Mitsubishi Shindoh Co.,Ltd.
4-7-35, Kita-Shinagawa, Shinagawa-ku, TOKYO 140-8550
TEL +81-3-5449-2511 // FAX +81-3-5449-2525

ELV Stakeholder Consultation

ECO BRASS

ECO BRASS was developed as a Pb-free copper alloy and total sales have exceeded 110,000 tonnes. ECO BRASS is mainly used for water meters, valves and other components in water supply sector, but it is also selected by the automobile industry. ECO BRASS has been used for components in more than 16 million cars. ECO BRASS is not only Pb-free but also a high performance copper alloy which is superior in strength equivalent to stainless steel, machinability, and corrosion resistance. These properties satisfy economic efficiencies of society by reducing weight and thickness of components, while reducing its environmental burden.

Executive Summary

This paper tries to alleviate concerns that Pb-free brass alternative materials are not available or not suitable for the automotive sector.

We show that ECO BRASS is widely available from various suppliers, that the trend in sales have rapidly increased, and at this time stand at about 3,000 tonnes per month. Our data shows that since 2012 the annual increase is nearly doubling and that ECO BRASS is no longer a minor alloy but the major Pb-free alternative.

ECO BRASS has unique properties and is suitable for forging, machining, and casting. Examples of all these processing methods have been provided to demonstrate the industry can adapt to Pb-free materials, can realize production gains, and can utilize advanced material properties to cut costs and make better products. Many of the examples are water supply related, simply because the sector is leading the world in Pb-free technology.

While segregating Pb-free material from leaded brass will have the benefit of saving cost and energy of lead (Pb) removal, recycling ECO BRASS does not have the impact bismuth brass does should it be mixed in the traditional scrap stream. Silicon, the chipbreaker in ECO BRASS, can easily be removed in secondary recycling.

With this paper, we hope to demonstrate that despite resistance to change, that ultimately lead (Pb) will be eliminated as an additive to copper alloys for the automotive and electronic sectors and that by removing the 4% exemption will benefit society as it has for the water supply industry.

I. Market Trend

1. Status of License

- Fig.1 is a mapping of the ECO BRASS licensees.
- Since 2003, we made license agreements with 26 companies in total.
- In Asia, we licensed six rod and five cast manufacturers in Japan and one cast manufacturer in China.
- In Europe, we made agreements with five rod manufacturers and four casting manufacturers including sub-licensees.
- In North America, we licensed one rod manufacturer and four casting manufacturers including sub-licensees.
- We established an ECO BRASS supply chain providing material comprised of the same composition and quality in all the major producing countries around the globe.

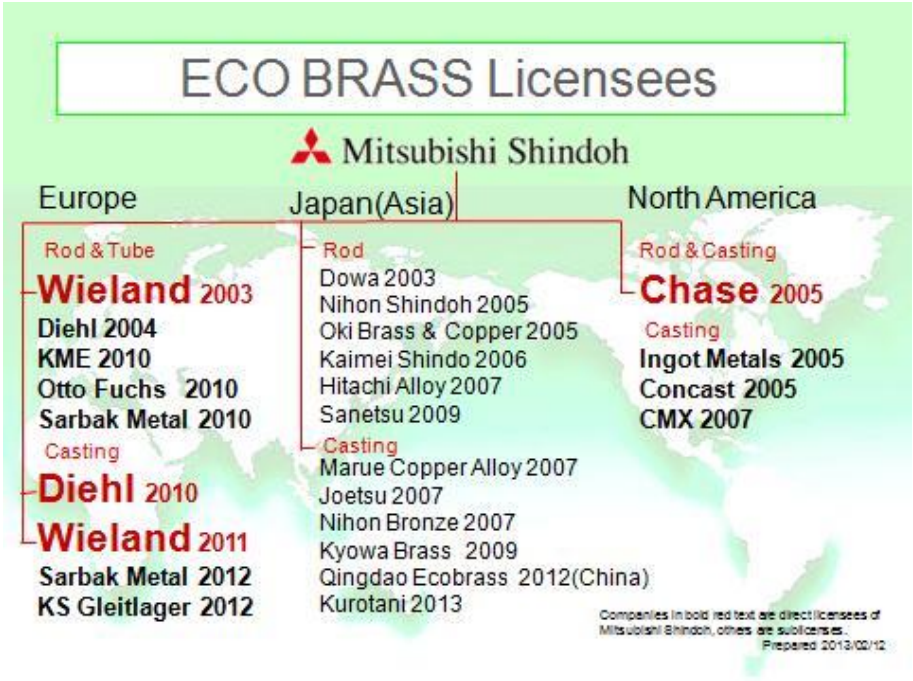


Fig.1 ECO BRASS Licensee Mapping

2. Current status of regulations for lead (Pb)

- Table 1 lists relevant regulations issued since 2010.

Table 1 Legislation and Regulation for Lead (Pb)

Date	Item	Content
2010.1	AB1953	0.25% weighted average Pb max US California, Vermont, others
2010.2	CPSIA	0.03%Pb max. in children's products
2011.8	CPSIA	Pb max.(0.03% => 0.01%), if technically feasible
2012.7	NSF61	Annex F 15ppb => 5ppb
2013	TWVo	EN15664:Pb leachate 10μg/L(10ppb)
2014.1	S3874	US national legislation: 0.25% weighted average Pb max

- Drinking water regulations tend to be strengthened every year as lead (Pb) has a direct influence on human health.
- US regulation S3874 enforced from January 2014 restricted the lead (Pb) content of drinking water components to lower than 0.25% substantially increasing the demand for Pb-free materials.
- Worldwide sales of ECO BRASS have increased in conjunction with the growing enforcement of lead (Pb) regulations.

3. Trends in Sales of ECO BRASS

- Fig. 2 shows the steady growth of global sales and Fig. 3 shows the area breakdown of the first half of 2014 sales.
- Sales have increased steadily since 2007 as regulation of lead (Pb) has tightened.
- Total global sales to June 2014 amounted to 112,000 tonnes.
- First half (January - June) 2014 global sales totaled 16,125 tonnes with a monthly average of 2,688 tonnes.
- First half 2014 sales increased 3.5 times compared to 2009 when the previous evaluation of the ELV lead (Pb) exemption was carried out.
- Regional ratios: ASIA: 19% Europe: 37%, North America: 44%.
- Fig. 4 shows 2014 first half global sales breakdown of rod and Fig. 5 shows sales of rod by region.
- In 2014 first half (January - June), global sales came to 12,528 tonnes and monthly average is 2,088 tonnes.
- The monthly average (2,088t/m) equals 3% of the production of copper alloy rod containing lead (Pb) in Japan, USA, and Europe.
- Regional ratio ASIA: 10%, Europe: 46%, North America: 44%
- European rod sales have markedly increased with 2014 first half sales (968t/m) 3 times greater than sales in 2012 (317 t/m) and exceeds sales in North America (908t/m).
- Fig. 6 shows 2014 first half global sales breakdown of casting and Fig. 7 shows sales of casting by region.
- In the first half of 2014 (January to June) global sales of casting material totaled 3,597 tonnes with a monthly average of 599 tonnes.
- Regional ratio ASIA: 49%, Europe; 5%, North America 46%
- Global sales of casting materials have greatly increased in North

America with first half 2014 sales totaling 275t/m. This is a 5.6 times increase over 2012 sales of 49 t/m. We believe the impact of the material will be great considering the substantial size of the North American casting market.

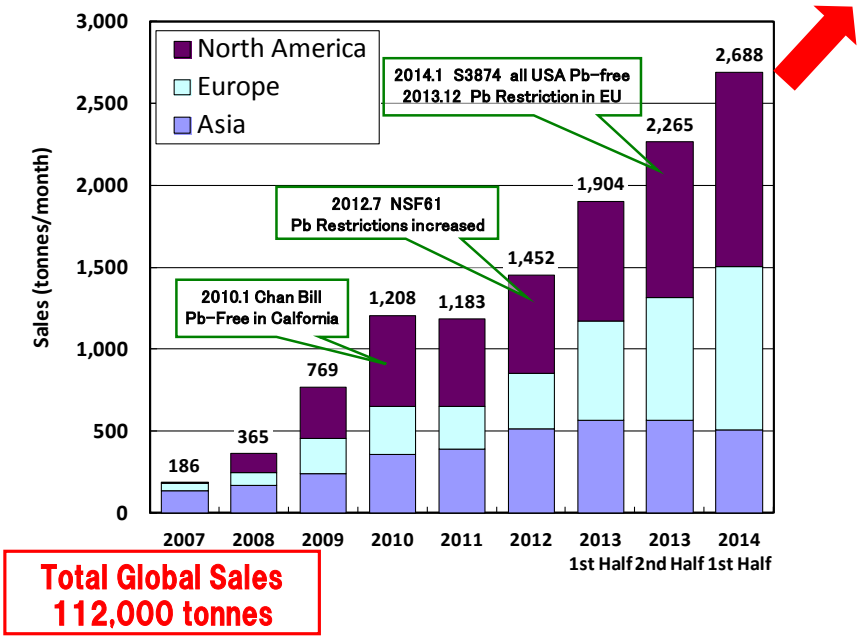


Fig.2 Growth of Sales

Fig.3 Area Breakdown First Half 2014 Global Sales

Fig.4 2014 First Half World Sales Breakdown of Rod

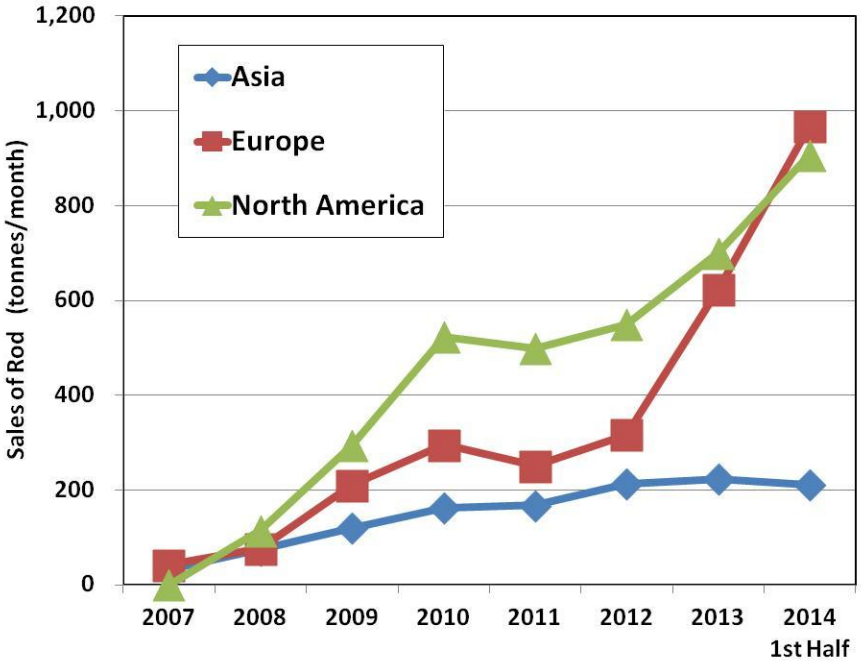


Fig.5 Sales of Rod by Region

Fig.6 2014 First Half World Sales Breakdown of Casting

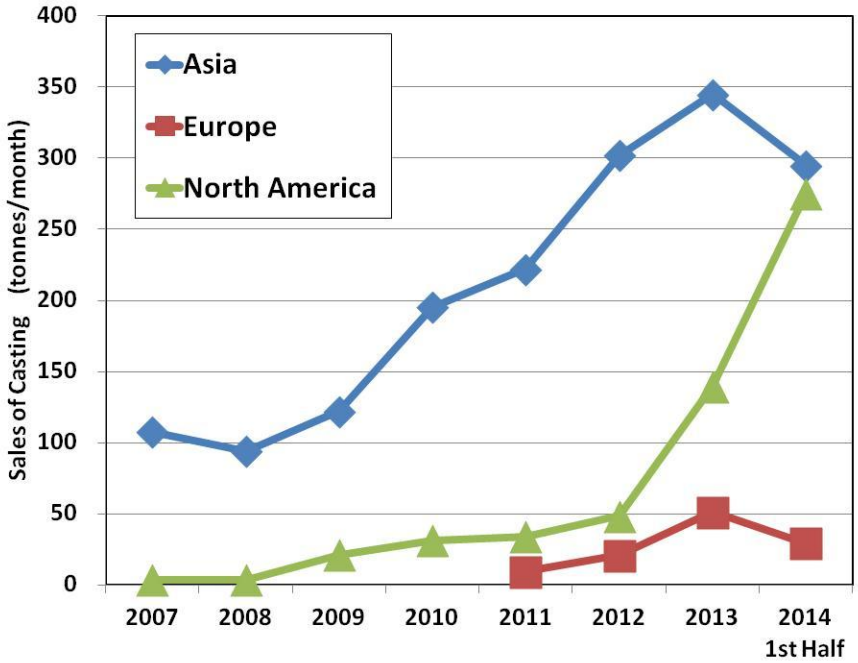


Fig.7 Sales of Casting by Region

4. Examples of changes in sales in Japanese market for ECO BRASS products

Changes in Sales of Rod

- The most common use of rod in the automotive sector is the control

valve for variable displacement air-conditioner compressors.

- This valve was originally made from leaded brass rod C36000 (equivalent JIS H3250 C3604), however, due to wear resistance and cavitation erosion, there were many part failures resulting in defective air conditioners.
- ECO BRASS is superior in cavitation erosion and wear resistance [1, 2] thus, about 40% of the market switched to ECO BRASS.
- Fig.8 shows changes in sales of control valves for variable displacement air-conditioner compressor, and Fig. 9 shows a sketch of the part.
- ECO BRASS was selected in 2007, and current monthly sales are about 100 tonnes. We estimate the number of automobiles using ECO BRASS parts might have come to 16 million calculated from weight of material sold.
- We presume material change from leaded brass C36000 shall increase.
- ECO BRASS is also used for check valves in variable displacement air-conditioner compressors.
- Fig.10 shows changes in sales of check valves for variable displacement air-conditioner compressor, and Fig. 11 shows a sketch of the part.
- This is a very small part weighing just 0.5g. Estimated sales of automobiles using this ECO BRASS part is about 14 million calculated from weight of material sold. We are confident that the demand for ECO BRASS for this application will continue to increase.

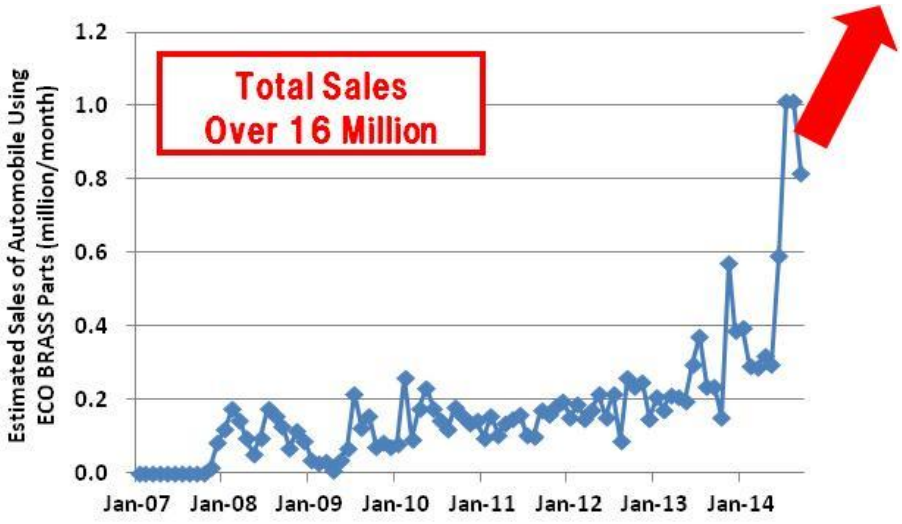


Fig.8 Sales of Control Valve for Variable Displacement Air-conditioner Compressor

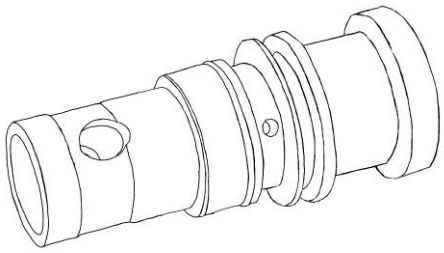


Fig.9 Drawing of Control Valve for Variable Displacement Air-conditioner Compressor

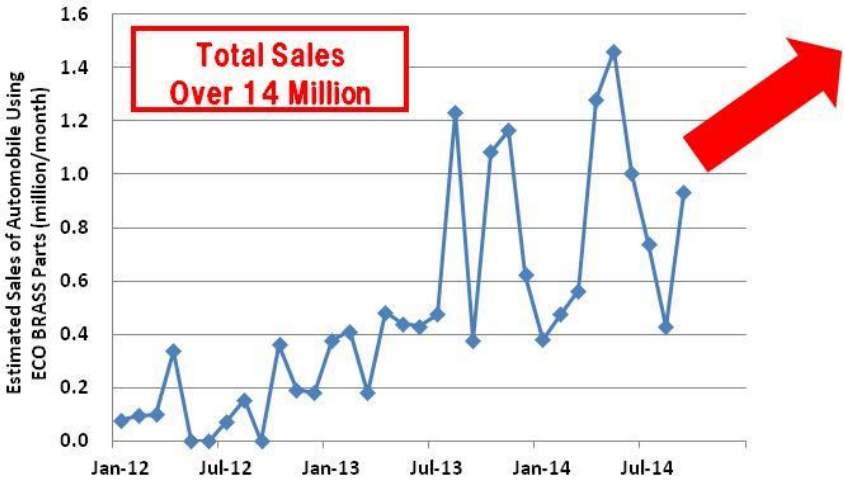


Fig.10 Sales of Check Valve for Variable Displacement Air-conditioner Compressor

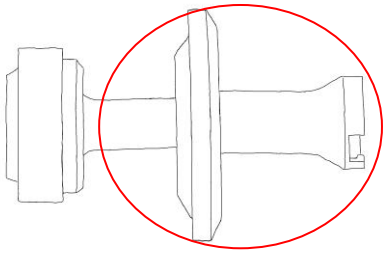


Fig.11 Drawing of Check Valve for Variable Displacement Air-conditioner Compressor

Changes in Sales of Forged Product

- Because of the NSF14 standard for dezincification resistance and stress corrosion cracking resistance for water faucet parts the consumption of ECO BRASS continues to increase.
- Components of fire suppression sprinklers are in constant contact with water and corrosion resistance, stress corrosion cracking

resistance are important qualities. Hot forged ECO BRASS is selected for fire suppression sprinkler parts to meet stringent corrosion resistance requirements.

- Fig.12 shows the changes in sales of fire suppression sprinkler parts and Fig. 13 shows a sketch of the part.
- Sales volume of this part came to 16 million or more and part reliability has been established.
- There are no known issues with hot forging ECO BRASS, no known problems with mass production by machining.
- We received positive comments from the companies that have established manufacturing conditions suitable for hot forging and machining, that the productivity of ECO BRASS parts is the same as conventional products.

Fig.12 Sales of Forged Fire Suppression Sprinkler Parts

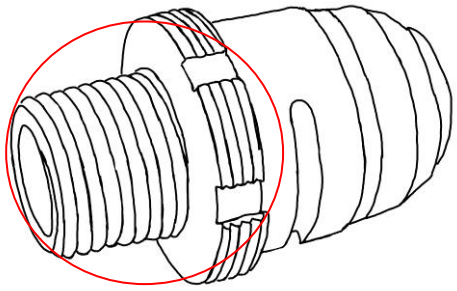


Fig.13 Drawing of a Forged Fire Suppression Sprinkler Part

Changes in Sales in the Casting Product

- Water meters have the greatest sales in the cast product sector.
- Fig.14 shows share of water meter and Fig.15 shows a sketch of a meter body.
- Corrosion resistance and erosion corrosion resistance are important qualities for water meters.

- C83600 (85Cu-5Sn-5Pb-5Zn) used to be the most common material for water meter bodies.
- At the change-over to Pb-free materials, bismuth (Bi) bronze (C89833, 88Cu-5Sn-2Bi-5Zn) was initially selected and it used to have about 80% share of market. However, as the yield and productivity of ECO BRASS is equivalent to C83600, the market switched to ECO BRASS which now accounts for about 85% of the market.
- Water meters are produced by casting and machining. According to casting manufacturers, it is possible to improve the yield rate and productivity of ECO BRASS to the same level as C83600 by optimizing manufacturing conditions..

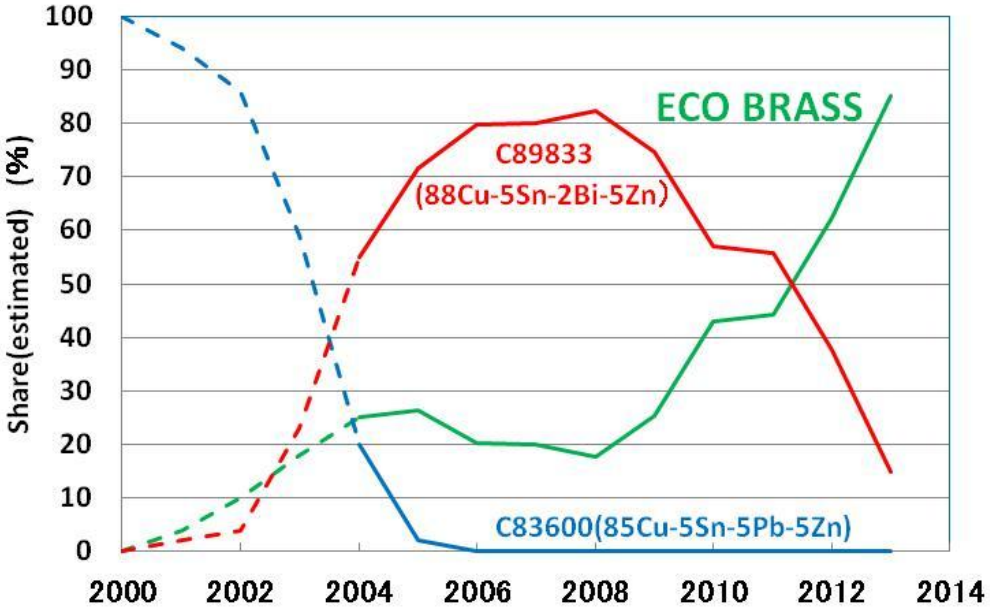


Fig.14 Share of Water Meters

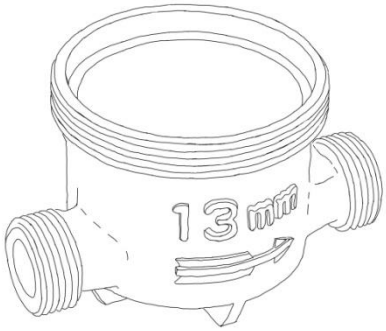


Fig.15 Drawing of a Water Meter

- Table 2 lists a machinability index number of for C83600, bismuth bronze (C89833) and ECO BRASS based on test data from a public laboratory. The index number shows the difficulty in machining using

C83600 as the base with a value of 100. From this data it can be see that the machinability of ECO BRASS is better than that of bismuth bronze and it is equivalent to C83600 under appropriate cutting conditions.

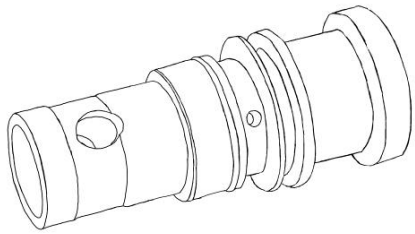
Table 2 Machinability Index (%)

Alloy	100m/min.		200m/min.	
	Rough	Finish	Rough	Finish
JIS CAC406 C83600	100	100	100	100
JIS CAC804 ECO BRASS	94	80	87	77
JIS CAC902 Bi Bronze	82	87	86	83

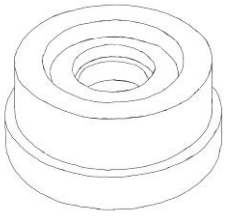
Rough feed: 0.2mm/rev., depth of cut: 1.0mm
Finish feed: 0.1mm/rev., depth of cut: 0.1mm

5. Example of applications for automobile parts

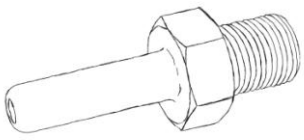
- Fig.16 shows some applications for automobile parts.
- ECO BRASS is often selected as a Pb-free replacement material but also to gain high performance properties such as high strength and wear resistance.



Control Valve for Variable Displacement Air-conditioner Compressor



Pressure Sensor



Relief Valve

Fig.16 Examples of Automobile Parts Selected for High Performance

6. Examples of applications for other industries

- ECO BRASS is used for products in many other industries. Fig. 17 shows some examples.

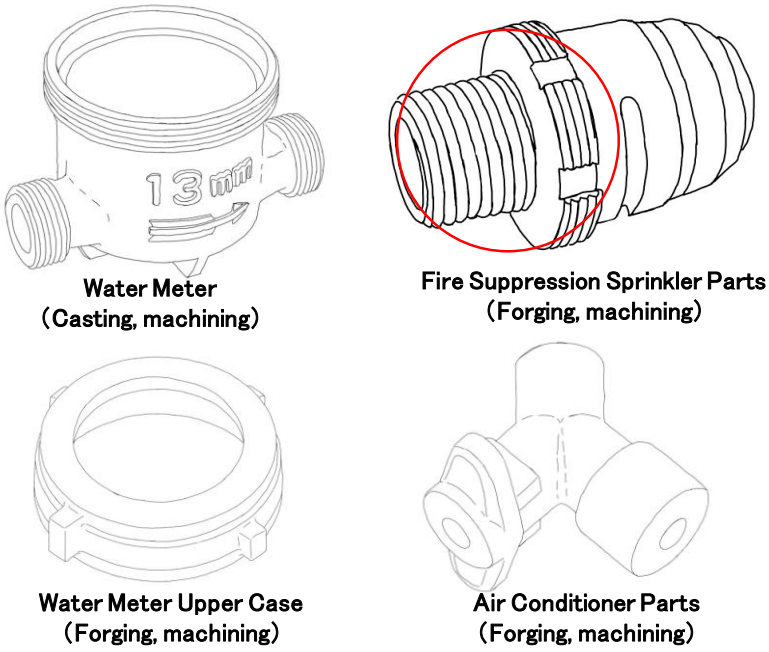


Fig.17 Examples of Products Made from ECO BRASS

II. Detailed Properties of ECO BRASS

- Table 3 shows the properties of ECO BRASS compared to C36000 (equivalent JIS H3250 C3604).
- Fig. 18 shows the stress-strain curve of extruded materials, Fig. 19 shows stress-strain curve of cast materials, and Fig. 20 shows creep resistance properties.

Table 3 Properties

	Properties		ECO BRASS	C36000	C36000 ratio
Physical Properties	Specific Gravity		8.30	8.50	0.98
	Melting Point – Liquidus	℃	885	895	0.99
	Melting Point – Solidus	℃	875	880	0.99
	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	–

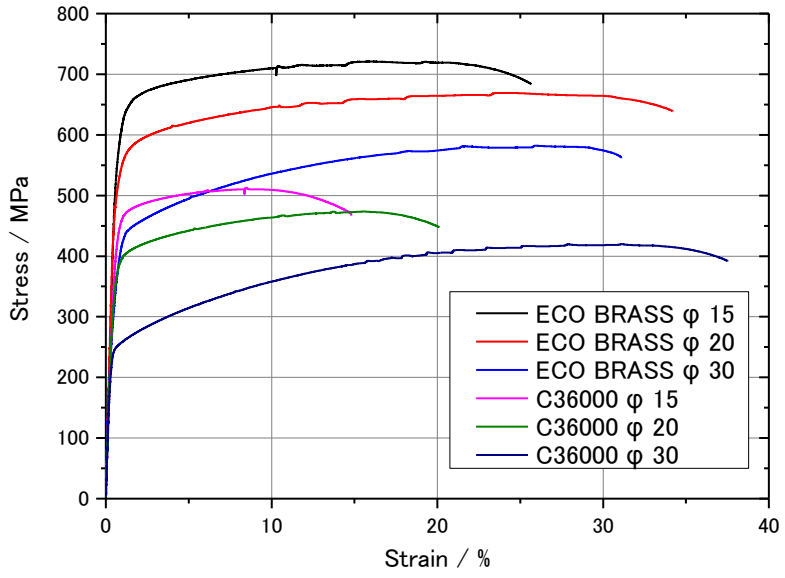


Fig.18 Stress-Strain Curve of Extruded Rods

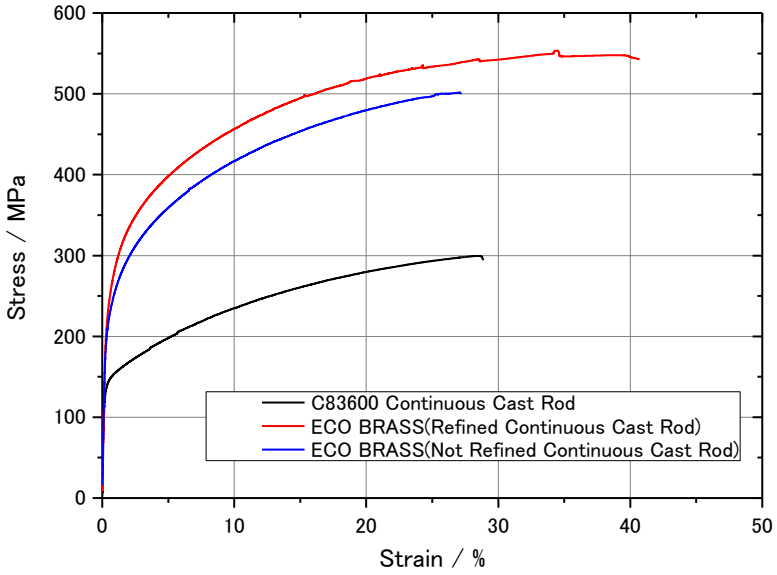


Fig.19 Stress-Strain Curve of Continuous Cast Rods

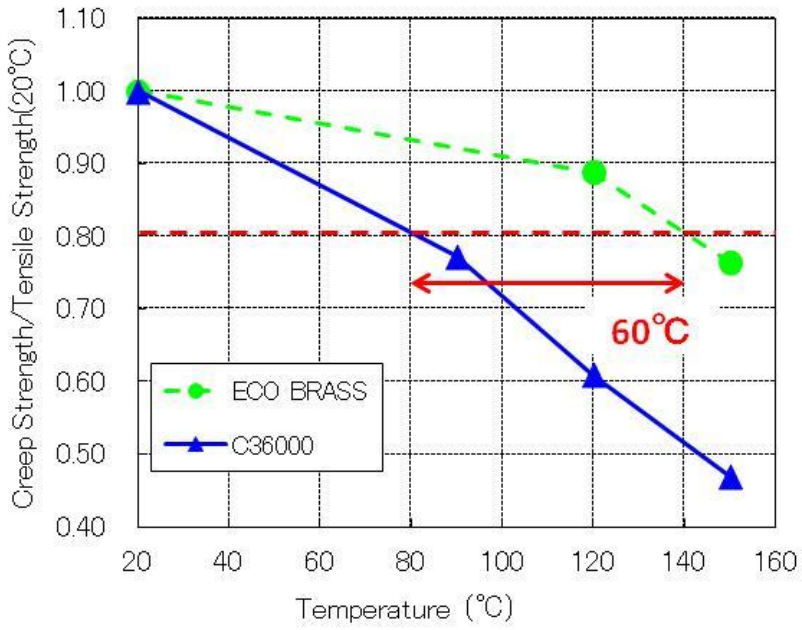


Fig.20 Relation between Temperature and
Creep Strength/Tensile strength(20°C)

- ECO BRASS rod has 1.4 times higher tensile strength than leaded alloy C36000 (see Fig. 18). Because of this, the thickness and weight of components can be reduced.
- The elongation of ECO BRASS rod is equal to or better than leaded brass C36000.
- ECO BRASS castings have 1.7 times higher tensile strength than

C83600 (85Cu-5Sn-5Pb-5Zn). (see Fig. 19) Further, grain refined ECO BRASS castings have 1.8 times higher tensile strength than C83600.

- 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.
- Setting 80% tensile strength as limit of creep strength, ECO BRASS has the same strength of leaded brass C36000 at temperatures 60^{o}C or higher.
- In Figure 20, we can see that the creep strength of ECO BRASS at 140^{o}C is almost equal to that of C36000 at 80^{o}C. ECO BRASS is suitable for high temperature environments such as the engine room.
- ECO BRASS is a copper alloy which is superior in machinability [3), 5), 6), 9), 12), 14)], corrosion resistance [3), 4), 5), 6), 9)], stress corrosion cracking resistance [4), 6), 8)], erosion corrosion resistance [9)], cavitation resistance [1)], Pb leaching resistance [3), 6), 7), 11), 13)], castability [3), 5), 6), 15)], and fatigue strength [20)].

III. Comments on 2010 Report

1. Mechanical Properties of ECO BRASS

- Table 4 lists the tensile strength test results of rod samples used to create the data for Fig. 18 stress strain curve.

Table 4 Mechanical Properties

Item	Diameter	TS/MPa	PS/MPa	EL/%	EC/%IACS	HV5
ECO BRASS	15mm	721	585	24	7.7	215
	20mm	669	508	31	7.8	193
	30mm	584	318	31	7.7	164
C36000 Equivalent JIS C3604	15mm	507	423	17	23.3	157
	20mm	474	354	21	22.9	144
	30mm	420	243	36	26.1	119

- The above table shows that the elongation of ECO BRASS is equal to or more than that of leaded brass C36000.

2. Machinability of ECO BRASS

- Fig.21 shows the outward appearance of chips and cross-sectional microstructure for each alloy, ECO BRASS and leaded brass C36000.
- ECO BRASS consists of 3 phases; α, κ, and γ, and stress is concentrated on hard phases of κ and γ and thus it works as chip breakers.
- Appearance of chips is shear-type, same as C36000 with a thickness

that is equivalent to that of leaded brass C36000 [3].

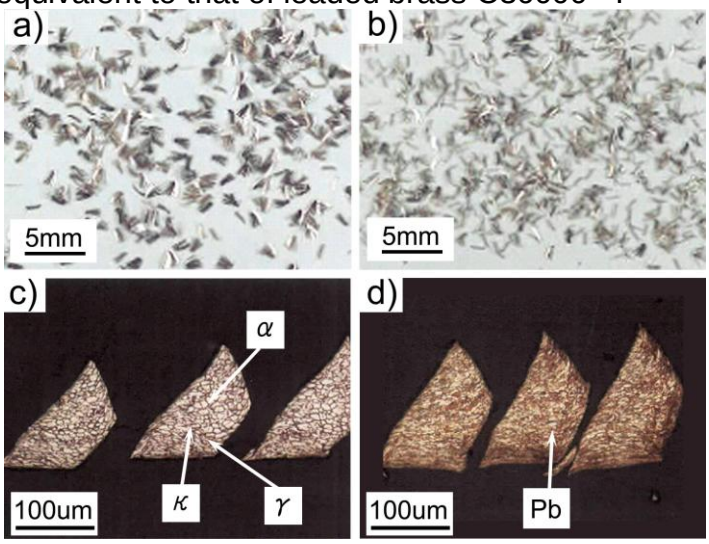
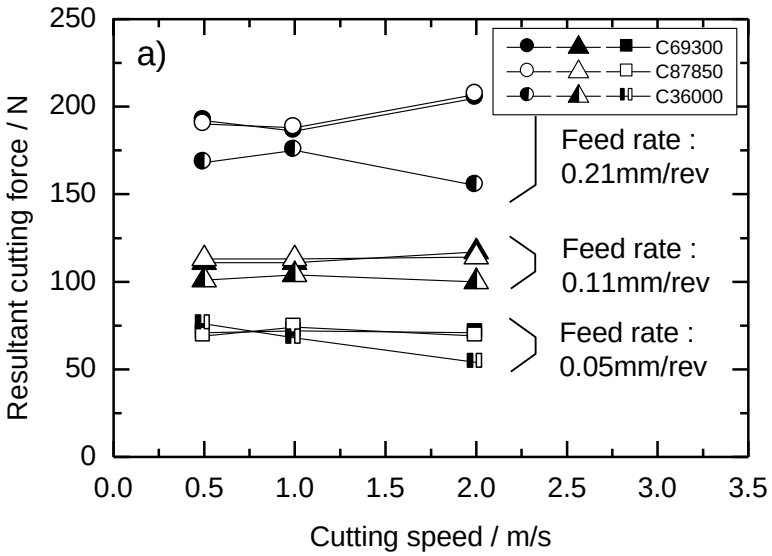


Fig.21 Appearances of Chips on a) ECO BRASS, b) C36000 and Cross-sectional Structures of c) ECO BRASS, d) C36000

- Fig.22 shows relationship between cutting conditions and cutting force.
- As cutting force depends on thickness of chips and shearing stress, cutting force of ECO BRASS is equal to about 1.4 times of that of C36000.



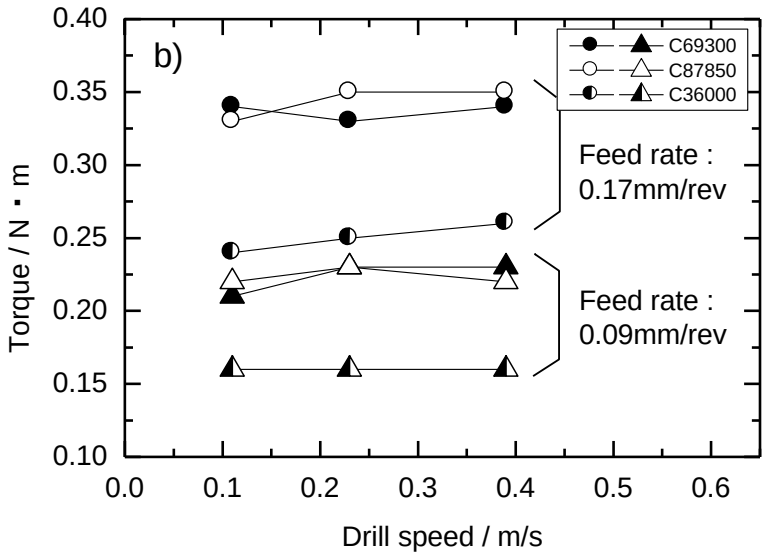


Fig.22 Relationship between Cutting Conditions and a) Cutting Force on Turning, b) Torque on Drilling a) Turning Tool; Carbide (ISO K10), b) Drill; Dia.3.5 mm High Speed Steel (JIS SKH51)

- Fig.23 shows chips of ECO BRASS produced under various cutting conditions, and Fig. 24 shows relationship between number of pieces and tool wear.
- ECO BRASS differs from C36000 in the chip breaking mechanism, therefore it is necessary to adjust the cutting conditions by lowering the cutting force.
- Reducing the cutting speed and increasing the feed results in good chip breaking and should be basis for setting cutting conditions.
- Cycle time can be shortened by making feed larger.
- Tool life when cutting ECO BRASS using tool steel without lubricant is about 70% of that of C36000 [3), 4), 6)].

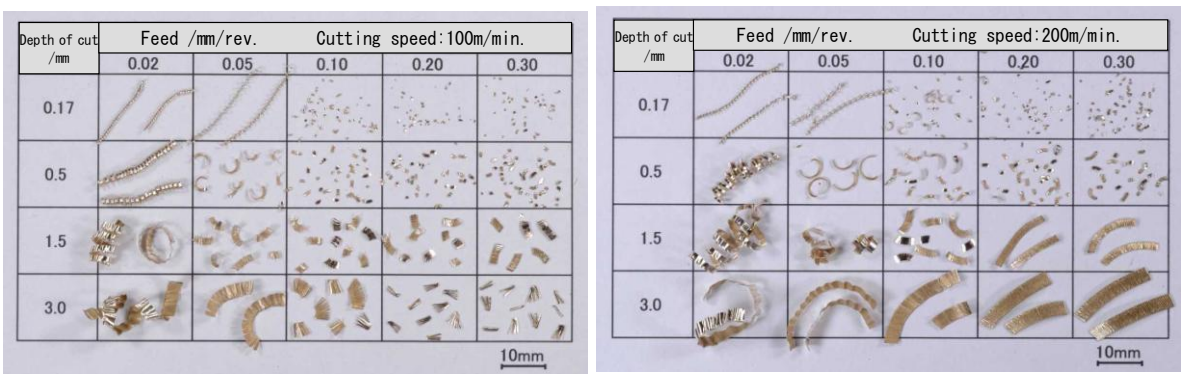


Fig.23 Turning Chips

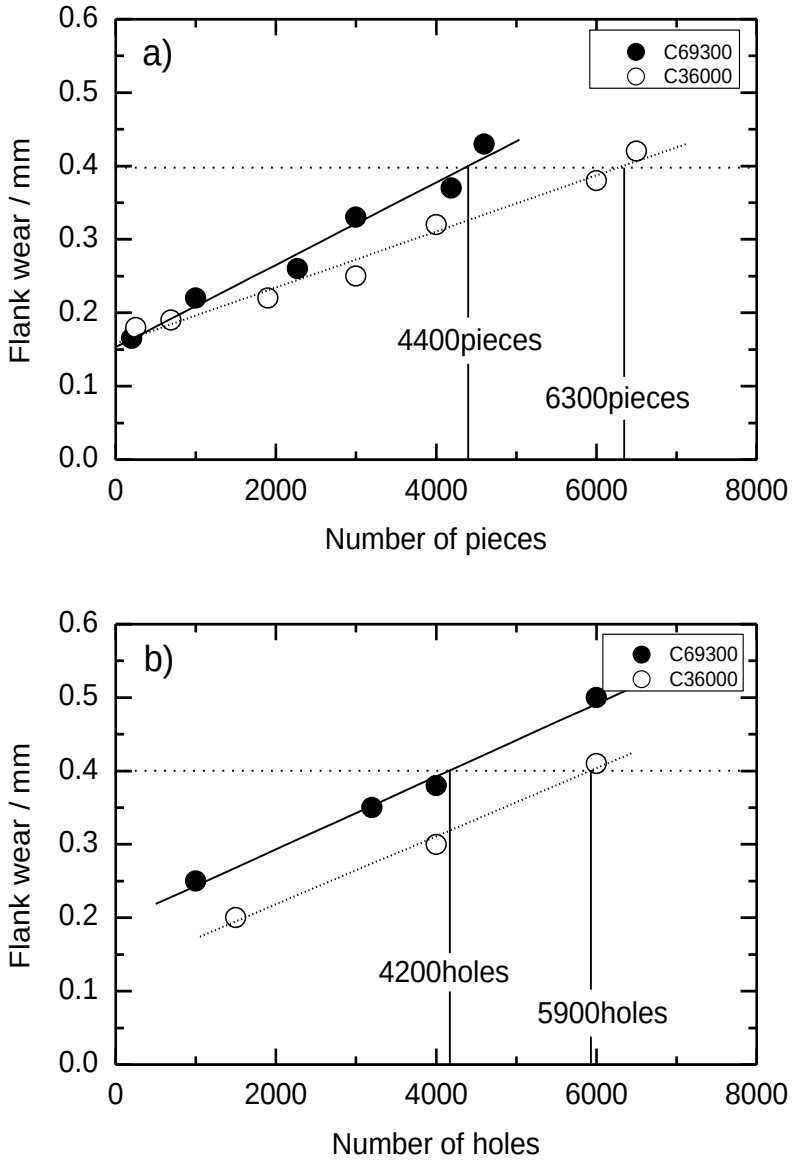


Fig.24 Relationship between tool Flank wear and a) Number of cut pieces, b) Number of drilled holes a) Cutting speed; 1.67 m/s, Feed rate; 0.20 mm/rev, Depth of cut; 2.0 mm, Cutting length; 53 mm/piece, Turning Tool: High speed steel (JIS SKH57), b) Drill speed; 1.31 m/s, Feed rate; 0.20 mm/rev, Drill; Dia.10 mm High Speed Steel (JIS SKH51)

- Productivity of ECO BRASS is equal to that of C36000 by optimizing cutting conditions and cutting tools for each product.
- Fig.25 shows machining condition of valve stem and Fig. 26 shows machining condition of automobile parts.

Fig.25 Machining Conditions of Valve Stem

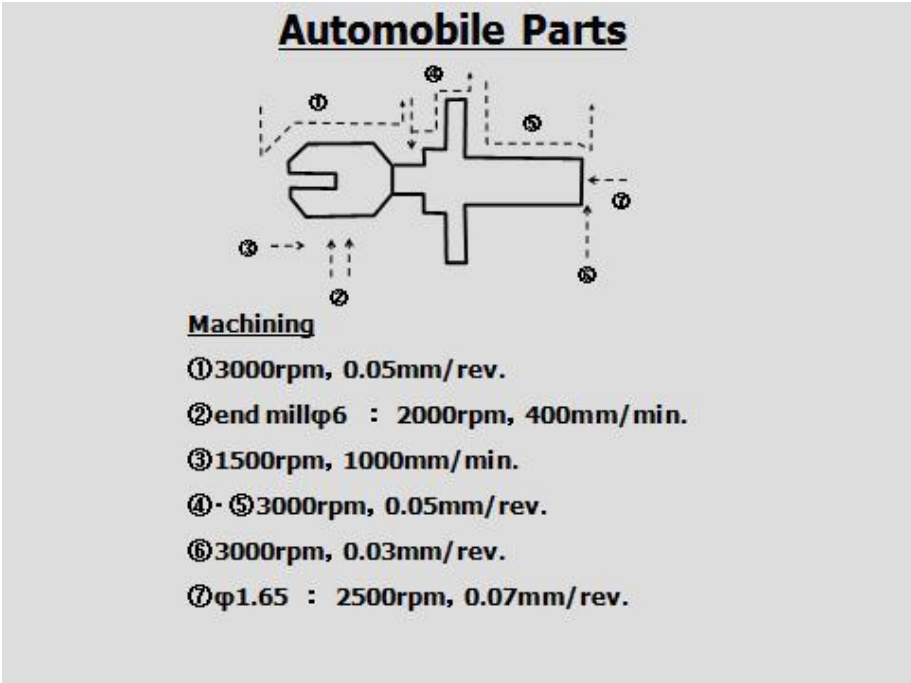


Fig.26 Machining Conditions of Automobile Parts

3. Wear Resistance

- Fig.27 shows wear resistance of Cu-Zn-Si materials and Cu-Zn-Pb materials [2)].
- Wear loss increases linearly with an increase in the amount of Pb for lubricated and non-lubricated Cu-Zn-Pb materials.

- 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(equivalent JIS H3250 C3604) containing 3% Pb, we can see the wear loss of ECO BRASS is equal to 1/18 (non-lubricated) of C36000 and 1/44 (lubricated) of C36000.

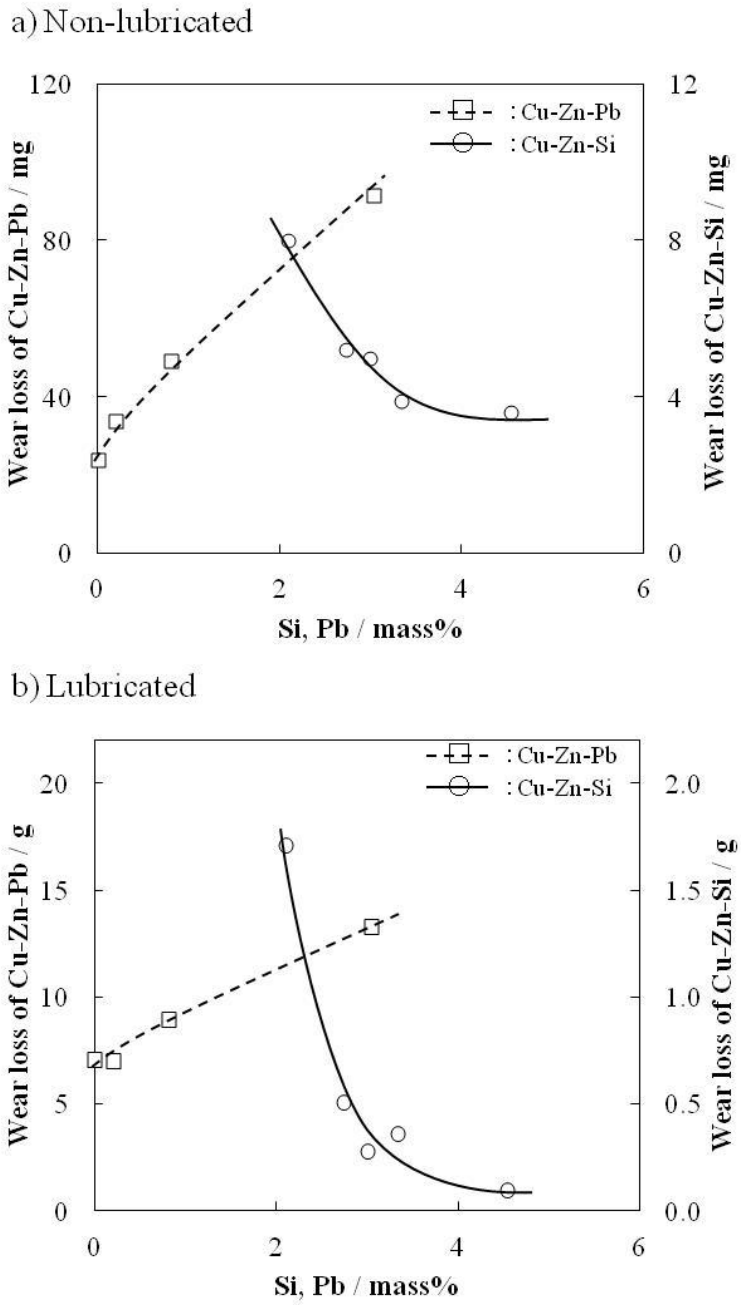


Fig.27 Wear Loss as a Function of Si or Pb. a) Non-lubricated, b) Lubricated.

4. Hot Forgeability

- Fig. 28 shows the high-temperature deformation stress of ECO BRASS and forging brass C37700 (60Cu-38Zn-2Pb) [4].
- The deformation stress of ECO BRASS is higher than forging brass C37700 however it is as same at 50°C higher temperature.
- When hot forging ECO BRASS the optimum temperature is 50°C higher than C37700.

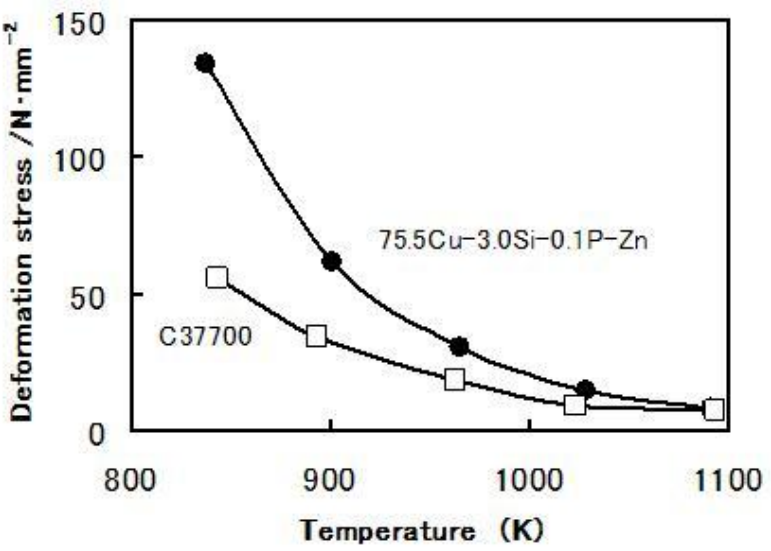


Fig.28 Deformation Stress by Temperature

IV. Final Comments/Summary

- We made license agreements with leading companies in Asia, Europe, and North America to enable global procurement of ECO BRASS.
- Total sales have exceeded 110,000 tonnes and it has been used as Pb-free material successfully.
- Since October 2014, the monthly sales of ECO BRASS is about 3,000 tonnes and equals 3% of total production of leaded copper alloy rod in Japan, North America, Europe.
- ECO BRASS is used in automobile components in more than 16 million cars (estimated sales).
- We received many reports that productivity of ECO BRASS is equivalent to leaded brass C36000 (equivalent JIS H3250 C3604), forging brass C37700 (60Cu-38Zn-2Pb), and C83600 (85Cu-5Sn-5Pb-5Zn) by optimizing cutting conditions, forging conditions and other production parameters.
- ECO BRASS is not only Pb-free but also a high performance copper alloy which is superior in strength equivalent to stainless steel,

elongation, fatigue strength, creep strength, machinability, corrosion resistance, stress corrosion cracking resistance, erosion corrosion resistance, cavitation resistance, castability, wear resistance, and hot forgeability.

- ECO BRASS is an ideal material in order to realize Pb-free industrial society, it has excellent properties in strength equivalent to stainless steel, machinability and wear resistance, which enables manufactures to reduce the weight and thickness of components leading to economic efficiencies.

V. References

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