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(54) **SULFUR-RICH CORROSION-RESISTANT COPPER-ZINC ALLOY**

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(57) **ABSTRACT**

Copper-zinc alloys exhibiting enhanced oxidation resistance are provided by adding an amount of sulfur that is effective to enhance oxidative resistance. Such sulfur addition can be achieved by forming a sulfur-rich pre-mix that is added to a base alloy composition. This technique provides improved homogeneity and distribution of the sulfur predominantly in the form of a metal sulfide.

SULFUR-RICH CORROSION-RESISTANT COPPER-ZINC ALLOY

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority under 35 U.S.C. §119(e) to U.S. Provisional Patent Application No. 61/556,376, filed Nov. 7, 2011, entitled "SULFUR-RICH CORROSION-RESISTANT COPPER-ZINC ALLOY", which is herein incorporated by reference in its entirety.

FIELD

[0002] Disclosed are sulfur-rich, corrosion-resistant copper-zinc alloys and methods for preparing same.

BACKGROUND

[0003] Sulfur is typically an incidental impurity in brass alloys, and is typically present in an amount that does not exceed 0.005% by weight. In fact, it is disclosed in the published literature that sulfur in an amount greater than 0.01% by weight may negatively impact brass alloys, causing the brass alloy to become brittle.

[0004] However, it is known to add sulfur to brass alloys to impart improved machinability. More specifically, sulfur has been added to molten ferrous and non-ferrous alloys (including copper alloys) to promote free-machining characteristics. The sulfur acts singularly or in combination with other alloy constituents to produce particles that act as chip breakers during machining. For example, U.S. Pat. No. 5,137,685 discloses the addition of sulfur to copper alloys, in combination with bismuth, in order to improve machinability. However, this patent expressly places an upper limit for sulfur at about 2% by weight, and indicates a preference for an amount of sulfur that is from about 0.1% to about 1.0%.

[0005] Generally, the insolubility of free sulfur and of sulfur-rich inter-metallic compounds in the alloy matrix is understood to determine the effectiveness of sulfur addition for improving machinability.

[0006] It is believed that the known benefit of adding sulfur to a brass alloy is limited to improved machinability, and that the known brass alloys incorporating sulfur, even those exhibiting improved machinability due to sulfur addition, do not exhibit enhanced corrosion resistance.

SUMMARY

[0007] One embodiment includes a copper-zinc alloy having from about 10% to about 45% zinc by weight, at least about 50% copper by weight, and an amount of sulfur that is effective to enhance the oxidative resistance thereof.

[0008] Another embodiment relates to a process for preparing an oxidation resistant copper-zinc alloy by combining sulfur and a pre-mix metal under conditions suitable for forming a molten alloy pre-mix, preparing a base alloy, and combining the alloy pre-mix and the base alloy, where the pre-mix metal is chosen from the group of copper, zinc, aluminum, lead, bismuth, tin or a combination thereof. The base alloy may comprise primarily copper, primarily zinc, or a mixture of copper and zinc, and may also contain other alloying additives.

[0009] Another embodiment relates to the use of an oxidation-resistant brass alloy as described herein as a component of a water-conveying conduit system for potable water.

DETAILED DESCRIPTION

[0010] This disclosure is concerned primarily with the use of sulfur to enhance corrosion-resistance of copper-zinc alloys.

[0011] The copper-zinc alloys described herein are generally referred to as brass alloys or brasses. The terms "brass alloys" or "brasses" used herein generally refer to an alloy including copper and zinc wherein the element in greatest abundance is copper and wherein zinc is present in an amount that is in excess of about 10% by weight.

[0012] As used herein, the term "oxidative resistance" (or "oxidation resistant") refers to resistance to dezincification and stress corrosion cracking, and resistance to corrosion in general, or any combination of the foregoing.

[0013] The expression "substantially free of lead" is generally synonymous with the expression "lead-free" and refers to a brass alloy that does not contain any deliberately added lead and only contains very low levels of unavoidable lead impurities. Such brass alloys that are substantially free of lead contain lead in an amount of about 0.25% or less on a weight basis, such as less than or about 0.2% or less than or about 0.1%.

[0014] Dezincification is characterized by the selective loss of zinc from a brass alloy. Dezincification is generally caused by contact of a brass alloy with corrosive agents or contaminants, which are commonly found in water or water vapor. Over an extended period of time (e.g., greater than about 3 years), contact between conventional brasses and moisture causes a white, loose zinc oxide surface deposit to form.

[0015] Stress corrosion cracking refers to a type of cracking that occurs either with or without dezincification, and causes a loss of mechanical strength and may ultimately result in fracture of an alloy due to internal stresses associated with the composition or processing of the alloy.

[0016] All percentages, unless otherwise indicated herein, refer to the amount by weight of the element, irrespective of whether the element is present in the alloy in its elemental form or in the form of an inter-metallic complex.

[0017] The oxidation resistance of brass alloys can be improved by the addition of sulfur. Different alloy types generally require different sulfur levels to gain optimum oxidation resistance. In general, the enhanced oxidation resistance benefits are expected to apply to substantially all brass alloys containing zinc in an amount that is in excess of about 10% by weight, for example, from about 10% to about 45% by weight, from about 12% to about 40% by weight, and from about 15% to about 35% by weight, or from about 35% to about 45% by weight. The addition of sulfur as described herein is effective for enhancing corrosion resistance of either leaded brass alloys or lead-free brass alloys.

[0018] Surprisingly, the sulfur additive is at least as effective at imparting oxidation resistance as conventional brass corrosion inhibiting additives such as selenium, tellurium, lead, tin, iron, nickel, aluminum, manganese, bismuth, antimony, phosphorous, arsenic, etc., and costs significantly less. While sulfur can be employed as an effective oxidation resistance additive for brasses containing conventional corrosion inhibiting additives, such conventional corrosion inhibiting additives are not necessary to achieve effective oxidation resistance when a sulfur additive is employed. Eliminating or reducing the use of conventional corrosion inhibiting additives is expected to mitigate undesirable property changes caused by their addition and reduce or eliminate the need for environmentally undesirable or questionable additives. Thus,

the use of a sulfur as an oxidation resistant additive as disclosed herein offers a potentially low cost and environmentally more acceptable technique for achieving oxidation resistance in brass alloys.

[0019] There are drawbacks to many of the traditional corrosion inhibitors used with brass alloys. For example, additions of arsenic and/or antimony in amounts less than about 0.2% inhibit dezincification of certain brass alloys, but require heat treatment in order to be effective and the additives are generally ineffective at inhibiting stress corrosion cracking. Nickel, tin, and/or aluminum may be added in amounts ranging from about 0.25% to about 2% to inhibit dezincification, but the nickel, tin and/or aluminum additives tend to cause the brass alloy to develop undesirable property changes. The use of excess traditional corrosion inhibitors may promote initiation of internal stress corrosion fractures along grain boundaries of the brass alloy. In contrast, sulfur appears to present no risk of stress corrosion cracking as demonstrated by excellent mechanical performance.

[0020] Degrading elements such as iron, manganese, calcium, tellurium and cobalt tend to react with conventional dezincification inhibitors to reduce their beneficial effect, or to cause a deleterious effect on the alloy when the degrading element is present at a high level. The high reaction potential of zinc and sulfur is expected to limit the negative influence of such degrading elements.

[0021] Additionally, there are no previously known inhibitor additives that are generally effective for fully protecting brasses containing greater than about 35% zinc. For brass alloys containing greater than about 35% zinc, the traditional corrosion inhibitors become sensitized to stress corrosion cracking. However, as described herein, the sulfur additive provides increased oxidation resistance for brass alloys with zinc concentrations from about 35% to about 45%. Brass alloys having a zinc content in excess of about 35% by weight have two separate structural components, including one that is copper-rich, and another that is zinc-rich. As the zinc content increases the percent of the zinc-rich component increases. Corrosion potential increases with a greater zinc-rich component percentage and the zinc-rich component is preferentially attacked during both dezincification and stress corrosion cracking, with a dramatic spike occurring above about 38% zinc by weight. Machinability also increases with an elevated percentage of the zinc-rich component, with a dramatic improvement in machinability occurring for a zinc content over 38% by weight.

[0022] When sulfur is present in high concentrations in a brass alloy through late addition of sulfur to the melt or without employing methods to aid in its distribution throughout the alloy, the sulfur tends to have an uneven distribution in the brass alloy. The uneven distribution of the sulfur, usually in the form of zinc sulfide, negatively impacts mechanical properties of parts made from the alloy. However, the reaction between zinc and sulfur to form a zinc sulfide, which generally floats on top of the molten alloy and is removed as slag during processing, generally works to limit sulfur below 0.1% by weight in brass alloys unless additional methods are used to aid the distribution of the sulfur. The level of sulfur is therefore self-regulated to lower concentrations that do not negatively impact mechanical properties due to the removal of zinc sulfide as slag during processing, and the sulfur which remains is generally retained along grain boundaries.

[0023] Non-limiting examples of methods to aid in the distribution of sulfur include the addition of alloying elements which aid in the distribution of sulfur, including without limitation aluminum and tin, the addition of the sulfur as part of a pre-mix, and the use of certain casting methods, including without limitation rapid casting solidification through a process such as permanent mold casting. Higher levels of sulfur in the alloy with a more uniform distribution throughout the alloy may be achieved using such methods.

[0024] Sulfur increases oxidation resistance of brass alloys due to an inherent segregation of zinc sulfide or copper sulfide along alloy grain boundaries. This grain boundary oxidation resistance barrier is similar to that afforded by the addition of the traditional corrosion inhibiting agent arsenic, however, the sulfur-induced oxidation resistance barrier does not require heat treatment to develop its oxidation resistance.

[0025] The base oxidation resistance that is imparted to a brass alloy by sulfur-enrichment can be increased by grain refinement through manufacturing processes. For example, forging and cold-working processes reduce microstructural grain size, limiting pathways for corrosion or oxidation to penetrate into the brass alloy. The permanent mold casting process has a similar end result of grain refinement and increased oxidation resistance because of the rapid solidification of metal during casting. The sulfur-enhanced oxidation resistance of castings can also be further improved through the addition of traditional grain refiners, such as phosphorus.

[0026] Sulfur-enriched brass alloys demonstrate excellent mechanical properties, including high ductility, and are considered to be highly resistant to stress corrosion cracking Also, the observed high ductility is considered to have an important benefit with respect to cold working of certain brass alloys. The presence of inter-granular zinc sulfide is believed to promote slip along grain boundaries, resulting in reduced yield strength and higher percent elongation for certain brass alloys.

[0027] Additionally, aluminum has been found to be effective in retaining sulfur in brass alloys. During alloy melting, it has been observed that the retention of sulfur within certain brasses is strongly influenced by a high zinc content in the alloy. The strong affinity of sulfur for zinc promotes the formation of zinc sulfides that tend to float up in the furnace melt and are ultimately removed from the surface of the bath as slag. Although a portion of the zinc sulfides do remain within the alloy along grain boundaries in amounts adequate to aid dezincification resistance, the retention of the sulfur is less predictable. The addition of aluminum has been shown to maintain sulfur in the alloy, increasing sulfur recoveries and the consistency of sulfur-enrichment. A suitable amount of sulfur additive that may be used to achieve enhanced oxidative resistance can be in excess of about 2% by weight, such as from about 2.1% to about 4% by weight, or from about 2.5% to about 4% by weight. However, smaller amounts may also be employed to achieve a beneficial improvement in oxidative resistance. When distributed throughout the brass alloy as described herein, sulfur in amounts as low as 0.006% are expected to provide some enhancements to the oxidation resistance of the resulting brass alloy.

[0028] In addition to the specified amounts of zinc, copper and sulfur, and any optional alloying elements previously described, the brass alloys disclosed herein may contain minor amounts of elements including without limitation silicon, selenium, tellurium, manganese, bismuth, antimony, phosphorous, lead, tin, iron, nickel, aluminum and/or arsenic. These elements may be present in amounts from about 0.006% to about 6% by weight, and preferably in amounts

from about 0.1% and about 6%, or, for tin and aluminum from about 0.02% to about 6%. These elements may also be present in trace amounts in certain embodiments, and lesser amounts may provide some minor additional benefit for processing. Additional trace elements or impurities may also be present in the brass alloys.

[0029] Unlike with previously known sulfur additions to brasses, which generally sought to segregate sulfur in larger sulfur-rich phases to improve machinability, certain processes disclosed herein seek to achieve a more homogeneous distribution of sulfur in the form of much smaller particles. In addition, in accordance with certain embodiments, the added sulfur is homogeneously distributed throughout the alloy in the form of a metal sulfide. The zinc sulfide is fluorescent and shows as a distinct yellow throughout an alloy that has uniform distribution of the sulfide.

[0030] The copper-zinc alloys disclosed herein can be prepared by a conventional process in which elemental sulfur is simply added directly to a brass furnace melt. This method appears to provide less control over sulfur content than other processes disclosed herein. Additionally, much of the added sulfur tends to float on top of the melt and is not incorporated into the alloy, as described above. Late additions of elemental sulfur also tend to generate excess sulfur dioxide fuming in non-controlled atmospheres, and may result in substantial sulfur loss due to the low vapor point of sulfur and the reaction between sulfur and zinc. The risk of release of toxic sulfur dioxide and zinc sulfide releases can be mitigated through the use of proper melting equipment and practices, such as the traditional practice of using an inert gas cover over the molten bath, which eliminates exposure of the metal to oxygen and mitigates sulfur dioxide evolution.

[0031] An alternative method involves combining sulfur and zinc under conditions sufficient to form a molten alloy pre-mix. In this process, elemental zinc and sulfur (e.g., in the form of a powder) are placed in a containment vessel. Oxygen is replaced with nitrogen for some batches, but either atmosphere works satisfactorily to create a sulfur-zinc pre-mix. In order to combine the sulfur and zinc, the vessel is heated to approximately 1000° F. After the vessel has been heated long enough to combine the elements into a mixture, the vessel is cooled, and the sulfur-rich atmosphere is evacuated. The sulfur-zinc mixture is then removed.

[0032] A base charge of the copper alloy is prepared in a melting furnace. The base alloy includes all additions needed to complete alloying other than zinc and sulfur. Some elemental zinc can then be added to the base alloy containment vessel to reduce the melting point of the base alloy when the sulfur-zinc mixture is added. The resulting alloy can be cast into articles, such as pipe fittings or other components, or cast into ingots. If desired, the solidified brass alloy may be subjected to various treatments before being used to fabricate articles. Such treatments include without limitation cold-working, annealing, etc.

[0033] In another alternative method, sulfur and copper are combined under conditions to form a molten alloy pre-mix. In this process, elemental copper and sulfur (e.g., powder form) are placed in a containment vessel and heated to a molten state to produce a sulfur-copper pre-mix. Additional elements such as aluminum may be added to the copper-sulfur pre-mix to help retain the sulfur within the pre-mix melt.

[0034] In this processing method, a base alloy containing zinc and optionally containing copper and/or other elements in minor amounts is prepared. Thereafter, the copper-sulfur pre-mix and the base alloy are combined. Optionally, added zinc, copper and/or other elements may be combined with the alloy pre-mix and/or the base alloy. The resulting alloy may be cast or treated as stated previously.

[0035] Alternatively, after preparation of a copper-sulfur pre-mix, zinc can be added in a controlled manner to the copper-sulfur pre-mix. The reaction between zinc and sulfur is moderated by the foundational sulfur-enriched copper-sulfur premix.

[0036] It is believed that the processes involving combining sulfur and zinc to form a pre-mix that is combined with a base copper alloy and/or the process for combining sulfur and copper to form a pre-mix that is combined with a base alloy have the effect of ensuring that a larger proportion of the elemental sulfur addition is homogenously distributed within the completed alloy, and is present in the form of a metal sulfide (e.g., zinc sulfide or copper sulfide) in higher proportion than has been achieved with known techniques of incorporating sulfur within a brass alloy. For example, it is expected that copper zinc alloys prepared in accordance with certain processes disclosed herein will provide homogenous distribution of sulfur throughout the solid alloy predominately in the form of an intermetallic sulfide (e.g., copper sulfide and/or zinc sulfide).

[0037] Once the sulfur alloy has been properly constructed, sulfur levels have only modest loss through repeated re-melting. The metal off-fall streams of manufacturing (such as gating and scrap) can be melted repeatedly for reuse without any significant loss of sulfur.

[0038] Another alloy preparation method includes combining sulfur and a secondary alloying ingredient together to create an additive pre-mix. For example, sulfur powders can be melted together with metal powders or metal solid forms in an oxygen-free containment vessel to produce sulfur-metal mixtures that can be added to a molten alloy bath containing the remaining constituents of the brass alloy. Certain pre-mix combinations are preferred due to the reaction and loss of sulfur in specific alloys. The metals that can be used in the premix include without limitation, copper, zinc, aluminum, lead, bismuth and tin.

[0039] A pre-mix as described herein can also be used to adjust the sulfur content in a brass alloy directly before casting.

[0040] The addition of sulfur in the form of a copper-based pre-mix may also aid in removing oxides from the molten metal. This late alloy addition may offer an alternative to traditional deoxidizing additives such as phosphorus copper.

[0041] In addition to enhanced corrosion resistance, other benefits have been demonstrated by the disclosed sulfur additions to copper-zinc alloys. For example, heat treatment of such alloys has proven to improve free-machining properties of sulfur-rich alloys by agglomerating sulfur into chip-breaking constituents. Corrosion resistance appears to be modestly degraded by heat treatment and the resultant agglomeration of sulfur. The amount of sulfur added can be increased in these heat treated alloys to off-set the agglomerated sulfur.

[0042] In leaded alloys, it is expected that heat treatment will potentially segregate sulfur along with free pockets of lead. In other words, the lead is not expected to significantly go into solution within the alloy matrix, but is instead expected to form discrete volumes of lead agglomerates that improve machinability. Heat treatment (and the resultant segregation of sulfur) is expected to aid machining as a secondary benefit of these alloys.

[0043] Additionally, the sulfur additive is expected to reduce the amount of lead leeching from a lead-containing part into potable water. More specifically, it is expected that the combination of lead and sulfur within the alloy will be less susceptible to leeching.

[0044] Preliminary data suggests that the disclosed sulfur treatment does not have a detrimental effect on soldering, but may actually improve solderability.

[0045] The intermetallic sulfide at the surface of a casting made of the disclosed alloys appears to be cleaned by zinc chloride flux without adverse corrosion or unwanted flux to metal reaction during soldering.

[0046] Sulfur treated parts have maintained corrosion resistance after the treatment with dilute citric acid and/or ultrasonic cleaning.

[0047] The copper-zinc alloys described herein are sufficiently resistant to corrosion via dezincification and stress corrosion cracking that they are expected to be suitable for use in the fabrication of a plumbing component or other component used in a water-conveying conduit system (e.g., cooling tower piping). Prior to the current disclosure, it was believed that the copper-zinc alloys had inadequate corrosion resistance for use in plumbing systems or other water-conveying conduit systems.

EXAMPLE 1

[0048] One example of the making of brass alloy parts includes melting copper, and adding zinc and aluminum to the melted copper to create a base metal bath. Sulfur is then added directly to the molten metal bath under an inert gas blanket. In this example, the target amount of sulfur added to the bath was 0.1% sulfur. The inert gas allows retention of some of the sulfur in the bath, though some is lost as a zinc sulfide or because it is otherwise not incorporated into the bath. The molten metal is then formed into ingots with the following composition: 63.12% copper, about 36.76% zinc, about 0.064% aluminum; 0.003% lead and 0.031% sulfur. These base ingots were then melted, and some parts were made by casting and some by forging. The cast and forged parts each had a composition of: 63.46% copper, 37.13% zinc, 0.039% aluminum, 0.001% tin, 0.002% lead, and 0.025% sulfur.

[0049] The final chemistry of the part indicates that there is some loss of added aluminum, presumably through the formation of aluminum oxide. Some zinc sulfide is also believed to be lost as slag from the mixture. Mechanical properties of the final brass alloy parts according to Example 1 are as shown in Table 1 below. Parts manufactured from the final brass alloy exhibited good oxidative resistance when cast, and exceptional oxidative resistance when forged, as shown in Table 2 below. This example demonstrates that there is a corrosion resistance advantage provided by adding sulfur to a brass alloy even without forging, due largely to grain boundary corrosion protection. The alloy is further made very corrosion-resistant by forging, i.e., refinement of grain. The corrosion resistant sulfur alloy could also have been made more resistant by adding a grain-refiner, including without limitation phosphorous, or by using a process that produced grain refinement due to rapid casting solidification, including without limitation permanent mold casting.

EXAMPLE 2

[0050] Another example of a brass alloy includes melting of the base alloy ingot described above, with a foundation of copper and additions of zinc, aluminum and sulfur. The base ingot included about 63.12% copper, about 36.76% zinc, about 0.064% aluminum; 0.003% lead and 0.031% sulfur. After the base ingot was melted, tin was added to the molten bath prior to casting. The final brass alloy parts had a chemical composition of 63.09% copper, 36.61% zinc, 0.036% aluminum, 0.052% tin, 0.028% lead and 0.025% sulfur. The brass alloy was cast using green sand casting, which does not result in inherent grain refinement of the alloy due to the slow rate of solidification cooling, which produces a large grain size. Exceptional corrosion resistance was achieved with cast components having the formulation of Example 2. Cast brasses with similar amounts of zinc are normally sensitive to dezincification corrosion due to their inherent grain structures. The corrosion resistance of Example 2 was enhanced by the use of an additional corrosion inhibiting component, tin, in addition to the sulfur. The sulfur and tin are believed to combine to enhance the corrosion resistance of the alloy matrix. Mechanical properties of the final brass alloy parts according to Example 2 are as shown in Table 1 below. Parts manufactured from the final brass alloy exhibited exceptional oxidative resistance as shown in Table 2 below.

TABLE 1

Mechanical Properties

Cast (Green Sand) Specimen	UTS (psi)	YS (psi)	% Elongation
Example 1: High Zinc - Trace Lead - Low Sulfur Alloy			
Test Bar 1	45,453	11,690	54.95
Test Bar 2	42,842	12,673	50.65
Example 2: High Zinc - Trace Lead - Low Sulfur Alloy (+Tin)			
Test Bar 1	41,030	12,728	46.5
Test Bar 2	43,162	13,028	48.45

TABLE 2

Corrosion Resistance

Process	Maximum	Minimum	Average	PASS/ FAIL*
Example 1				
Green Sand Casting	350 microns	50 microns	200 microns	Fail
Forging	100 microns	0 microns	<50 microns	Pass
Example 2				
Green Sand Casting	200 microns	120 microns	160 microns	Pass

Test Method: * BS EN ISO 6509 & Acceptance Criteria BS EN 13828: Penetration 200 micron max.

EXAMPLE 3

[0051] Another example brass alloy was constructed by forming a base alloy by adding zinc to copper without any other intentional elemental addition. The molten bath surface was protected from the atmosphere by a granular graphite cover material. This base alloy contained 65.35% copper, 34.583% zinc, <0.001% aluminum, 0.013% tin, 0.021% lead,

and <0.003% sulfur. Some parts were cast out of this molten base alloy for comparison with sulfur-added parts.

[0052] A second sulfur-enriched brass alloy was constructed by again adding zinc to the molten copper starter bath with a cover material of granular graphite. For this second brass alloy, sulfur was added to the established furnace bath by plunging a copper envelope containing powder sulfur. The target sulfur content for this second brass alloy was 0.25%, and sufficient sulfur was added to reach this percentage if all of the sulfur remained in the alloy. The final chemistry of this metal heat was 70.09% copper, 29.83% zinc, <0.001% aluminum, 0.011% tin, 0.019% lead, and 0.024% sulfur.

[0053] Comparison dezincification testing revealed no corrosion protection for the first example and an improvement in corrosion resistance for the sulfur-enriched brass alloy. This example also provides a demonstration of a greater melt loss of sulfur with sulfur directly to the molten bath than with a pre-mix or with the use of additional alloying elements.

EXAMPLE 4

[0054] A sulfur brass alloy was built using a pre-mix containing tin and sulfur. The sulfur in the pre-mix was a sufficient amount to target 0.1% sulfur when combined with the base alloy. The tin in the pre-mix was sufficient to allow the sulfur to be evenly dispersed throughout the tin, and amounts from about 6 parts to about 10 parts of tin were used for each 1 part of sulfur. When the sulfur was dispersed in the tin, the tin-sulfur pre-mix was added to a base alloy. The base alloy was constructed by first adding zinc to the copper and then adding aluminum to aid in later sulfur retention. The prescribed pre-mix was then added to the established melt directly before casting. The resultant chemistry was 62.61% copper, 37.05% zinc, 0.036% aluminum, 0.117% tin, 0.012% lead and 0.023% sulfur. Parts were then cast from the combined alloy, and tested with good corrosion resistance.

[0055] Corrosion test surfaces showed clear dezincification of the non-sulfur added alloy. This example indicates the uniformity provided by adding sulfur to the alloy melt as part of a pre-mix.

[0056] Standardized tests that can be used to establish "enhanced corrosion resistance" are: ISO 6957—Copper Alloys—Ammonia test for stress corrosion resistance for stress corrosion cracking; and BS EN ISO 6509—Corrosion of metals and alloys—Determination of dezincification resistance of brass for dezincification resistance.

[0057] The pass criteria for the stress corrosion cracking test is that no cracks are evident after test exposure. The sulfur enriched alloy does not have cracking. The acceptance criterion used for assessing dezincification corrosion penetration is based on BS EN 13828 and is set at 200 micron penetration. Certain embodiments have achieved no corrosion penetration for the dezincification test.

[0058] It is also important to note that the current disclosure includes exemplary embodiments, and is illustrative only. Although only a few embodiments of the present innovations have been described in detail in this disclosure, those skilled in the art who review this disclosure will readily appreciate that many modifications are possible (e.g., variations in additives, heating times, heating temperatures, dimensions and structures manufactured from the alloys, etc.) without materially departing from the novel teachings and advantages of the subject matter recited. Accordingly, all such modifications are intended to be included within the scope of the present innovations. Other substitutions, modifications, changes, and omissions may be made in the composition, design, operating conditions, and arrangement of the desired and other exemplary embodiments without departing from the spirit of the present innovations.

[0059] It will be understood that any described processes or steps within described processes may be combined with other disclosed processes or steps to form structures within the scope of the present invention. The exemplary structures and processes disclosed herein are for illustrative purposes and are not to be construed as limiting.

[0060] It is also to be understood that variations and modifications can be made on the aforementioned compositions, structures and methods without departing from the concepts of the present invention, and further it is to be understood that such concepts are intended to be covered by the following claims unless these claims by their language expressly state otherwise.

What is claimed is:

1. A copper-zinc alloy having an elemental composition comprising:

from about 10% to about 45% zinc by weight;

at least 50% copper by weight; and

an amount of sulfur that is effective to enhance oxidative resistance.

2. An alloy according to claim **1**, in which the sulfur is present in the form of a sulfide chosen from the group comprising zinc-sulfide, copper-sulfide, and a combination thereof.

3. An alloy according to claim **2**, in which the sulfide is homogenously distributed throughout the alloy.

4. An alloy according to claim **1**, in which the element zinc is present in an amount from about 10% to about 40% by weight.

5. An alloy according to claim **1**, in which the element zinc is present in an amount form about 35% to about 45% by weight.

6. An alloy according to claim **1**, further comprising one or more additives selected from the group consisting of silicon, selenium, tellurium, lead, tin, manganese, bismuth, antimony, phosphorous, iron, nickel, aluminum, and arsenic, each of the one or more additives present in an amount of from about 0.006% to about 6% by weight.

7. An alloy according to claim **1**, in which the sulfur is present in an amount that is between about 0.006% and about 4% by weight.

8. An alloy according to claim **1**, in which the sulfur is present in an amount of from about 2.1% to about 4% by weight.

9. An alloy according to claim **1**, in which the sulfur is present in an amount of from about 0.006% to about 2.0% by weight.

10. An alloy according to claim **1**, in which the sulfur is present in an amount of from about 0.006% to about 0.10% by weight.

11. An alloy according to claim **1**, in which the sulfur is predominantly present in the form of an intermetallic sulfide.

12. A water-conveying conduit system comprising:

a conduit component fabricated from a copper-zinc alloy according to claim **1**.

13. A process for preparing an oxidation resistant copper-zinc alloy, comprising:

combining sulfur and a pre-mix metal under conditions to form a molten alloy pre-mix, wherein the pre-mix metal

is chosen from the group consisting of copper, zinc, aluminum, lead, bismuth, tin, and a combination thereof;

preparing a base alloy; and

combining the alloy pre-mix and the base alloy.

14. A process according to claim **13**, wherein the pre-mix metal comprises zinc.

15. A process according to claim **13**, wherein the pre-mix metal comprises copper.

16. A process according to claim **15**, wherein the pre-mix metal further comprises aluminum.

17. A process according to claim **16**, wherein the pre-mix metal further comprises tin and lead.

18. A process according to claim **13**, wherein the base alloy comprises copper.

19. A process according to claim **13**, wherein the base alloy comprises zinc.

20. A process according to claim **19**, wherein the base alloy further comprises copper.

21. A process according to claim **13**, in which the resulting alloy is solidified and subsequently heat treated to enhance machinability.

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