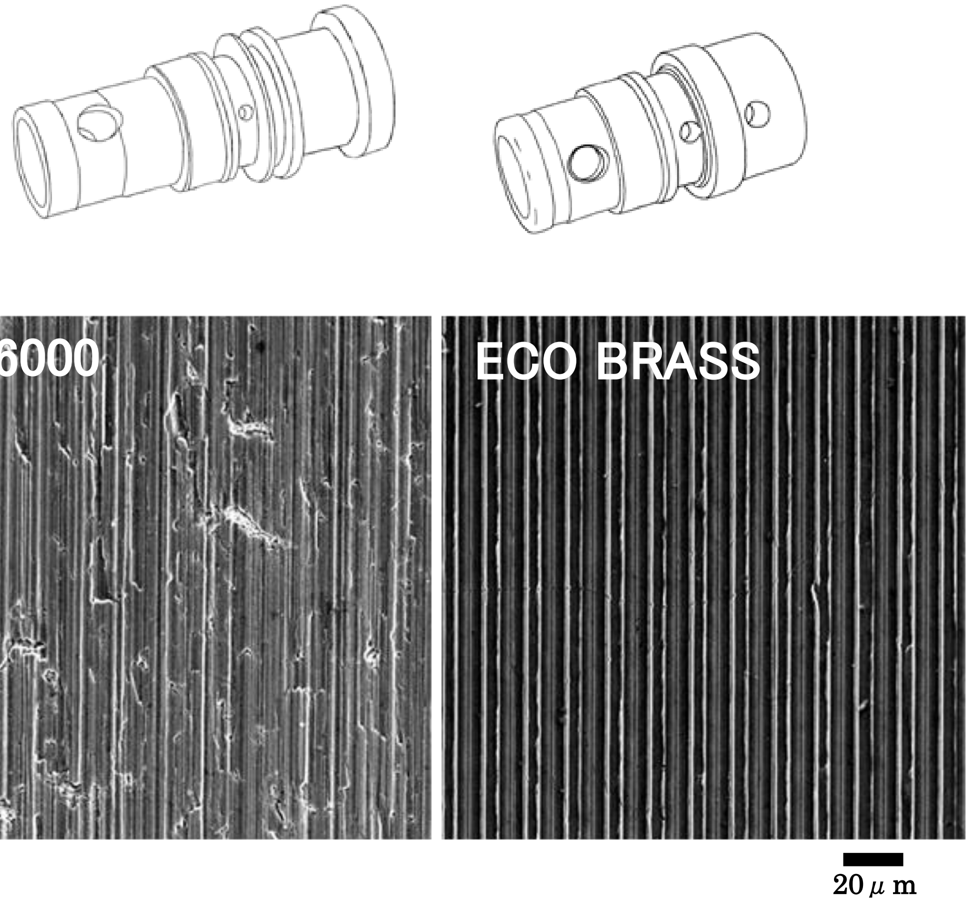


Fig.12 Inside Machined Surface of Sliding Components.

- With appropriate mass production conditions applied to each material, inside the machined surface of ECO BRASS is uniform in contrast to C36000 which is torn due to Pb particles in C36000.
- Our customers' evaluation of ECO BRASS machined in mass production found that the productivity of ECO BRASS is more than 90% of that of C36000 and that the tool life is about 80% of C36000.
- In order to further improve productivity, a change in specification for the machining tool, such as coating is being considered.

Consequently, ECO BRASS is a high-performance material with excellent properties in strength with no issues in mass production machining which allows thinning of the wall and downsizing of electrical and electronic components. The lighter weight of components and reduction of copper consumption has various merits aside from being lead-free contributing to the sustainable society.

4. Supply Distribution / Licensing Status

Fig.13 is a mapping of the ECO BRASS licensees.

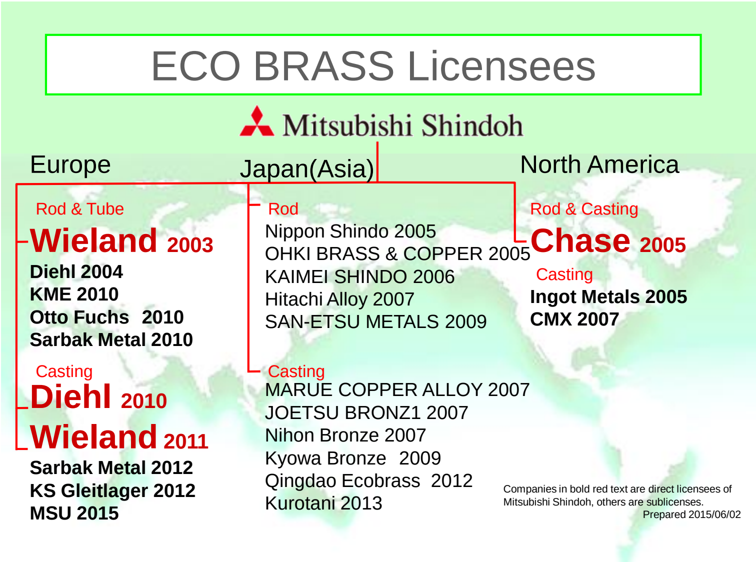


Fig.13 ECO BRASS Licensee Mapping.

- Since 2003, we have made licensing agreements with 25 companies in total.
- In Asia, we licensed five rod and five casting manufacturers in Japan and a subsidiary in China.
- In Europe, we made agreements with five rod manufacturers and five casting manufacturers including sub-licensees.
- In North America, we licensed one rod manufacturer and three casting manufacturers including sub-licensees.
- We established an ECO BRASS supply chain providing material comprising of the same composition and quality in all the major producing countries around the globe.

5. Summary

- More than 150,000 tonnes of ECO BRASS has been sold in Japan, North America and Europe in total and it is widely used as lead free copper alloy for drinking water, vehicle and electrical and electronic components.
- In the first half of 2015, sales in Japan, North America and Europe achieved 3,000 mt/mo, and European rod sales have markedly increased. Using ECO BRASS leads to a reduction of about 1,000 tonnes of lead per year in the material stage.
- Since the early 21st century,
  - A) ECO BRASS has been used under various environments, and consequently high reliability such as durability or corrosion resistance has been proven.
  - B) For recycling, segregation management system has been established for smooth recovery and recycling of scrap.
  - C) The productivity of ECO BRASS and the tool life are near equal to that of leaded copper alloys under appropriate machining conditions.

- It is not possible to replace all leaded copper alloys with ECO BRASS but the shape of fixtures or components for drinking water is similar to that of electrical home appliances such as refrigerators, washing machines or air-conditioners which contain liquid or gas. Thus we believe ECO BRASS can substitute leaded brass for many of these applications.
- ECO BRASS is a lead-free high performance copper alloy with superior properties to currently used alloys. ECO BRASS has high strength, excellent machinability, exceptional wear resistance, good creep properties, and superior corrosion resistance allowing for thinner wall components and weight reduction. Lead-free, lighter and stronger parts can reduce the environmental burden on society.

6. References

1) M. Takasaki, ”Wear Characteristics of Free Cutting Copper Alloys”, J.JRICu ,53,2013,88-94.

2）M. Takasaki, T. Hokazono, Y. Gotoh, K. Oishi ”Wear Characteristics of Free Cutting Copper Alloys Under Lubrication”, J.JRICu ,54,2014,146-151.

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4）K. Oishi, ”Development of Pb free copper alloy (Cu-Si-Zn alloy) for Casting, Forging, and Machining”, SOKEIZAI, 45, No.12, 2004, 28-32.

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6）H. Kato, S. Nakata, N. Ikenaga, H. Sugita,” Improvement of Chip Evacuation in Drilling of Lead-Free Brass Using Micro Drill”, Int. J. of Automation Technology Vol.8 No.6, 2014, 874-879.