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(54) FREE-CUTTING COPPER ALLOY

(57) Free-cutting alloys with industrially satisfactory machinability comprising 69 to 79 percent, by weight, of copper, 2.0 to 4.0 percent, by weight, of silicon; 0.02 to 0.4, by weight, of lead and the remaining percent, by weight, of zinc.

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Description

BACKGROUND OF THE INVENTION

1. Field of The Invention

[0001] The present invention relates to free-cutting copper alloys.

2. Prior Art

[0002] Among the copper alloys with a good machinability are bronze alloys such as the one under JIS designation H5111 BC6 and brass alloys such as the ones under JIS designations H3250-C3604 and C3771. Those alloys are so enhanced in machinability with the addition of 1.0 to 6.0 percent, by weight, of lead as to give industrially satisfactory results as easy-to-work copper alloy. Because of their excellent machinability, those lead-contained copper alloys have been an important basic material for a variety of articles such as city water faucets, water supply/drainage metal fittings and valves.

[0003] In those conventional free-cutting copper alloys, lead does not form a solid solution in the matrix but disperses in granular form, thereby improving the machinability of those alloys. To produce the desired results, lead has to be added in as much as 2.0 or more percent by weight. If the addition of lead is less than 1.0 percent by weight, chippings will be spiral in form as (D) in Fig. 1. Spiral chippings cause various troubles such as, for example, tangling with the tool. If, on the other hand, the content of lead is 1.0 or more percent by weight and not larger than 2.0 percent by weight, the cut surface will be rough, though that will produce some results such as reduction of the cutting resistance. It is usual, therefore, that lead is added in not smaller than 2.0 percent by weight. Some expanded copper alloys in which a high degree of cutting property is required are mixed with some 3.0 or more percent, by weight, of lead. Further, some bronze castings have a lead content of as much as some 5.0 percent, by weight. The alloy under the JIS H 5111 BC6, for example, contains some 5.0 percent, by weight, of lead.

[0004] However, the application of those lead-mixed alloys has been greatly limited in recent years, because lead contained therein is harmful to humans as an environment pollutant. That is, the lead-contained alloys pose a threat to human health and environmental hygiene because lead finds its way in metallic vapor that generates in the steps of processing those alloys at high temperatures such as melting and casting and there is also danger that lead contained in the water system metal fittings, valves and others made of those alloys will dissolve out into drinking water.

[0005] On that ground, the United States and other advanced nations have been moving to tighten the standards for lead-contained copper alloys to drastically limit the permissible level of lead in copper alloys in recent years. In Japan, too, the use of lead-contained alloys has been increasingly restricted, and there has been a growing call for development of free-cutting copper alloys with a low lead content.

SUMMARY OF THE INVENTION

[0006] It is an object of the present invention to provide a free-cutting copper alloy which contains an extremely small amount (0.02 to 0.4 percent by weight) of lead as a machinability improving element, yet is quite excellent in machinability, can be used as safe substitute for the conventional easy-to-cut copper alloy with a large content of lead, and presents no environmental hygienic problems while permitting the recycling of chippings, thus providing a timely answer to the mounting call for restriction of lead-contained products.

[0007] It is an another object of the present invention to provide a free-cutting copper alloy which has a high corrosion resistance coupled with an excellent machinability and is suitable as basic material for cutting works, forgings, castings and others, thus having a very high practical value. The cutting works, forgings, castings and others include city water faucets, water supply/drainage metal fittings, valves, stems, hot water supply pipe fittings, shaft and heat exchanger parts.

[0008] It is yet another object of the present invention to provide a free-cutting copper alloy with a high strength and wear resistance coupled with an easy-to-cut property which is suitable as basic material for the manufacture of cutting works, forgings, castings and other uses requiring a high strength and wear resistance such as, for example, bearings, bolts, nuts, bushes, gears, sewing machine parts and hydraulic system parts, hence has a very high practical value.

[0009] It is a further object of the present invention to provide a free-cutting copper alloy with an excellent high-temperature oxidation resistance combined with an easy-to-cut property which is suitable as basic material for the manufacture of cutting works, forgings, castings and other uses where a high thermal oxidation resistance is essential, e.g. nozzles for kerosene oil and gas heaters, burner heads and gas nozzles for hot-water dispensers, hence has a very high practical value.

[0010] The objects of the present inventions are achieved by provision of the following copper alloys:

1. A free-cutting copper alloy with an excellent easy-to-cut feature which is composed of 69 to 79 percent, by weight, of copper, 2.0 to 4.0 percent, by weight, of silicon, 0.02 to 0.4 percent, by weight, of lead and the remaining percent, by weight, of zinc. For purpose of simplicity, this copper alloy will be hereinafter called the "first invention alloy".

Lead forms no solid solution in the matrix but disperses in a granular form to improve the machinability. Silicon raises the easy-to-cut property by producing a gamma phase (in some cases, a kappa phase) in the structure of metal. That way, both are the same in that they are effective in improving the machinability, though they are quite different in contribution to the properties of the alloy. On the basis of that recognition, silicon is added to the first invention alloy so as to bring about a high level of machinability meeting the industrial requirements, while making it possible to reduce greatly the lead content. That is, the first invention alloy is improved in machinability through formation of a gamma phase with the addition of silicon.

The addition of less than 2.0 percent, by weight, of silicon can not form a gamma phase sufficient enough to secure an industrially satisfactory machinability. With the increase in the addition of silicon, the machinability improves. But with the addition of more than 4.0 percent, by weight, of silicon, the machinability will not go up in proportion. The problem is, however, that silicon is high in melting point and low in specific gravity and also liable to oxidize. If silicon in a single form is fed into the furnace in the melting step, silicon will float on the molten metal and is oxidized into oxides of silicon or silicon oxide, hampering the production a silicon-contained copper alloy. In producing the ingot of silicon-contained copper alloy, therefore, silicon is usually added in the form of a Cu-Si alloy, which boosts the production cost. In the light of the cost of making the alloy, too, it is not desirable to add silicon in a quantity exceeding the saturation point or plateau of machinability improvement - 4.0 percent by weight. An experiment showed that when silicon is added in the amount of 2.0 to 4.0 percent, by weight, it is desirable to hold the content of copper at 69 to 79 percent, by weight, in consideration of its relation to the content of zinc in order to maintain the intrinsic properties of the Cu-Zn alloy. For this reason, the first invention alloy is composed of 69 to 79 percent, by weight, of copper and 2.0 to 4.0 percent, by weight, of silicon respectively. The addition of silicon improves not only the machinability but also the flow of the molten metal in casting, strength, wear resistance, resistance to stress corrosion cracking, high-temperature oxidation resistance. Also, the ductility and dezincing corrosion resistance will be improved to some extent.

The addition of lead is set at 0.02 to 0.4 percent by weight on this ground. In the first invention alloy, a sufficient level of machinability is obtained by adding silicon that has the aforesaid effect even if the addition of lead is reduced. Yet, lead has to be added in the amount not smaller than 0.02 percent by weight if the alloy is to be superior to the conventional free-cutting copper alloy in machinability, while the addition of lead exceeding 0.4 percent would have adverse effects, resulting in a rough surface condition, poor hot workability such as poor forging behaviour and low cold ductility. Meanwhile, it is expected that such a small content of not higher than 0.4 percent by weight will be able to clear the lead-related regulations however strictly they are to be stipulated in the advanced nations including Japan in the future. On that ground, the addition range of lead is set at 0.02 to 0.4 percent by weight in the first and also second to eleventh invention alloys which will be described later.

2. Another embodiment of the present invention is a free-cutting copper alloy also with an excellent easy-to-cut feature which is composed of 69 to 79 percent, by weight, of copper; 2.0 to 4.0 percent, by weight, of silicon; 0.02 to 0.4 percent, by weight, of lead; one selected from among 0.02 to 0.4 percent, by weight, of bismuth, 0.02 to 0.4 percent, by weight, of tellurium, and 0.02 to 0.4 percent, by weight, of selenium; and the remaining percent, by weight, of zinc. This second copper alloy will be hereinafter called the "second invention alloy".

That is, the second invention alloy is composed of the first invention alloy and, in addition, one selected element from among 0.02 to 0.4 percent, by weight, of bismuth, 0.02 to 0.4 percent, by weight, of tellurium, and 0.02 to 0.4 percent, by weight, of selenium.

Bismuth, tellurium and selenium as well as lead do not form a solid solution with the matrix but disperse in granular form to enhance the machinability. That makes up for the reduction of the lead content. The addition of any one of those elements along with silicon and lead could further improve the machinability beyond the level hoped from the addition of silicon and lead. From this finding, the second invention alloy is worked out in which one element selected from among bismuth, tellurium and selenium is mixed. The addition of bismuth, tellurium or selenium as well as silicon and lead could make the copper alloy so machinable that complicated forms could be freely cut out at a high speed. But no improvement in machinability can be realized from the addition of bismuth, tellurium or selenium in the amount less than 0.02 percent, by weight. Meanwhile, those elements are expensive as compared with copper. Even if the addition exceeds 0.4 percent by weight, the proportional improvement in machinability is so small that the addition beyond that does not pay off economically. What is more, if the addition is more than 0.4 percent by weight, the alloy will deteriorate in hot workability such as forgeability and cold workability such as ductility. While it might be feared that heavy metals like bismuth would cause a problem similar to that of lead, a very small addition of less than 0.4 percent by weight is negligible and would present no particular problems. From those considerations, the second invention alloy is prepared with the addition of bismuth, tellurium or selenium kept to

0.02 to 0.4 percent by weight. In this regard, it is desired to keep the combined content of lead and bismuth, tellurium or selenium to not higher than 0.4 percent by weight. That is because if the combined content exceeds 0.4 percent by weight, if slightly, then there will begin a deterioration in hot workability and cold ductility and also there is fear that the form of chippings will change from (B) to (A) in Fig. 1. But the addition of bismuth, tellurium or selenium, which improves the machinability of the copper alloy though a mechanism different from that of silicon as mentioned above, would not affect the proper contents of copper and silicon. On this ground, the contents of copper and silicon in the second invention alloy are set at the same level as those in the first invention alloy.

3. Another embodiment of the present invention is a free-cutting copper alloy also with an excellent easy-to-cut feature which is composed of 70 to 80 percent, by weight, of copper; 1.8 to 3.5 percent, by weight, of silicon; 0.02 to 0.4 percent, by weight, of lead; at least one selected from among 0.3 to 3.5 percent, by weight, of tin, 1.0 to 3.5 percent, by weight, of aluminum, and 0.02 to 0.25 percent, by weight, of phosphorus; and the remaining percent, by weight, of zinc. This third copper alloy will be hereinafter called the "third invention alloy".

Tin works the same way as silicon. That is, if tin is added, a gamma phase will be formed and the machinability of the Cu-Zn alloy will be improved. For example, the addition of tin in the amount of 1.8 to 4.0 percent by weight would bring about a high machinability in the Cu-Zn alloy containing 58 to 70 percent, by weight, of copper, even if silicon is not present. Therefore, the addition of tin to the Cu-Si-Zn alloy could facilitate the formation of a gamma phase and further improve the machinability of the Cu-Si-Zn alloy. The gamma phase is formed with the addition of tin in the amount of 1.0 or more percent by weight and the formation reaches the saturation point at 3.5 percent, by weight, of tin. If tin exceeds 3.5 percent by weight, the ductility will drop instead. With the addition of tin in the amount less than 1.0 percent by weight, on the other hand, an insufficient gamma phase will be formed. If the addition is 0.3 or more percent by weight, then tin will be effective in uniformly dispersing the gamma phase formed by silicon. Through that effect of dispersing the gamma phase, too, the machinability is improved. In other words, the addition of tin in the amount not smaller than 0.3 percent by weight improves the machinability.

Aluminum is, too, effective in facilitating the formation of the gamma phase. The addition of aluminum together with or in place of tin could further improve the machinability of the Cu-Si-Zn alloy. Aluminum is also effective in improving the strength, wear resistance and high-temperature oxidation resistance as well, as the machinability and also in keeping down the specific gravity. If the machinability is to be improved at all, aluminum will have to be added in the amount of at least 1.0 percent by weight. But the addition of more than 3.5 percent by weight could not produce the proportional results. Instead, that could lower the ductility as is the case with tin.

As to phosphorus, it has no property of forming the gamma phase as tin and aluminum. But phosphorus works to uniformly disperse and distribute the gamma phase formed as a result of the addition of silicon alone or with tin or aluminum or both of them. That way, the machinability improvement through the formation of gamma phase is further enhanced. In addition to dispersing the gamma phase, phosphorus helps refine the crystal grains in the alpha phase in the matrix, improving hot workability and also strength and resistance to stress corrosion cracking. Furthermore, phosphorus substantially increases the flow of molten metal in casting. To produce such results, phosphorus will have to be added in the amount not smaller than 0.02 percent by weight. But if the addition exceeds 0.25 percent by weight, no proportional effect can be obtained. Instead, there would be a fall in hot forging property and extrudability.

In consideration of those observations, the third invention alloy is improved in machinability by adding to the Cu-Si-Pb-Zn alloy (first invention alloy) at least one selected from among 0.3 to 3.5 percent, by weight, of tin, 1.0 to 3.5 percent, by weight, of aluminum, and 0.02 to 0.25 percent, by weight, of phosphorus.

Meanwhile, tin, aluminum and phosphorus are to improve the machinability by forming a gamma phase or dispersing that phase, and work closely with silicon in promoting the improvement in machinability through the gamma phase. In the third invention alloy to which silicon is added along with tin, aluminum or phosphorus, the addition of silicon is smaller than that in the second invention alloy to which is added bismuth, tellurium or selenium which replaces silicon of the first invention in improving machinability. That is, those elements bismuth, tellurium and selenium contribute to improving the machinability, not acting on the gamma phase but dispersing in the form of grains in the matrix. Even if the addition of silicon is less than 2.0 percent by weight, silicon along with tin, aluminum or phosphorus will be able to enhance the machinability to an industrially satisfactory level as long as the percentage of silicon is 1.8 or more percent by weight. But even if the addition of silicon is not larger than 4.0 percent by weight, adding of tin, aluminum or phosphorus together will silicon will saturate the effect of silicon in improving the machinability, when the silicon content exceeds 3.5 percent by weight. On this ground, the addition of silicon is set at 1.8 to 3.5 percent by weight in the third invention alloy. Also, in consideration of the addition amount of silicon and also the addition of tin, aluminum or phosphorus, the content range of copper in this third invention alloy is slightly raised from the level in the second invention alloy and copper is properly set at 70 to 80 percent by weight.

4. A free-cutting copper alloy also with an excellent easy-to-cut feature which is composed of 70 to 80 percent, by weight, of copper; 1.8 to 3.5 percent, by weight, of silicon; 0.02 to 0.4 percent, by weight, of lead; at least one element selected from among 0.3 to 3.5 percent, by weight, of tin, 1.0 to 3.5 percent, by weight, of aluminum, and 0.02

to 0.25 percent, by weight, of phosphorus; one element selected from among 0.02 to 0.4 percent, by weight, of bismuth, 0.02 to 0.4 percent, by weight, of tellurium, and 0.02 to 0.4 percent, by weight, of selenium; and the remaining percent, by weight, of zinc. This fourth copper alloy will be hereinafter called the "fourth invention alloy".

The fourth invention alloy has any one selected from among 0.02 to 0.4 percent, by weight, of bismuth, 0.02 to 0.4 percent, by weight, of tellurium, and 0.02 to 0.4 percent, by weight, of selenium in addition to the components in the third invention alloy. The grounds for mixing those additional elements and setting those amounts to be added are the same as given for the second invention alloy.

5. A free-cutting copper alloy with an excellent easy-to-cut feature and with a high corrosion resistance which is composed of 69 to 79 percent, by weight, of copper; 2.0 to 4.0 percent, by weight, of silicon; 0.02 to 0.4 percent, by weight, of lead; at least one element selected from among 0.3 to 3.5 percent, by weight, of tin, 0.02 to 0.25 percent, by weight, of phosphorus, 0.02 to 0.15 percent, by weight, of antimony, and 0.02 to 0.15 percent, by weight, of arsenic, and the remaining percent, by weight, of zinc. This fifth copper alloy will be hereinafter called the "fifth invention alloy".

The fifth invention alloy has, in addition to the first invention alloy, at least one element selected from among 0.3 to 3.5 percent, by weight, of tin, 0.02 to 0.25 percent, by weight, of phosphorus, 0.02 to 0.15 percent, by weight, of antimony, and 0.02 to 0.15 percent, by weight, of arsenic.

Tin is effective in improving not only the machinability but also corrosion resistance properties (dezincification corrosion resistance) and forgeability. In other words, tin improves the corrosion resistance in the alpha phase matrix and, by dispersing the gamma phase, the corrosion resistance, forgeability and stress corrosion cracking resistance. The fifth invention alloy is thus improved in corrosion resistance by the property of tin and in machinability mainly by adding silicon. Therefore, the contents of silicon and copper in this alloy are set at the same as those in the first invention alloy. To raise the corrosion resistance and forgeability, on the other hand, tin would have to be added in the amount of at least 0.3 percent by weight. But even if the addition of tin exceeds 3.5 percent by weight, the corrosion resistance and forgeability will not improve in proportion to the amount added of tin. It is no good economy.

As described above, phosphorus disperses the gamma phase uniformly and at the same time refines the crystal grains in the alpha phase in the matrix, thereby improving the machinability and also the corrosion resistance properties (dezincification corrosion), forgeability, stress corrosion cracking resistance and mechanical strength. The fifth invention alloy is thus improved in corrosion resistance and others through the action of phosphorus and in machinability mainly by adding silicon. The addition of phosphorus in a very small quantity, that is, 0.02 or more percent by weight could produce results. But the addition in more than 0.25 percent by weight would not be so effective as hoped from the quantity added. Rather, that would reduce the hot forgeability and extrudability.

Just as phosphorus, antimony and arsenic in a very small quantity - 0.02 or more percent by weight - are effective in improving the dezincification corrosion resistance and other properties. But the addition exceeding 0.15 percent by weight would not produce results in proportion to the quantity added. Rather, it would affect the hot forgeability and extrudability as phosphorus applied in excessive amounts.

Those observations indicate that the fifth invention alloy is improved in machinability and also corrosion resistance and other properties by adding at least one element selected from among tin, phosphorus, antimony and arsenic (which improve corrosion resistance) in quantities within the aforesaid limits in addition to the same quantities of copper and silicon as in the first invention copper alloy. In the fifth invention alloy, the additions of copper and silicon are set at 69 to 79 percent by weight and 2.0 to 4.0 percent by weight respectively - the same level as in the first invention alloy in which any other machinability improver than silicon and a small amount of lead is not added - because tin and phosphorus work mainly as corrosion resistance improver like antimony and arsenic.

6. A free-cutting copper alloy also with an excellent easy-to-cut feature and with a high corrosion resistance which is composed of 69 to 79 percent, by weight, of copper; 2.0 to 4.0 percent, by weight, of silicon; 0.02 to 0.4 percent, by weight, of lead; at least one element selected from among 0.3 to 3.5 percent, by weight, of tin, 0.02 to 0.25 percent, by weight, of phosphorus, 0.02 to 0.15 percent, by weight, of antimony, and 0.02 to 0.15 percent, by weight, of arsenic; one element selected from among 0.02 to 0.4 percent, by weight, of bismuth, 0.02 to 0.4 percent, by weight, of tellurium, and 0.02 to 0.4 percent, by weight, of selenium; and the remaining percent, by weight, of zinc. This sixth copper alloy will be hereinafter called the "sixth invention alloy".

The sixth invention alloy has any one element selected from among 0.02 to 0.4 percent, by weight, of bismuth, 0.02 to 0.4 percent, by weight, of tellurium, and 0.02 to 0.4 percent, by weight, of selenium in addition to the components in the fifth invention alloy. The machinability is improved by adding, in addition to silicon and lead, any one element selected from among bismuth, tellurium and selenium as in the second invention alloy and the corrosion resistance and other properties are raised by adding at least one selected from among tin, phosphorus, antimony and arsenic as in the fifth invention alloy. Therefore, the additions of copper, silicon, bismuth, tellurium and selenium are set at the same levels as those in the second invention alloy, while the additions of tin, phosphorus, antimony and arsenic are adjusted to those in the fifth invention alloy.

7. A free-cutting copper alloy also with an excellent easy-to-cut feature and with an excellent high strength feature and high corrosion resistance which is composed of 62 to 78 percent, by weight, of copper; 2.5 to 4.5 percent, by weight, of silicon; 0.02 to 0.4 percent, by weight, of lead; at least one element selected from among 0.3 to 3.0 percent, by weight, of tin, 0.2 to 2.5 percent, by weight, of aluminum, and 0.02 to 0.25 percent, by weight, of phosphorus; and at least one element selected from among 0.7 to 3.5 percent, by weight, of manganese and 0.7 to 3.5 percent, by weight, of nickel; and the remaining percent, by weight, of zinc. The seventh copper alloy will be hereinafter called the "seventh invention alloy".

Manganese and nickel combine with silicon to form intermetallic compounds represented by MnxSiy or NixSiy which are evenly precipitated in the matrix, thereby raising the wear resistance and strength. Therefore, the addition of manganese and nickel or either of the two would improve the high strength feature and wear resistance. Such effects will be exhibited if manganese and nickel are added in the amount of not less than 0.7 percent by weight respectively. But the saturation state is reached at 3.5 percent by weight, and even if the addition is increased beyond that, no proportional results will be obtained. The addition of silicon is set at 2.5 to 4.5 percent by weight to match the addition of manganese or nickel, taking into consideration the consumption to form intermetallic compounds with those elements.

It is also noted that tin, aluminum and phosphorus help to reinforce the alpha phase in the matrix, thereby improving the machinability. Tin and phosphorus disperse the alpha and gamma phases, by which the strength, wear resistance and also machinability are improved. Tin in the amount of 0.3 or more percent by weight is effective in improving the strength and machinability. But if the addition exceeds 3.0 percent by weight, the ductility will fall. For this reason, the addition of tin is set at 0.3 to 3.0 percent by weight to raise the high strength feature and wear resistance in the seventh invention alloy and also to enhance the machinability. Aluminum also contributes to improving the wear resistance and exhibits its effect of reinforcing the matrix when added in the amount of 0.2 or more percent by weight. But if the addition exceeds 2.5 percent by weight, there will be a fall in ductility. Therefore, the addition of aluminum is set at 0.2 to 2.5 in consideration of improvement of machinability. Also, the addition of phosphorus disperses the gamma phase and at the same time pulverizes the crystal grains in the alpha phase in the matrix, thereby improving the hot workability and also the strength and wear resistance. Furthermore, it is very effective in improving the flow of molten metal in casting. Such results will be produced when phosphorus is added in the amount of 0.02 to 0.25 percent by weight. The content of copper is set at 62 to 78 percent by weight in the light of the addition of silicon and the property of manganese and nickel of combining with silicon.

8. A free-cutting copper alloy also with an excellent easy-to-cut feature and with an excellent high-temperature oxidation resistance which comprises 69 to 79 percent, by weight, of copper, 2.0 to 4.0 percent, by weight, of silicon, 0.02 to 0.4 percent, by weight, of lead, 0.1 to 1.5 percent, by weight, of aluminum, and 0.02 to 0.25 percent, by weight, of phosphorus, and the remaining percent, by weight, of zinc. The eighth copper alloy will be hereinafter called the "eighth invention alloy".

Aluminum is an element which improves the strength, machinability, wear resistance and also high-temperature oxidation resistance. Silicon, too, has a property of enhancing the machinability, strength, wear resistance, resistance to stress corrosion cracking and also high-temperature oxidation resistance. Aluminum works to raise the high-temperature oxidation resistance when it is used together with silicon and that in not smaller than 0.1 percent by weight. But even if the addition of aluminum increases beyond 1.5 percent by weight, no proportional results can be expected. For this reason, the addition of aluminum is set at 0.1 to 1.5 percent by weight.

Phosphorus is added to enhance the flow of molten metal in casting. Phosphorus also works for improvement of the aforesaid machinability, dezincification corrosion resistance and also high-temperature oxidation resistance in addition to the flow of molten metal. Those effects are exhibited when phosphorus is added in the amount not smaller than 0.02 percent by weight. But even if phosphorus is used in more than 0.25 percent by weight, it will not result in a proportional increase in effect rather weakening the alloy. For this consideration, the addition of phosphorus settles down on 0.02 to 0.25 percent by weight.

While silicon is added to improve the machinability as mentioned above, it is also capable of improving the flow of molten metal like phosphorus. The effect of silicon in improving the flow of molten metal is exhibited when it is added in the amount of not smaller than 2.0 percent by weight. The range of the addition for the flow improvement overlaps that for improvement of the machinability. These taken into consideration, the addition of silicon is set to 2.0 to 4.0 percent by weight.

9. A free-cutting copper alloy also with excellent easy-to-cut feature coupled with a good high-temperature oxidation resistance which is composed of 69 to 79 percent, by weight, of copper; 2.0 to 4.0 percent, by weight, of silicon; 0.02 to 0.4 percent, by weight, of lead; 0.1 to 1.5 percent, by weight, of aluminum; 0.02 to 0.25 percent, by weight, of phosphorus; one element selected from among 0.02 to 0.4 percent, by weight, of bismuth, 0.02 to 0.4 percent, by weight, of tellurium, and 0.02 to 0.4 percent, by weight, of selenium; and the remaining percent, by weight, of zinc. The ninth copper alloy will be hereinafter called the "ninth invention alloy".

The ninth invention alloy contains one element selected from among 0.02 to 0.4 percent, by weight, of bismuth, 0.02 to 0.4 percent, by weight, of tellurium and 0.02 to 0.4 percent, by weight, of selenium in addition to the components of the eighth invention alloy. While a high-temperature oxidation resistance as good as in the eighth invention alloy is secured, the machinability is further improved by adding one element selected from among bismuth and other elements which are as effective as lead in raising the machinability.

10. A free-cutting copper alloy also with excellent easy-to-cut feature and a good high-temperature oxidation resistance which is composed of 69 to 79 percent, by weight, of copper; 2.0 to 4.0 percent, by weight, of silicon; 0.02 to 0.4 percent, by weight, of lead; 0.1 to 1.5 percent, by weight, of aluminum; 0.02 to 0.25 percent, by weight, of phosphorus; at least one selected from among 0.02 to 0.4 percent, by weight, of chromium and 0.02 to 0.4 percent, by weight, of titanium; and the remaining percent, by weight, of zinc. The tenth copper alloy will be hereinafter called the "tenth invention alloy".

Chromium and titanium are intended for improving the high-temperature oxidation resistance. Good results can be expected especially when they are added together with aluminum to produce a synergistic effect. Those effects are exhibited when the addition is no less than 0.02 percent by weight, whether they are added alone or in combination. The saturation point is 0.4 percent by weight. For consideration of such observations, the tenth invention alloy has at least one element selected from among 0.02 to 0.4 percent by weight of chromium and 0.02 to 0.4 percent by weight of titanium in addition to the components of the eighth invention alloy and thus further improved over the eighth invention alloy with regard to the high-temperature oxidation resistance.

11. A free-cutting copper alloy also with excellent easy-to-cut feature and a good high-temperature oxidation resistance which is composed of 69 to 79 percent, by weight, of copper; 2.0 to 4.0 percent, by weight, of silicon; 0.02 to 0.4 percent, by weight, of lead; 0.1 to 1.5 percent, by weight, of aluminum; 0.02 to 0.25 percent, by weight, of phosphorus; at least one element selected from among 0.02 to 0.4 percent, by weight, of chromium and 0.02 to 0.4 percent, by weight, of titanium; one element selected from among 0.02 to 0.4 percent, by weight, of bismuth, 0.02 to 0.4 percent, by weight, of tellurium and 0.02 to 0.4 percent, by weight, of selenium; and the remaining percent, by weight, of zinc. The eleventh copper alloy will be hereinafter called the "eleventh invention alloy".

The eleventh invention alloy contains any one selected from among 0.02 to 0.4 percent, by weight, of bismuth, 0.02 to 0.4 percent, by weight, of tellurium and 0.02 to 0.4 percent, by weight, of selenium in addition to the components of the tenth invention alloy. While as high a high-temperature oxidation resistance as in the tenth invention alloy is secured, the eleventh invention alloy is further improved in machinability by adding one element selected from among bismuth and other elements which are as effective as lead in raising the machinability.

12. A free-cutting copper alloy also with further improved easy-to-cut feature obtained by subjecting any one of the preceding respective invention alloys to a heat treatment for 30 minutes to 5 hours at 400 to 600°C. The twelfth copper alloy will be hereinafter called the "twelfth invention alloy".

The first to eleventh invention alloys contain machinability improving elements such as silicon and have an excellent machinability because of the addition of such elements. The effect of those machinability improving elements could be further enhanced by heat treatment. For example, the first to eleventh invention alloys which are high in copper content with gamma phase in small quantities and kappa phase in large quantities undergo a change in phase from the kappa phase to the gamma phase in a heat treatment. As a result, the gamma phase is finely dispersed and precipitated, and the machinability is improved. In the manufacturing process of castings, expanded metals and hot forgings in practice, the materials are often force-air-cooled or water cooled depending on the forging conditions, productivity after hot working (hot extrusion, hot forging etc.), working environment and other factors. In such cases, with the first to eleventh invention alloys, the alloys with a low content of copper in particular are rather low in the content of the gamma phase and contain beta phase. In a heat treatment, the beta phase changes into gamma phase, and the gamma phase is finely dispersed and precipitated, whereby the machinability is improved.

But a heat treatment temperature at less than 400°C is not economical and practical in any case, because the aforesaid phase change will proceed slowly and much time will be needed. At temperatures over 600°C, on the other hand, the kappa phase will grow or the beta phase will appear, bringing about no improvement in machinability. From the practical viewpoint, therefore, it is desired to perform the heat treatment for 30 minutes to 5 hours at 400 to 600°C.

BRIEF DESCRIPTION OF THE DRAWING

[0011]

Fig. 1 shows perspective views of cuttings formed in cutting a round bar of copper alloy by lathe.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Example 1

[0012] As the first series of examples of the present invention, cylindrical ingots with compositions given in Tables 1 to 15, each 100 mm in outside diameter and 150 mm in length, were hot extruded into a round bar 15 mm in outside diameter at 750 C to produce the following test pieces: first invention alloys Nos. 1001 to 1007, second invention alloys Nos. 2001 to 2006, third invention alloys Nos. 3001 to 3010, fourth invention alloys Nos. 4001 to 4021, fifth invention alloys Nos. 5001 to 5020, sixth invention alloys Nos. 6001 to 6045, seventh invention alloys Nos. 7001 to 7029, eighth invention alloys Nos. 8001 to 8008, ninth invention alloys Nos. 9001 to 9006, tenth invention alloys Nos. 10001 to 10008, and eleventh invention alloys Nos. 11001 to 11011. Also, cylindrical ingots with the compositions given in Table 16, each 100 mm in outside diameter and 150 mm in length, were hot extruded into a round bar 15 mm in outside diameter at 750°C to produce the following test pieces: twelfth invention alloys Nos. 12001 to 12004. That is, No. 12001 is an alloy test piece obtained by heat-treating an extruded test piece with the seine composition as first invention alloy No. 1006 for 30 minutes at 580°C. No. 12002 is an alloy test piece obtained by heat-treating an extruded test piece with the same composition as No. 1006 for two hours at 450°C. No. 12003 is an alloy test piece obtained by heat-treating an extruded test piece with the same composition as first invention alloy No. 1007 under the sane conditions as for No. 12001 - for 30 minutes at 580°C. No. 12004 is an alloy test piece obtained by heat-treating an extruded test piece with the same composition as No. 1007 under the same conditions as for No. 12002 - for two hours at 450°C.

[0013] As comparative examples, cylindrical ingots with the compositions as shown in Table 17, each 100 mm in outside diameter and 150 mm in length, were hot extruded into a round bar 15 mm in outside diameter at 750°C to obtain the following round extruded test pieces: Nos. 13001 to 13006 (hereinafter referred to as the "conventional alloys"). No. 13001 corresponds to the alloy "JIS C 3604", No. 13002 to the alloy "CDA C 36000", No. 13003 to the alloy "JIS C 3771" and No. 13004 to the alloy "CDA C 69800". No. 13005 corresponds to the alloy "JIS C 6191". This aluminum bronze is the most excellent of the expanded copper alloys under the JIS designations with regard to strength and wear resistance. No. 13006 corresponds to the naval brass alloy "JIS C 4622" and is the most excellent of the expanded copper alloys under the JIS designations with regard to corrosion resistance.

[0014] To study the machinability of the first to twelfth invention alloys in comparison with the conventional alloys, cutting tests were carried out. In the tests, evaluations were made on the basis of cutting force, condition of chippings, and cut surface condition. The tests were conducted this way: The extruded test pieces thus obtained were cut on the circumferential surface by a lathe provided with a point noise straight tool at a rake angle of - 8 degrees and at a cutting rate of 50 meters/minute, a cutting depth of 1.5 mm, a feed of 0.11 mm/rev. Signals from a three-component dynamometer mounted on the tool were converted into electric voltage signals and recorded on a recorder. The signals were then converted into the cutting resistance. It is noted that while, to be perfectly exact, the amount of the cutting resistance should be judged by three component forces - cutting force, feed force and thrust force, the judgement was made on the basis of the cutting force (N) of the three component forces in the present example. The results are shown in Table 18 to Table 33.

[0015] Furthermore, the chips from the cutting work were examined and classified into four forms (A) to (D) as shown in Fig. 1. The results are enumerated in Table 18 to Table 33. In this regard, the chippings in the form of a spiral with three or more windings as (D) in Fig. 1 are difficult to process, that is, recover or recycle, and could cause trouble in cutting work as, for example, getting tangled with the tool and damaging the cut metal surface. Chippings in the form of a spiral arc from one with a half winding to one with two windings as shown in (C), Fig. 1 do not cause such serous trouble as the chippings in the form of a spiral with three or more windings yet are not easy to remove and could get tangled with the tool or damage the cut metal surface. In contrast, chippings in the form of a fine needle as (A) in Fig. 1 or in the form of arc shaped pieces as (B) will not present such problems as mentioned above and are not bulky as the chippings in (C) and (D) and easy to process. But fine chippings as (A) still could creep in on the slide table of a machine tool such as a lathe and cause mechanical trouble, or could be dangerous because they could stick into the worker's finger, eye or other body parts. Those taken into account, when judging machinability, the alloy with the chippings in (B) is the best, and the second best is the one with the chippings in (A). Those with the chippings in (C) and (D) are not good. In Table 18 to Table 33, the alloys with the chippings shown in (B), (A), (C) and (D) are indicated by the symbols "◎", "o", "△" and "x" respectively.

[0016] In addition, the surface condition of the cut metal surface was checked after cutting work. The results are shown in Table 18 to Table 33. In this regard, the commonly used basis for indication of the surface roughness is the maximum roughness (Rmax). While requirements are different depending on the application field of brass articles, the alloys with Rmax < 10 microns are generally considered excellent in machinability. The alloys with 10 microns ≤ Rmax < 15 microns are judged as industrially acceptable while those with Rmax ≥ 15 microns are taken as poor in machinability. In Table 18 to Table 33, the alloys with Rmax < 10 microns are marked "o"; those with 10 microns ≤ Rmax < 15 microns are indicated in "△" and those with Rmax ≥ 15 microns are represented by a symbol "x".

[0017] As is evident from the results of the cutting tests shown in Table 18 to Table 33, the following invention alloys are all equal to the conventional lead-contained alloys Nos. 13001 to 13003 in machinability: first invention alloys Nos. 1001 to 1007, second invention alloys Nos. 2001 to 2006, third invention alloys Nos. 3001 to 3010, fourth invention alloys Nos. 4001 to 4021, fifth invention alloys Nos. 5001 to 5020, sixth invention alloys Nos. 6001 to 6045, seventh invention alloys Nos. 7001 to 7029, eighth invention alloys Nos. 8001 to 8008, ninth invention alloys Nos. 9001 to 9006, tenth invention alloys Nos. 10001 to 10008, eleventh invention alloys Nos. 11001 to 11011, twelfth invention alloys Nos. 12001 to 12004. Especially with regard to the form of chippings, those invention alloys are favorably compared not only with the conventional alloys Nos. 13004 to 13006 with a lead content of not higher than 0.1 percent by weight but also Nos. 13001 to 13003 which contain large quantities of lead. Also to be noted is that the twelfth invention alloys Nos. 12001 to 12004, which are obtained by heat-treating the first invention alloys Nos. 1006 and 1007, are improved over the first invention alloys in machinability. It is understood that a proper heat treatment could further enhance the machinability of the first to eleventh invention alloys, depending upon the alloy compositions and other conditions.

[0018] In another series of tests, the first to twelfth invention alloys were examined in comparison with the conventional alloys in hot workability and mechanical properties. For the purpose, hot compression and tensile tests were conducted the following way.

[0019] First, two test pieces, first and second test pieces, in the same shape 15 mm in outside diameter and 25 mm in length were cut out of each extruded test piece obtained as described above. In the hot compression tests, the first test piece was held for 30 minutes at 700°C, and then compressed at the compression rate of 70 percent in the direction of axis to reduce the length from 25 mm to 7.5 mm. The surface condition after the compression (700°C deformability) was visually evaluated. The results were given in Table 18 to Table 33. The evaluation of deformability was made by visually checking for cracks on the side of the test piece. In Table 18 to Table 33, the test pieces with no cracks found are marked "o"; those with small cracks are indicated by "△" and those with large cracks are represented by a symbol "x".

[0020] The second test pieces were put to a tensile test by the commonly practised test method to determine the tensile strength, N/mm^2 and elongation, %.

[0021] As the test results of the hot compression and tensile tests in Table 18 to Table 33 indicate, it was confined that the first to twelfth invention alloys are equal to or superior to the conventional alloys Nos. 13001 to 13004 and No. 13006 in hot workability and mechanical properties and are suitable for industrial use. The seventh invention alloys in particular have the same level of mechanical properties as the conventional alloy No. 13005, i.e. the aluminum bronze which is the most excellent in strength of the expanded copper alloys under the JIS designations, and thus have understandably a prominent high strength feature.

[0022] Furthermore, the first to six and eighth to twelfth invention alloys were put to dezincification corrosion and stress corrosion cracking tests in accordance with the test methods specified under "ISO 6509" and "JIS H 3250" respectively to examine the corrosion resistance and resistance to stress corrosion cracking in comparison with the conventional alloys.

[0023] In the dezincing corrosion test by the "ISO 6509" method, the test piece taken from each extruded test piece was imbedded laid in a phenolic resin material in such a way that the exposed test piece surface is perpendicular to the extrusion direction of the extruded test piece. The surface of the test piece was polished with emery paper No. 1200, and then ultrasonic-washed in pure water and dried. The test piece thus prepared was dipped in a 12.7 g/l aqueous solution of cupric chloride dihydrate ($CuCl_2.2H_2O$) 1.0% and left standing for 24 hours at 75°C. The test piece was taken out of the aqueous solution and the maximum depth of dezincing corrosion was determined. The measurements of the maximum dezincification corrosion depth are given in Table 18 to Table 25 and Table 28 to Table 33.

[0024] As is clear from the results of dezincification corrosion tests shown in Table 18 to Table 25 and Table 28 to Table 33, the first to fourth invention alloys and the eighth to twelfth invention alloys are excellent in corrosion resistance in comparison with the conventional alloys Nos. 13001 to 13003 which contain great amount of lead. And it was confirmed that especially the fifth and sixth invention alloys whose improvement in both machinability and corrosion resistance has been intended are very high in corrosion resistance in comparison with the conventional alloy No. 13006, a naval brass which is the most resistant to corrosion of all the expanded alloys under the JIS designations.

[0025] In the stress corrosion cracking tests in accordance with the test method described in "JIS H 3250", a 150-mm-long test piece was cut out from each extruded material. The test piece was bent with the center placed on an arc-shaped tester with a radius of 40 mm in such a way that one end forms an angle of 45 degrees with respect the other end. The test piece thus subjected to a tensile residual stress was degreased and dried, and then placed in an ammonia environment in the desiccator with a 12.5% aqueous ammonia (ammonia diluted in the equivalent of pure water). To be exact, the test piece was held some 80 mm above the surface of aqueous ammonia in the desiccator. After the test piece was left standing in the ammonia environment for 2 hours, 8 hours and 24 hours, the test piece was taken out from the desiccator, washed in sulfuric acid solution 10% and examined for cracks under a magnifier of 10 magnifications. The results are given in Table 18 to Table 25 and Table 28 to Table 33. In those tables, the alloys which developed clear cracks when held in the ammonia environment for two hours are marked "xx." The test pieces which had no cracks at two hours but were found clearly cracked in 8 hours are indicated in "x." The test pieces which had no cracks in 8 hours, but were found clearly to have cracks in 28 hours are identified by the symbol "△". The test pieces which were found to have no cracks at all in 24 hours are given a symbol "o".

[0026] As is indicated by the results of the stress corrosion cracking test given in Table 18 to Table 25 and Table 28 to Table 33, it was confirmed that not only the fifth and sixth invention alloys whose improvement in both machinability and corrosion resistance has been intended but also the first to fourth invention alloys and the eighth to twelfth alloys in which nothing particular was done to improve corrosion resistance were both equal to the conventional alloy No. 13005, an aluminum bronze containing no zinc, in stress corrosion cracking resistance. Those invention alloys were superior in stress corrosion cracking resistance to the conventional naval brass alloy No. 13006, the best in corrosion resistance of all the expanded copper alloys under the JIS designations.

[0027] In addition, oxidation tests were carried out to study the high-temperature oxidation resistance of the eighth to eleventh invention alloys in comparison with the conventional alloys.

[0028] Test pieces in the shape of a round bar with the surface cut to a outside diameter of 14 mm and the length cut to 30 mm were prepared from each of the following extruded materials: No. 8001 to No. 8008, No. 9001 to No. 9006, No. 10001 to No. 10008, No. 11001 to No. 11011 and No. 13001 to No. 13006. Each test piece was then weighed to measure the weight before oxidation. After that, the test piece was placed in a porcelain crucible and held in an electric furnace maintained at 500°C. At the passage of 100 hours, the test piece was taken out of the electric furnace and was weighed to measure the weight after oxidation. From the measurements before and after oxidation was calculated the increase in weight by oxidation. It is understood that the increase by oxidation is the amount, mg, of increase in weight by oxidation per 10 cm^2 of the surface area of the test piece and is calculated by the equation: increase in weight by oxidition, mg/10 cm^2 = (weight, mg, after oxidation - weight, mg, before oxidation) x (10 cm^2 / surface area, cm^2 , of test piece) . The weight of each test piece increased after oxidation. The increase was brought about by high-temperature oxidation. Subjected to a high temperature, oxygen combines with copper, zinc and silicon to form Cu_20, Zn0, $Si0_2$. That is, oxygen adds to the weight. It can be said, therefore, that the alloys which are smaller in weight increase by oxidation are more excellent in high-temperature oxidation resistance. The results obtained are shown in Table 28 to Table 31 and Table 33.

[0029] As is evident from the test results shown in Table 23 to Table 31 and Table 33, the eighth to eleventh invention alloys are equal, in regard to weight increase by oxidation to the conventional alloy No. 13005, an aluminum bronze ranking high in resistance to high-temperature oxidation among the expanded copper alloys under the JIS designations and are far smaller than any other conventional copper alloy. Thus, it was confirmed that the eighth to eleventh invention alloys are very excellent in machinability and resistance to high-temperature oxidation as well.

Example 2

[0030] As the second series of examples of the present invention, circular cylindrical ingots with compositions given in Tables 9 to 11, each 100 mm in outside diameter and 200 mm in length, were hot extruded into a round bar 35 mm in outside diameter at 700°C to produce seventh invention alloys Nos. 7001a to 7029a. In parallel, circular cylindrical ingots with compositions given in Table 17, each 100 mm in outside diameter and 200 mm in length, were hot extruded into a round bar 35 mm in outside diameter at 700°C to produce the following alloy test pieces: Nos. 13001a to 13006a as second comparative examples (hereinafter referred to as the "conventional alloys"). It is noted that the alloys Nos. 7001a to 7029a and Nos. 13001a to 13006a are identical in composition with the aforesaid copper alloys Nos. 7001 to 7029 and Nos. 13001 to No. 13006 respectively.

[0031] Those seventh invention alloys Nos. 7001a to 7029a were put to wear resistance tests in comparison with the conventional alloys Nos. 13001a to 13006a.

[0032] The tests were carried out in this procedure. Each extruded test piece thus obtained was cut on the circumferential surface, holed and cut down into a ring-shaped test piece 32 mm in outside diameter and 10 mm in thickness (that is, the length in the axial direction). The test piece was then fitted and clamped on a rotatable shaft, and a roll 48 mm in diameter placed in parallel with the axis of the shaft was thrusted against the test piece under a load of 50 kg. The roll was made of stainless steel under the JIS designation SUS 304. Then, the SUS 304 roll and the test piece put against the roll were rotated at the same number of revolutions/minute - 209 r.p.m., with multipurpose gear oil being dropping on the circumferential surface of the test piece. When the number of revolutions reached 100,000, the SUS 304 roll and the test piece were stopped, and the weight difference between before and after the end of rotation, that is, the loss of weight by wear, mg, was determined. It can be said that the alloys which are smaller in the loss of weight by wear are higher in wear resistance. The results are given in Tables 34 to 36.

[0033] As is clear from the wear resistance test results shown in Tables 34 to 36, the tests showed that those seventh invention alloys Nos. 7001a to 7029a were excellent in wear resistance as compared with not only the conventional alloys Nos. 13001a to 13004a and 13006a but also No. 13005a, which is an aluminium bronze most excellent in wear resistance among expanded copper designated in JIS. From comprehensive considerations of the test results including the tensile test results, it may safely be said that the seventh invention alloys are excellent in machinability and also possess a high strength feature and wear resistance equal to or superior to the aluminum bronze which is the highest in wear resistance of all the expanded copper alloys under the JIS designations.

[Table 1]

No.	alloy composition (wt%)			
	Cu	Si	Pb	Zn
1001	74.8	2.9	0.03	remainder
1002	74.1	2.7	0.21	remainder
1003	78.1	3.6	0.10	remainder
1004	70.6	2.1	0.36	remainder
1005	74.9	3.1	0.11	remainder
1006	69.3	2.3	0.05	remainder
1007	78.5	2.9	0.05	remainder

[Table 2]

No.	alloy composition (wt%)						
	Cu	Si	Pb	Bi	Te	Se	Zn
2001	73.8	2.7	0.05	0.03			remainder
2002	69.9	2.0	0.33	0.27			remainder
2003	74.5	2.8	0.03		0.31		remainder
2004	78.0	3.6	0.12		0.05		remainder
2005	76.2	3.2	0.05			0.33	remainder
2006	72.9	2.6	0.24			0.06	remainder

[Table 3]

No.	alloy composition (wt%)						
	Cu	Si	Pb	Sn	Al	P	Zn
3001	70.8	1.9	0.23	3.2			remainder
3002	74.5	3.0	0.05	0.4			remainder
3003	78.8	2.5	0.15		3.4		remainder
3004	74.9	2.7	0.09		1.2		remainder
3005	74.6	2.3	0.26	1.2	1.9		remainder
3006	74.8	2.8	0.18			0.03	remainder
3007	76.5	3.3	0.04			0.21	remainder
3008	73.5	2.5	0.05	1.6		0.05	remainder
3009	74.9	2.0	0.35		2.7	0.13	remainder

[Table 3] (continued)

No.	alloy composition (wt%)						
	Cu	Si	Pb	Sn	Al	P	Zn
3010	75.2	2.9	0.23	0.8	1.4	0.04	remainder

[Table 4]

No.	alloy composition (wt%)									
	Cu	Si	Pb	Sn	Al	P	Bi	Te	Se	Zn
4001	73.8	2.8	0.04	0.5			0.10			remainder
4002	74.5	2.6	0.11		1.5		0.04			remainder
4003	73.7	2.1	0.21	1.2	2.2		0.03			remainder
4004	76.8	3.2	0.05			0.03	0.31			remainder
4005	74.1	2.6	0.07	1.4		0.04	0.09			remainder
4006	75.5	1.9	0.32		3.2	0.15	0.16			remainder
4007	74.8	2.8	0.10	0.7	1.2	0.05	0.05			remainder
4008	70.5	1.9	0.22	3.4				0.03		remainder
4009	79.1	2.7	0.15		3.4			0.05		remainder
4010	74.5	2.8	0.10			0.05		0.05		remainder
4011	77.3	3.3	0.07	0.4		0.21		0.31		remainder
4012	76.8	2.8	0.05		2.0	0.03		0.13		remainder
4013	74.5	2.6	0.18	1.4	2.1			0.21		remainder
4014	74.0	2.5	0.20	2.1	1.1	0.10		0.07		remainder
4015	72.5	2.4	0.11	1.0					0.05	remainder
4016	76.1	2.5	0.07		2.3				0.10	remainder
4017	76.4	2.7	0.05	0.6	3.1				0.22	remainder
4018	74.0	2.5	0.23			0.22			0.03	remainder
4019	71.2	2.2	0.11	2.8		0.05			0.30	remainder
4020	75.3	2.7	0.22		1.4	0.03			0.05	remainder
4021	74.1	2.5	0.05	2.4	1.2	0.07			0.07	remainder

[Table 5]

No.	alloy composition (wt%)							
	Cu	Si	Pb	Sn	P	Sb	As	Zn
5001	74.3	2.9	0.05	0.4				remainder
5002	69.8	2.1	0.31	3.1				remainder
5003	74.8	2.8	0.03		0.08			remainder

[Table 5] (continued)

No.	alloy composition (wt%)							
	Cu	Si	Pb	Sn	P	Sb	As	Zn
5004	78.2	3.4	0.16		0.21			remainder
5005	74.9	3.1	0.09			0.07		remainder
5006	72.2	2.4	0.25				0.13	remainder
5007	73.5	2.5	0.18	2.2	0.04			remainder
5008	77.0	3.3	0.06	0.7	0.15			remainder
5009	76.4	3.6	0.12	1.2				remainder
5010	71.4	2.3	0.26	2.6		0.03		remainder
5011	77.3	3.4	0.17	0.5		0.14		remainder
5012	74.8	2.8	0.07	1.4			0.03	remainder
5013	74.5	2.7	0.05		0.03	0.12		remainder
5014	76.1	3.1	0.14		0.18	0.03		remainder
5015	73.9	2.5	0.08		0.07		0.05	remainder
5016	74.5	2.8	0.07			0.08	0.04	remainder
5017	77.3	3.1	0.12	1.5	0.13	0.05		remainder
5018	72.8	2.4	0.18	0.7		0.03	0.09	remainder
5019	74.2	2.7	0.07	0.5	0.11		0.10	remainder
5020	74.6	2.8	0.05	0.9	0.07	0.05	0.03	remainder

[Table 6]

No.	alloy composition (wt%)										
	Cu	Si	Pb	Bi	Te	Se	Sn	P	Sb	As	Zn
6001	70.7	2.3	0.17	0.05			2.8				remainder
6002	74.6	2.5	0.08	0.03			0.7	0.06			remainder
6003	78.0	3.7	0.05	0.34			0.4		0.05		remainder
6004	69.5	2.1	0.32	0.02			3.3			0.03	remainder 1
6005	76.8	2.8	0.03	0.07			0.8	0.21	0.02		remainder
6006	74.2	2.7	0.18	0.10			0.5	0.03		0.13	remainder
6007	76.1	3.2	0.12	0.05			1.7		0.12	0.02	remainder
6008	75.3	2.8	0.20	0.16			1.3	0.10	0.03	0.05	remainder
6009	77.0	3.1	0.14	0.06				0.21			remainder
6010	72.5	2.5	0.07	0.09				0.05	0.03		remainder
6011	74.7	2.9	0.10	0.32				0.14		0.10	remainder
6012	71.4	2.3	0.25	0.14				0.07	0.03	0.02	remainder
6013	74.7	3.0	0.13	0.05					0.12		remainder
6014	77.2	3.2	0.27	0.23					0.07	0.04	remainder

[Table 6] (continued)

No.	alloy composition (wt%)										
	Cu	Si	Pb	Bi	Te	Se	Sn	P	Sb	As	Zn
6015	74.0	2.8	0.07	0.03						0.03	remainder
6016	69.8	2.1	0.22		0.17		3.2				remainder
6017	73.8	2.9	0.15		0.03		1.6	0.07			remainder
6018	75.8	2.8	0.08		0.06		0.4		0.03		remainder
6019	71.2	2.3	0.15		0.07		2.5			0.07	remainder
6020	72.0	2.6	0.12		0.04		0.9	0.03	0.05		remainder

[Table 7]

No.	alloy composition (wt.%)										
	Cu	Si	Pb	Bi	Te	Se	Sn	P	Sb	As	Zn
6021	76.8	2.9	0.20		0.30		0.8	0.17		0.03	remainder
6022	78.3	3.2	0.15		0.36		0.4		0.06	0.14	remainder
6023	73.4	2.3	0.12		0.06		2.7	0.02	0.11	0.03	remainder
6024	74.6	2.8	0.05		0.08			0.19			remainder
6025	78.5	3.7	0.22		0.25			0.23	0.03		remainder
6026	74.9	2.9	0.16		0.05			0.05		0.10	remainder
6027	73.8	2.5	0.07		0.03			0.06	0.02	0.04	remainder
6028	74.8	2.6	0.12		0.02				0.12		remainder
6029	74.2	2.8	0.37		0.10				0.11	0.02	remainder
6030	76.3	3.2	0.08		0.05					0.07	remainder
6031	70.8	2.4	0.11			0.05	2.6				remainder
6032	74.6	3.0	0.25			0.32	0.6	0.06			remainder
6033	75.0	2.8	0.03			0.12	0.3		0.13		remainder
6034	73.5	2.8	0.12			0.07	1.0			0.11	remainder
6035	78.0	3.3	0.07			0.03	0.5	0.16	0.02		remainder
6036	72.4	2.5	0.13			0.05	3.1	0.03		0.05	remainder
6037	78.0	2.8	0.18			0.20	1.7		0.08	0.02	remainder
6038	76.5	3.1	0.10			0.11	1.7	0.03	0.03	0.04	remainder
6039	71.9	2.4	0.12			0.17		0.04			remainder
6040	77.0	3.5	0.03			0.35		0.23	0.03		remainder

[Table 8]

No.	alloy composition (wt%)										
	Cu	Si	Pb	Bi	Te	Se	Sn	P	Sb	As	Zn
6041	74.7	2.9	0.07			0.12		0.06		0.03	remainder
6042	72.8	2.5	0.20			0.06			0.03		remainder
6043	78.0	3.7	0.33			0.15			0.02	0.10	remainder
6044	74.0	2.8	0.12			0.05				0.08	remainder
6045	76.1	3.1	0.05			0.07		0.03	0.09	0.03	remainder

[Table 9]

No.	alloy composition (wt%)								
	Cu	Si	Pb	Sn	Al	P	Mn	Ni	Zn
7001	67.0	3.8	0.04	1.6			3.2		remainder
7001a									
7002	69.3	4.2	0.15	0.4				2.2	remainder
7002a									
7003	63.8	2.6	0.33	2.8			0.9		remainder
7003a									
7004	66.5	3.4	0.07	1.5			2.0		remainder
7004a									
7005	67.2	3.6	0.10	0.9			1.8	0.9	remainder
7005a									
7006	63.0	2.7	0.27	2.7	1.2		2.1		remainder
7006a									
7007	68.7	3.4	0.05	1.4	1.3		0.9		remainder
7007a									
7008	70.6	4.1	0.03	0.5	1.6		3.4		remainder
7008a									
7009	67.8	3.6	0.12	2.6	2.1			3.3	remainder
7009a									
7010	68.4	3.5	0.06	0.4	0.3			1.8	remainder
7010a									

[Table 10]

No.	alloy composition (wt%)								
	Cu	Si	Pb	Sn	Al	P	Mn	Ni	Zn
7011	73.9	4.4	0.17	1.2	1.7		0.8	1.5	remainder
7011a									
7012	65.5	2.9	0.20	1.5	1.0	0.12	2.3		remainder
7012a									
7013	66.1	3.3	0.08	1.8	1.1	0.03		2.6	remainder
7013a									
7014	70.3	3.9	0.15	1.0	1.4	0.21	1.8	1.2	remainder
7014a									
7015	66.8	3.7	0.20	2.6		0.14	2.7		remainder
7015a									
7016	69.0	4.0	0.07	0.5		0.20		3.2	remainder
7016a									
7017	64.5	2.9	0.19	1.8		0.05	1.5	0.8	remainder
7017a									
7018	72.4	3.5	0.08		1.5		1.1		remainder
7018a									
7019	69.2	3.9	0.03		0.4		3.1		remainder
7019a									
7020	76.6	4.3	0.14		2.3		1.9		remainder
7020a									

[Table 11]

No.	alloy composition (wt%)								
	Cu	Si	Pb	Sn	Al	P	Mn	Ni	Zn
7021	75.0	4.2	0.19		1.7			2.1	remainder
7021a									
7022	72.3	3.7	0.05		1.4		1.1	0.8	remainder
7022a									
7023	64.5	3.8	0.35		0.3		2.0	2.3	remainder
7023a									
7024	75.8	3.9	0.05		2.7	0.04	1.0		remainder
7024a									
7025	70.1	3.5	0.06		1.2	0.23		3.0	remainder
7025a									

[Table 11] (continued)

No.	alloy composition (wt%)								
	Cu	Si	Pb	Sn	Al	P	Mn	Ni	Zn
7026	67.2	2.8	0.22		1.8	0.14	2.2	0.9	remainder
7026a									
7027	70.2	3.8	0.11			0.03	3.2		remainder
7027a									
7028	75.9	4.4	0.03			0.20		1.1	remainder
7028a									
7029	66.0	3.0	0.18			0.12	1.0	2.1	remainder
7029a									

[Table 12]

No.	alloy composition (wt%)					
	Cu	Si	Pb	Al	P	Zn
8001	74.5	2.9	0.16	0.2	0.05	remainder
8002	76.0	2.7	0.03	1.2	0.21	remainder
8003	76.3	3.0	0.35	0.6	0.12	remainder
8004	69.9	2.1	0.27	0.3	0.03	remainder
8005	71.5	2.3	0.12	0.8	0.10	remainder
8006	78.1	3.6	0.05	0.2	0.13	remainder
8007	77.7	3.4	0.18	1.4	0.06	remainder
8008	77.5	3.5	0.03	0.9	0.15	remainder

[Table 13]

No.	alloy composition (wt%)								
	Cu	Si	Pb	Al	P	Bi	Te	Se	Zn
9001	74.8	2.8	0.05	0.6	0.07	0.03			remainder
9002	76.6	2.9	0.12	0.9	0.03	0.32			remainder
9003	72.3	2.2	0.32	0.5	0.12		0.25		remainder
9004	77.2	3.0	0.07	1.4	0.21		0.05		remainder
9005	78.1	3.6	0.16	0.3	0.15			0.29	remainder
9006	74.5	2.6	0.05	0.6	0.08			0.07	remainder

[Table 14]

No.	alloy composition (wt%)							
	Cu	Si	Pb	Al	P	Cr	Ti	Zn
10001	76.0	2.8	0.12	0.7	0.13		0.21	remainder
10002	75.0	3.0	0.03	0.2	0.05		0.03	remainder
10003	78.3	3.4	0.06	1.3	0.20		0.34	remainder
10004	69.6	2.1	0.25	0.8	0.03		0.17	remainder
10005	77.5	3.6	0.12	0.7	0.15	0.23		remainder
10006	71.8	2.2	0.32	1.2	0.08	0.32		remainder
10007	74.7	2.7	0.1	0.6	0.10	0.03		remainder
10008	75.4	2.9	0.03	0.3	0.06	0.12	0.08	remainder

[Table 15]

No.	alloy composition (wt%)									
	Cu	Si	Pb	Al	Bi	Te	Se	P	Cr	Ti	Zn
11001	76.5	2.9	0.08	0.9	0.03			0.12	0.03		remainder
11002	70.4	2.2	0.32	0.5	0.21			0.03	0.18		remainder
11003	78.2	3.5	0.16	1.3	0.35			0.20		0.34	remainder
11004	73.9	2.7	0.03	0.3	0.11			0.06		0.22	remainder
11005	75.8	3.0	0.06	0.6	0.08			0.11	0.10	0.07	remainder
11006	71.6	2.1	0.24	1.0		0.21		0.04	0.32		remainder
11007	73.8	2.4	0.10	1.1		0.04		0.07		0.03	remainder
11008	75.5	3.0	0.13	0.2		0.36		0.12	0.06	0.14	remainder
11009	77.7	3.2	0.03	1.4			0.17	0.23	0.23		remainder
11010	75.0	2.7	0.15	0.7			0.03	0.03		0.12	remainder
11011	72.9	2.4	0.20	0.8			0.31	0.06	0.09	0.05	remainder

[Table 16]

No.	alloy composition (wt%)				heat treatment	
	Cu	Si	Pb	Zn	temperature	time
12001	69.3	2.3	0.05	remainder	580°C	30min.
12002	69.3	2.3	0.05	remainder	450°C	2hr.
12003	78.5	2.9	0.05	remainder	580°C	30min.
12004	78.5	2.9	0.05	remainder	450°C	2hr.

[Table 17]

No.	alloy composition (wt%)								
	Cu	Si	Pb	Sn	Al	Mn	Ni	Fe	Zn
13001	58.8		3.1	0.2				0.2	remainder
13001a									
13002	61.4		3.0	0.2				0.2	remainder
13002a									
13003	59.1		2.0	0.2				0.2	remainder
13003a									
13004	69.2	1.2	0.1						remainder
13004a									
13005	remainder				9.8	1.1	1.2	3.9	
13005a									
13006	61.8		0.1	1.0					remainder
13006a									

[Table 18]

No.	machinability			corrosion resistance	hot workability	mechanical properties		stress corrosion cracking resistance
	form of chippings	condition of cut surface	cutting force (N)	maximum depth of corrosion (μm)	700°C deformability	tensile strength (N/mm^2)	elongation (%)	
1001	◎	○	117	160	○	533	35	○
1002	◎	○	114	170	○	520	32	○
1003	◎	○	119	140	△	575	36	○
1004	◎	○	118	220	△	490	30	△
1005	◎	○	114	170	○	546	34	○
1006	△	○	126	230	○	504	32	△
1007	◎	△	127	170	△	515	44	○

[Table 19]

No.	machinability			corrosion resistance	hot workability	mechanical properties		stress resistance corrosion cracking resistance
	form of chippings	condition of cut surface	cutting force (N)	maximum depth of corrosion (µm)	700°C deformability	tensile strength (N/mm^2)	elongation (%)	
2001	◎	○	116	180	○	510	33	○
2002	◎	○	115	230	△	475	28	△
2003	◎	○	115	160	△	540	32	○
2004	◎	○	117	150	△	576	35	○
2005	◎	○	116	140	△	543	37	○
2006	◎	○	114	180	△	502	32	○

[Table 20]

No.	machinability			corrosion resistance	hot workability	mechanical properties		stress resistance corrosion cracking resistance
	form of chippings	condition of cut surface	cutting force (N)	maximum depth of corrosion (µm)	700°C deformability	tensile strength (N/mm^2)	elongation (%)	
3001	◎	○	120	30	○	542	23	○
3002	◎	○	117	70	○	550	30	○
3003	◎	○	119	110	△	565	34	○
3004	◎	○	118	140	○	532	35	○
3005	◎	○	119	50	△	547	27	○
3006	◎	○	115	30	○	538	34	○
3007	◎	○	117	<5	△	562	36	○
3008	◎	○	119	<5	○	529	26	○
3009	◎	○	118	<5	△	518	30	○
3010	◎	○	116	<5	○	555	28	○

[Table 21]

No.	machinability			corrosion resistance	hot workability	mechanical properties		stress resistance corrosion cracking resistance
	form of chippings	condition of cut surface	cutting force (N)	maximum depth of corrosion (µm)	700°C deformability	tensile strength (N/mm^2)	elongation (%)	
4001	◎	○	119	70	○	535	30	○
4002	◎	○	116	120	○	547	33	○
4003	◎	○	118	60	△	539	26	○
4004	○	○	113	30	△	550	31	○
4005	◎	○	117	<5	○	534	27	○
4006	◎	○	118	<5	△	542	30	○
4007	○	○	116	<5	○	563	32	○
4008	◎	○	120	40	△	507	25	○
4009	◎	○	117	110	△	572	36	○
4010	◎	○	115	10	○	524	33	○
4011	◎	○	116	<5	△	580	31	○
4012	◎	○	114	20	○	575	34	○
4013	○	○	115	50	△	588	28	○
4014	◎	○	117	<5	○	543	26	○
4015	◎	○	117	60	○	501	27	○
4016	◎	○	116	130	△	539	32	○
4017	◎	○	118	50	○	574	34	○
4018	◎	○	115	<5	○	506	30	○
4019	◎	○	118	<5	○	523	28	○
4020	◎	○	115	20	△	548	32	○
4021	◎	○	118	<5	○	553	27	○

[Table 22]

No.	machinability			corrosion resistance	hot work-ability	mechanical properties		stress resistance corrosion cracking resistance
	form of chippings	condition of cut surface	cutting force (N)	maximum depth of corrosion (μm)	700°C deformability	tensile strength (N/mm^2)	elongation (%)	
5001	◎	○	116	70	○	525	34	○
5002	◎	○	120	40	△	501	25	○
5003	◎	○	117	<5	○	510	33	○
5004	◎	○	117	<5	△	547	42	○
5005	◎	○	115	<5	○	533	34	○
5006	◎	○	116	<5	○	470	30	△
5007	◎	○	118	<5	○	512	28	○
5008	◎	○	119	<5	△	558	36	○
5009	◎	○	120	50	△	595	31	○
5010	◎	○	121	<5	○	516	27	○
5011	◎	○	118	<5	△	569	34	○
5012	○	○	117	<5	○	523	30	○
5013	◎	○	116	<5	○	504	33	○
5014	○	○	114	<5	○	536	35	○
5015	◎	○	117	<5	○	488	31	○
5016	◎	○	116	<5	○	510	37	○
5017	◎	○	118	<5	△	557	32	○
5018	◎	○	117	<5	○	480	30	○
5019	◎	○	117	<5	○	511	31	○
5020	◎	○	115	<5	○	528	30	○

[Table 23]

No.	machinability			corrosion resistance	hot work-ability	mechanical properties		stress resistance corrosion cracking resistance
	form of chippings	condition of cut surface	cutting force (N)	maximum depth of corrosion (μm)	700°C deformability	tensile strength (N/mm^2)	elongation (%)	
6001	◎	○	119	40	○	515	25	○
6002	◎	○	117	<5	○	496	35	○
6003	◎	○	119	<5	△	570	34	○
6004	◎	○	118	<5	△	503	26	○
6005	◎	○	115	<5	○	536	37	○
6006	○	○	113	<5	○	512	33	○
6007	◎	○	117	<5	△	559	29	○
6008	○	○	115	<5	△	527	31	○
6009	◎	○	115	<5	△	546	40	○
6010	◎	○	116	<5	○	507	30	○
6011	○	○	113	<5	△	520	30	○
6012	◎	○	115	<5	△	488	29	△
6013	○	○	114	<5	○	531	32	○
6014	◎	○	114	<5	△	564	31	○
6015	◎	○	115	20	○	525	34	○
6016	◎	○	121	30	○	514	25	○
6017	◎	○	119	<5	○	510	27	○
6018	◎	○	116	<5	○	528	32	○
6019	◎	○	119	<5	○	526	28	○
6020	◎	○	116	<5	○	509	30	○

[Table 24]

No.	machinability			corrosion resistance	hot work-ability	mechanical properties		stress resistance corrosion cracking resistance
	form of chippings	condition of cut surface	cutting force (N)	maximum depth of corrosion (µm)	700°C deformability	tensile strength (N/mm^2)	elongation (%)	
6021	◎	○	113	<5	○	534	30	○
6022	◎	○	117	<5	○	562	34	○
6023	◎	○	120	<5	○	527	27	○
6024	◎	○	116	<5	○	515	33	○
6025	◎	○	117	<5	△	575	35	○
6026	◎	○	114	<5	○	524	32	○
6027	◎	○	119	<5	○	503	34	○
6028	◎	○	117	<5	○	510	33	○
6029	○	○	114	<5	△	522	30	○
6030	◎	○	118	40	○	546	37	○
6031	◎	○	119	<5	○	529	27	○
6032	◎	○	115	<5	△	545	30	○
6033	◎	○	116	<5	○	521	34	○
6034	◎	○	116	<5	○	513	31	○
6035	◎	○	118	<5	△	568	35	○
6036	◎	○	118	<5	○	536	26	○
6037	○	○	116	<5	○	530	29	○
6038	◎	○	117	<5	△	555	30	○
6039	◎	○	117	20	○	497	31	○
6040	◎	○	118	<5	△	574	35	○

[Table 25]

No.	machinability			corrosion resistance	hot work-ability	mechanical properties		stress resistance corrosion cracking resistance
	form of chippings	condition of cut surface	cutting force (N)	maximum depth of corrosion (μm)	700°C deformability	tensile strength (N/mm^2)	elongation (%)	
6041	◎	○	115	<5	○	520	34	○
6042	◎	○	117	20	△	501	31	○
6043	◎	○	118	<5	△	585	32	○
6044	◎	○	116	<5	○	516	32	○
6045	◎	○	116	<5	○	538	35	○

[Table 26]

No.	machinability			hot work-ability	mechanical properties	
	form of chippings	condition of cut surface	cutting force (N)	700°C deformability	tensile strength (N/mm^2)	elongation (%)
7001	◎	○	132	○	755	17
7002	◎	○	127	○	776	19
7003	◎	△	135	○	620	15
7004	◎	○	130	○	714	18
7005	◎	○	128	○	708	19
7006	◎	○	130	○	685	16
7007	◎	○	132	○	717	18
7008	◎	○	130	○	811	18
7009	◎	○	130	○	790	15
7010	◎	○	131	○	708	18
7011	◎	○	128	○	810	17
7012	◎	○	128	○	694	17
7013	◎	○	132	○	742	16
7014	◎	○	128	○	809	17
7015	◎	○	129	○	725	15
7016	◎	○	128	○	765	18
7017	◎	○	130	○	684	16
7018	◎	○	128	○	710	21
7019	◎	○	128	○	746	20

[Table 26] (continued)

No.	machinability			hot work-ability	mechanical properties	
	form of chippings	condition of cut surface	cutting force (N)	700°C deformability	tensile strength (N/mm^2)	elongation (%)
7020	◎	○	126	○	802	19

[Table 27]

No.	machinability			hot work-ability	mechanical properties	
	form of chippings	condition of cut surface	cutting force (N)	700°C deformability	tensile strength (N/mm^2)	elongation (%)
7021	◎	○	126	○	792	19
7022	◎	○	128	○	762	20
7023	◎	○	129	○	725	17
7024	◎	○	128	○	744	21
7025	◎	○	130	○	750	20
7026	△	○	132	○	671	23
7027	◎	○	128	○	740	23
7028	◎	○	133	○	763	22
7029	△	○	129	○	647	24

【Table 28】

No.	machinability			corrosion resistance	hot workability	mechanical properties		stress resistance	high-temperature oxidation
	form of chippings	condition of cut surface	cutting force (N)	maximum depth of corrosion (μm)	700℃ deformability	tensile strength (N/mm^2)	elongation (%)	corrosion cracking resistance	increase in weight by oxidation ($mg/10cm^2$)
8001	◎	○	114	<5	○	528	35	○	0.5
8002	◎	○	116	<5	○	545	37	○	0.2
8003	○	○	113	<5	△	547	34	○	0.4
8004	◎	○	116	40	○	482	30	△	0.5
8005	◎	○	117	<5	○	502	32	○	0.3
8006	◎	○	117	<5	△	570	36	○	0.4
8007	◎	○	117	<5	○	575	33	○	0.2
8008	◎	○	118	<5	○	552	36	○	0.3

【Table 2 9】

No.	machinability			corrosion resistance	hot work-ability	mechanical properties		stress resistance	high-temperature oxidation
	form of chipp-ings	conditi-on of cut surface	cutti-ng force (N)	maximum depth of corrosion (μm)	700℃ deformabi-lity	tensile strength (N/mm²)	elongat-ion (%)	corrosion cracking resistance	increase in weight by oxidation (mg/10cm²)
9001	◎	○	115	<5	○	526	33	○	0.4
9002	○	○	113	20	△	543	30	○	0.3
9003	○	○	115	<5	△	508	28	○	0.4
9004	◎	○	117	<5	○	567	37	○	0.2
9005	◎	○	115	<5	△	571	33	○	0.4
9006	◎	○	116	<5	○	513	35	○	0.4

【Table 30】

No.	machinability			corrosion resistance	hot workability	mechanical properties		stress resistance	high-temperature oxidation
	form of chippings	condition of cut surface	cutting force (N)	maximum depth of corrosion (μm)	700℃ deformability	tensile strength (N/mm^2)	elongation (%)	corrosion cracking resistance	increase in weight by oxidation ($mg/10cm^2$)
10001	◎	○	115	<5	○	534	38	○	0.1
10002	◎	○	116	10	○	538	36	○	0.4
10003	◎	○	117	<5	○	563	39	○	<0.1
10004	◎	○	115	<5	○	505	30	△	0.2
10005	◎	○	116	<5	△	572	38	○	0.2
10006	◎	○	115	<5	○	514	28	○	0.1
10007	◎	○	114	<5	○	525	34	○	0.2
10008	◎	○	115	20	○	530	36	○	0.2

【Table 31】

No.	machinability			corrosion resistance	hot workability	mechanical properties		stress resistance corrosion cracking resistance	high-temperature oxidation
	form of chippings	condition of cut surface	cutting force (N)	maximum depth of corrosion (μm)	700℃ deformability	tensile strength (N/mm^2)	elongation (%)		increase in weight by oxidation (mg/10cm^2)
11001	◎	○	115	<5	○	552	35	○	0.2
11002	◎	○	116	30	△	504	28	△	0.2
11003	◎	○	115	<5	△	598	34	○	<0.1
11004	◎	○	116	<5	○	515	32	○	0.1
11005	○	○	113	<5	○	540	35	○	0.1
11006	◎	○	116	20	△	487	31	○	0.1
11007	◎	○	117	<5	○	524	32	○	0.1
11008	○	○	114	<5	○	537	30	○	0.2
11009	◎	○	115	<5	△	569	35	○	0.1
11010	◎	○	115	10	○	531	32	○	0.1
11011	◎	○	116	<5	○	510	29	○	0.1

[Table 32]

No.	machinability			corrosion resistance	hot workability	mechanical properties		stress resistance corrosion cracking resistance
	form of chippings	condition of cut surface	cutting force (N)	maximum depth of corrosion (μm)	700°C deformability	tensile strength (N/mm^2)	elongation (%)	
12001	◎	○	122	210	○	486	36	○
12002	◎	○	119	200	○	490	35	○
12003	◎	○	120	160	△	501	40	○
12004	◎	○	119	160	△	505	41	○

【Table 33】

No.	machinability			corrosion resistance	hot workability	mechanical properties		stress resistance	high-temperature oxidation
	form of chippings	condition of cut surface	cutting force (N)	maximum depth of corrosion (μm)	700℃ deformability	tensile strength (N/mm^2)	elongation (%)	corrosion cracking resistance	increase in weight by oxidation ($mg/10cm^2$)
13001	○	○	103	1100	△	408	37	××	1.8
13002	○	○	101	1000	×	387	39	××	1.7
13003	○	△	112	1050	○	414	38	××	1.7
13004	×	○	223	900	○	438	38	×	1.2
13005	×	○	178	350	△	735	28	○	0.2
13006	×	○	217	600	○	425	39	×	1.8

【Table 34】

No.	wear resistance
	weight loss by wear (mg/100000rot.)
7001a	0.7
7002a	1.4
7003a	2.0
7004a	1.4
7005a	1.2
7006a	1.8
7007a	2.3
7008a	0.7
7009a	0.6
7010a	1.3
7011a	0.8
7012a	1.7
7013a	1.1
7014a	0.8
7015a	1.1
7016a	1.0
7017a	1.6
7018a	1.9
7019a	1.1
7020a	1.4

【Table 35】

No.	wear resistance
	weight loss by wear (mg/100000rot.)
7021a	1.5
7022a	1.4
7023a	0.9
7024a	2.0
7025a	1.2
7026a	1.2
7027a	1.1
7028a	2.1
7029a	1.5

[Table 36]

No.	wear resistance
	weight loss by wear (mg/100000rot.)
13001a	500
13002a	620
13003a	520
13004a	450
13005a	25
13006a	600

Claims

1. A free-cutting copper alloy which comprises 69 to 79 percent, by weight, of copper; 2.0 to 4.0 percent, by weight, of silicon; 0.02 to 0.4 percent, by weight, of lead; and the remaining percent, by weight, of zinc.

2. A free-cutting copper alloy which comprises 69 to 79 percent, by weight, of copper; 2.0 to 4.0 percent, by weight, of silicon; 0.02 to 0.4 percent, by weight, of lead; one element selected from among 0.02 to 0.4 percent, by weight,

of bismuth, 0.02 to 0.4 percent, by weight, of tellurium, and 0.02 to 0.4 percent, by weight, of selenium; and the remaining percent, by weight, of zinc.

3. A free-cutting copper alloy which comprises 70 to 80 percent, by weight, of copper; 1.8 to 3.5 percent, by weight, of silicon; 0.02 to 0.4 percent, by weight, of lead; at least one element selected from among 0.3 to 3.5 percent, by weight, of tin, 1.0 to 3.5 percent, by weight, of aluminum, and 0.02 to 0.25 percent, by weight, of phosphorus; and the remaining percent, by weight, of zinc.

4. A free-cutting copper alloy which comprises 70 to 80 percent, by weight, of copper; 1.8 to 3.5 percent, by weight, of silicon; 0.02 to 0.4 percent, by weight, of lead; at least one element selected from among 0.3 to 3.5 percent, by weight, of tin, 1.0 to 3.5 percent, by weight, of aluminum, and 0.02 to 0.25 percent, by weight, of phosphorus; one element selected from among 0.02 to 0.4 percent, by weight, of bismuth, 0.02 to 0.4 percent, by weight, of tellurium, and 0.02 to 0.4 percent, by weight, of selenium; and the remaining percent, by weight, of zinc.

5. A free-cutting copper alloy which comprises 69 to 79 percent, by weight, of copper; 2.0 to 4.0 percent, by weight, of silicon; 0.02 to 0.4 percent, by weight, of lead; at least one element selected from among 0.3 to 3.5 percent, by weight, of tin, 0.02 to 0.25 percent, by weight, of phosphorus, 0.02 to 0.15 percent, by weight, of antimony, and 0.02 to 0.15 percent, by weight, of arsenic, and the remaining percent, by weight, of zinc.

6. A free-cutting copper alloy which comprises 69 to 79 percent, by weight, of copper; 2.0 to 4.0 percent, by weight, of silicon; 0.02 to 0.4 percent, by weight, of lead; at least one element selected from among 0.3 to 3.5 percent, by weight, of tin, 0.02 to 0.25 percent, by weight, of phosphorus, 0.02 to 0.15 percent, by weight, of antimony, and 0.02 to 0.15 percent, by weight, of arsenic; one element selected from among 0.02 to 0.4 percent, by weight, of bismuth, 0.02 to 0.4 percent, by weight, of tellurium, and 0.02 to 0.4 percent, by weight, of selenium; and the remaining percent, by weight, of zinc.

7. A free-cutting copper alloy which comprises 62 to 78 percent, by weight, of copper; 2.5 to 4.5 percent, by weight, of silicon; 0.02 to 0.4 percent, by weight, of lead; at least one element selected from among 0.3 to 3.0 percent, by weight, of tin, 0.2 to 2.5 percent, by weight, of aluminum, and 0.02 to 0.25 percent, by weight, of phosphorus; and at least one element selected from among 0.7 to 3.5 percent, by weight, of manganese and 0.7 to 3.5 percent, by weight, of nickel; and the remaining percent, by weight, of zinc.

8. A free-cutting copper alloy which comprises 69 to 79 percent, by weight, of copper; 2.0 to 4.0 percent, by weight, of silicon; 0.02 to 0.4 percent, by weight, of lead; 0.1 to 1.5 percent, by weight, of aluminum; and 0.02 to 0.25 percent, by weight, of phosphorus; and the remaining percent, by weight, of zinc.

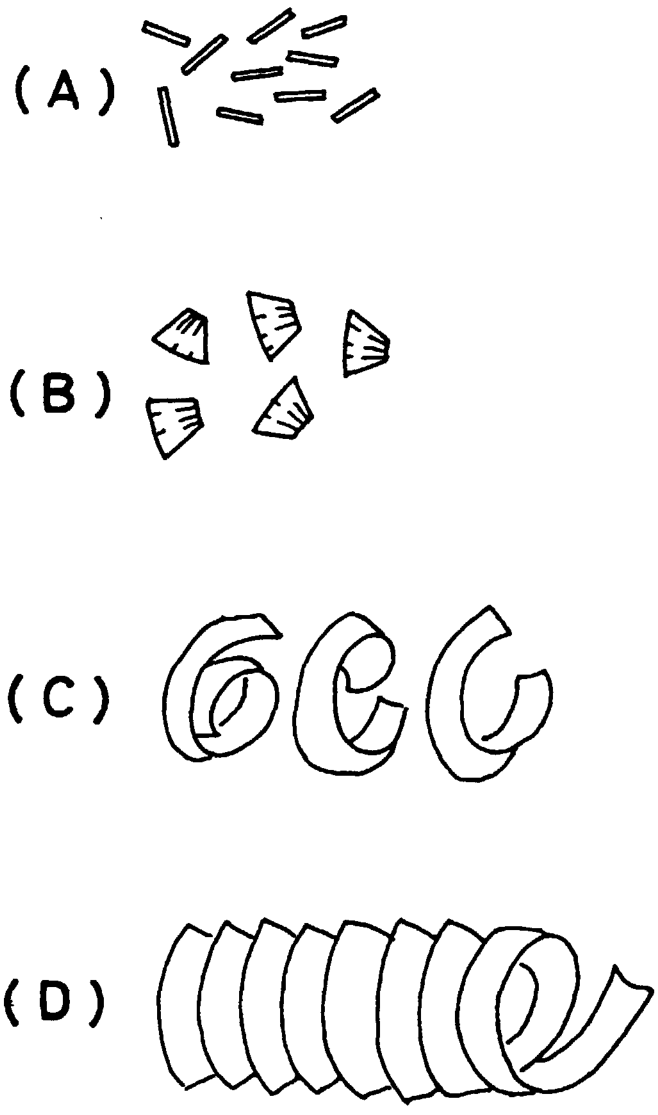
9. A free-cutting copper alloy which comprises 69 to 79 percent, by weight, of copper; 2.0 to 4.0 percent, by weight, of silicon; 0.02 to 0.4 percent, by weight, of lead; 0.1 to 1.5 percent, by weight, of aluminum; 0.02 to 0.25 percent, by weight, of phosphorus; one element selected from among 0.02 to 0.4 percent, by weight, of bismuth, 0.02 to 0.4 percent, by weight, of tellurium, and 0.02 to 0.4 percent, by weight, of selenium; and the remaining percent, by weight, of zinc.

10. A free-cutting copper alloy which comprises 69 to 79 percent, by weight, of copper; 2.0 to 4.0 percent, by weight, of silicon; 0.02 to 0.4 percent, by weight, of lead; 0.1 to 1.5 percent, by weight, of aluminum; 0.02 to 0.25 percent, by weight, of phosphorus; at least one element selected from among 0.02 to 0.4 percent, by weight, of chromium and 0.02 to 0.4 percent, by weight, of titanium; and the remaining percent, by weight, of zinc.

11. A free-cutting copper alloy which comprises 69 to 79 percent, by weight, of copper; 2.0 to 4.0 percent, by weight, of silicon; 0.02 to 0.4 percent, by weight, of lead; 0.1 to 1.5 percent, by weight, of aluminum; 0.02 to 0.25 percent, by weight, of phosphorus; at least one element selected from among 0.02 to 0.4 percent, by weight, of chromium and 0.02 to 0.4 percent by weight of titanium; one element selected from among 0.02 to 0.4 percent, by weight, of bismuth, 0.02 to 0.4 percent, by weight, of tellurium and 0.02 to 0.4 percent, by weight, of selenium; and the remaining percent, by weight, of zinc.

12. A free-cutting copper alloy as defined in claim 1, claim 2, claim 3, claim 4, claim 5, claim 6, claim 7, claim 8, claim 9, claim 10 or claim 11, which is subjected to a heat treatment for 30 minutes to 5 hours at 400 to 600°C.

FIGURE 1



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP98/05156

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl^6 C22C9/04, C22F1/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
Int.Cl^6 C22C9/04, C22F1/08

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1926-1996	Toroku Jitsuyo Shinan Koho	1994-1999
Kokai Jitsuyo Shinan Koho	1971-1999	Jitsuyo Shinan Toroku Koho	1996-1999

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP, 56-96040, A (Suwa Seikosha K.K.), 3 August, 1981 (03. 08. 81), Claims ; page 1, lower left column, lines 9 to 12 (Family: none)	1-12
X Y	JP, 61-133357, A (Showa Keikinzoku K.K.), 20 June, 1986 (20. 06. 86), Claims ; page 2, lower right column, line 16 to page 3, upper right column, line 15 (Family: none)	7 1-6, 8-12
X Y	JP, 62-297429, A (Japan Energy Corp.), 24 December, 1987 (24. 12. 87), Claims ; page 2, upper right column, line 15 to page 3, upper left column, line 2 (Family: none)	7, 12 1-6, 8-11

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