TITLE

Magnetically Permeable Liquid Forged Articles

FIELD OF THE INVENTION

This invention relates to magnetically permeable alloys, and articles formed by liquid forging of such alloys.

BACKGROUND OF THE INVENTION

Conventional cast aluminium (Al) alloys commonly have silicon (Si), copper (Cu), magnesium (Mg) and zinc (Zn) as major alloying elements. The amount of major alloying elements are limited to the eutectic composition in order to retain good fluidity of the molten alloy. Greater amounts than the eutectic composition result in viscous behavior of the molten alloy due to formation of second/intermetallic phases. Viscosity can cause severe porosities and lower mechanical properties of the alloy. However, in a special purpose wear resistance alloy, silicon of up to 30wt% in hyper-eutectic range is alloyed. Titanium (Ti) and boron (B) elements are added in minor quantities for grain refinement. Beryllium (Be) is added in trace amount in reducing aluminium oxidation and increasing surface beryllium oxide. Other elements such as iron (Fe), nickel (Ni), chromium (Cr), cobalt (Co), manganese (Mn), cadmium (Cd), lead (Pb), antimony (Sb), etc., are considered as impurities and limited within the range of 1wt%. For high pure alloys lower than 0.05-0.2% the impurity level is maintained. Usually, wrought aluminium alloys are prepared with low alloying content less than 2-3wt% for easy fabrication because of the fragmentation of second phases which weakens the structural parts. By powder particle synthesis, high temperature high strength aluminium alloys are developed using nickel, iron and cobalt of up to 50wt% alloying addition. A few

applications state cast and hot deformed aluminium alloys containing 50wt% of iron, nickel and titanium elements.

Hard disk base (HDB) plates are usually die cast using conventional A383 aluminium alloy. Recently, it has become desirable to have HDB plates smaller in size up to 1 inch with complex features. The components are assembled with magnetically permeable parts to balance the forces created by the magnetic looping. For instance, pole plate in hard disk drive balance the magnetic forces. To further reduce form factor and cost, it is desirable to have a HDB plate that is magnetically permeable.

To achieve this, Fe, Ni and CO with high magnetic permeability are added as alloying elements to Al. These soft magnetic elements can be added one by one or in combination. Fabrication of parts using these alloys by conventional casting and wrought methods is extremely difficult. In Al-Fe alloys, metastable $FeAl_6$ and Fe_2Al_9 phases form with stable iron aluminide-$FeAl_3$. In Al-Co, Al-Ni and Al-Fe-Ni alloys, aluminides such as Co_2Al_9, $NiAl_3$ and $FeNiAl_9$ form respectively. However, in other combinations (ternary and quaternary systems) of the alloying elements, formation of second phases are not clear or unknown. Presence of these aluminides dispersion strengthen the alloys, but increases brittleness of the alloys. Moreover, at low fracture energy the component will fail due to the presence of these brittle aluminides. In order to decrease the brittleness of the alloy zirconium (Zr), Ti, B, Cr can be alloyed in small quantities of 0.1-1.5wt% in order to refine grain size and improve the ductility. Alloy compositions nearer the eutectic points are classified as short freezing. For 30-40wt% composition, the freezing range is as high as 220°C, 300°C and 500°C for Al-Ni, Al-Co and Al-Fe alloys respectively. At this higher

freezing range, magnetically permeable Al alloys cannot be formed using conventional casting or wrought methods because use of high aluminide content alloys causes the alloy to have high viscosity and it will tend to solidify prior to completely filling a mold, resulting in voids.

SUMMARY OF THE INVENTION

According to one aspect, there is provided a liquid forgeable magnetically permeable Al alloy having at least one alloying element selected from the group consisting of: Fe, Ni and Co. Composition of the alloy by weight percentage may be selected from the group consisting of: Al-2Fe, Al-5Fe, Al-10Fe, Al-20Fe, Al-38Fe, Al-2Ni, Al-5Ni, Al-10Ni, Al-20Ni, Al-40Ni, Al-2Co, Al-5Co, Al-10Co, Al-20Co, Al-30Co, Al-10Fe-5Ni, Al-20Fe-5Ni, Al-30Fe-5Ni, Al-30Fe-10Ni, Al-10Fe-5Co, Al-20Fe-5Co, Al-30Fe-5Co, Al-30Fe-10Co, Al-10Fe-10Ni-10Co, Al-20Fe-5Ni-5Co, and Al-20Fe-10Ni-10Co. The alloy may further comprise at least one additive element selected from the group consisting of: Zr, Ti, B, and Cr. Weight percentage of the at least one additive element may range from 0.1 wt% to 1.5 wt%.

According to another aspect, there is provided an article comprising a liquid forgeable magnetically permeable Al alloy having at least one alloying element selected from the group consisting of: Fe, Ni and Co. The article may be formed by liquid forging. The article may further comprise a magnetically permeable insert, for example in the form of a wire mesh. The wire mesh may comprise wires having a diameter ranging from 50 μm to 2000 μm, preferably from 50 μm to 150 μm.

According to yet another aspect, there is provided a method of forming an article with a liquid forgeable magnetically permeable Al alloy having at least one alloying element selected from the group consisting of: Fe, Ni and Co, said method comprising the steps of pouring the alloy in molten form into a die cavity and pressurizing the molten alloy with a punch during solidification of the alloy. The method may further comprise a step of placing a magnetically permeable insert into the die cavity prior to pouring the alloy in molten form into the die cavity.

BRIEF DESCRIPTION OF THE DRAWINGS

In order that the present invention may be fully understood and readily put into practical effect, there shall now be described by way of non-limitative example only preferred embodiments of the present invention, the description being with reference to the accompanying illustrative drawings.

In the drawings:

Fig. 1 is a schematic front view of a punch and die set with a wire insert placed in the die cavity;

Fig. 2 is a schematic front view of the punch and die set of Fig. 1 with a molten alloy poured into the die cavity;

Fig. 3 is a schematic front view of the punch and die set of Fig. 2 with the molten alloy being pressurized by the punch; and

Fig. 4 is a schematic front view of the punch and die set of Fig. 3 with a finished article being ejected.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

According to one aspect, there is provided a magnetically permeable Al alloy for liquid forging into articles. In liquid forging, a pre-quantified amount of molten alloy is first

poured into a die cavity. Pressure is then applied to the molten alloy using a punch which fills the cavity. The molten alloy solidifies under pressure. A net shape article can thus be formed with minimal material wastage. The article is sound, having undergone pressurized solidification. An example of liquid forging is provided in published international patent application no. WO 2006/093469.

In order to reduce freezing range and lower the melting point of the alloy, the alloying elements Fe, Ni and Co are added in combination to aluminium. The weight percentage (wt%) of addition of each element depends on various factors such as strength of magnetic field in which an article is to be used, volume fraction of formation of second phases (aluminides), liquid forgeability of the alloy, melting point of the alloy, mechanical properties of the alloy, etc. Typically, alloying range is between 2 to 40 wt% for each alloying element.

Composition of the magnetically permeable aluminium alloy is selected from a group comprising of; Al-2Fe, Al-5Fe, Al-10Fe, Al-20Fe, Al-38Fe, Al-2Ni, Al-5Ni, Al-10Ni, Al-20Ni, Al-40Ni, Al-2Co, Al-5Co, Al-10Co, Al-20Co, Al-30Co, Al-10Fe-5Ni, Al-20Fe-5Ni, Al-30Fe-5Ni, Al-30Fe-10Ni, Al-10Fe-5Co, Al-20Fe-5Co, Al-30Fe-5Co, Al-30Fe-10Co, Al-10Fe-10Ni-10Co, Al-20Fe-5Ni-5Co, and Al-20Fe-10Ni-10Co.

During alloying, re-melting is carried out to reduce segregation of the alloy. Microstructure of the alloys show formation of aluminides such as $FeAl_3$, Co_2Al_9, $NiAl_3$ $FeNiAl_9$, etc. Brittleness of the alloy is increased for higher alloying content due to

formation of higher volume fraction of aluminides. In order to decrease brittleness, Zr, Ti, B, Cr are added in small quantities of 0.1-1.5wt%. This also refines grains and improves ductility of the alloy.

To further enhance magnetic permeability of an article made of the alloy, according to another aspect of the invention, the article can be liquid forged from the alloy together with an insert of Fe, Ni or Co. In one embodiment, the insert is a wire mesh. Figs. 1 to 4 show the steps of a method to form the article with an insert. In Fig. 1, a liquid forging punch 10 and die 12 set are shown in which a wire mesh 14 is placed in the die cavity 16. The alloy 18 is then poured in molten form into the die cavity 16 as shown in Fig. 2. Fig. 3 shows the molten alloy 18 being pressurized by the punch 10 during solidification of the alloy 18. The finished article 22 comprising the alloy 18 and wire mesh 14 is finally ejected by a pin 24 as shown in Fig. 4.

During liquid forging, both punch 10 and die 12 are heated in the range of 175°C to 300°C and the molten alloy 18 is poured with 125°C to 200°C superheat. Pressure is applied in the range of 30MPa to 120MPa for 15 to 30 seconds to attain a sound article 22 with minimal voids. Articles without an insert can be similarly formed by omitting the step of placing the insert prior to pouring the molten alloy.

For hard disk base plates having a cross-sectional thickness of 200 μm, wire mesh having wire diameter in the range of 50 μm to 150 μm is preferred. For other articles, wire

diameters of up to 2000 μm can be used. Mesh sizes can range from 20x20 μm to 200x200 μm.

Inserts of other geometries can also be used depending on the articles to be formed. Formation of intermetallic compound occurs at the interface of the insert, thereby providing intact bonding. Growth of the intermetallic compound at the interface is dependent on duration of liquid forging.

CLAIMS

1. A liquid forgeable magnetically permeable Al alloy having at least one alloying element selected from the group consisting of: Fe, Ni and Co.
2. The alloy according to claim 1, wherein composition of the alloy by weight percentage is selected from the group consisting of: Al-2Fe, Al-5Fe, Al-10Fe, Al-20Fe, Al-38Fe, Al-2Ni, Al-5Ni, Al-10Ni, Al-20Ni, Al-40Ni, Al-2Co, Al-5Co, Al-10Co, Al-20Co, Al-30Co, Al-10Fe-5Ni, Al-20Fe-5Ni, Al-30Fe-5Ni, Al-30Fe-10Ni, Al-10Fe-5Co, Al-20Fe-5Co, Al-30Fe-5Co, Al-30Fe-10Co, Al-10Fe-10Ni-10Co, Al-20Fe-5Ni-5Co, and Al-20Fe-10Ni-10Co.
3. The alloy of claim 1 or 2, further comprising at least one additive element selected from the group consisting of: Zr, Ti, B, and Cr.
4. The alloy of claim 3, wherein weight percentage of the at least one additive element ranges from 0.1 wt% to 1.5 wt%.
5. An article comprising the alloy of any one of claims 1 to 4, wherein said article is formed by liquid forging.
6. The article of claim 5, further comprising a magnetically permeable insert.
7. The article of claim 6, wherein the magnetically permeable insert is a wire mesh.
8. The article of claim 7, wherein the wire mesh comprises wires having a diameter ranging from 50 μm to 2000 μm, preferably from 50 μm to 150 μm.
9. A method of forming an article with the alloy of any one of claims 1 to 4, the method comprising the steps of:
    a. pouring the alloy in molten form into a die cavity; and
    b. pressurizing the molten alloy with a punch during solidification of the alloy.

10. The method of claim 9, further comprising the step of placing a magnetically permeable insert into the die cavity prior to pouring the alloy in molten form into the die cavity.

11. The method of claim 10, wherein the magnetically permeable insert is a wire mesh.

12. The method of claim 11, wherein the wire mesh comprises wires having a diameter ranging from 50 μm to 2000 μm, preferably from 50 μm to 150 μm.

13. The method of any one of claims 9 to 12, wherein the punch and die cavity are heated to a temperature ranging from 175°C to 300°C.

14. The method of any one of claims 9 to 13, wherein the molten alloy is poured with a superheat temperature ranging from 125°C to 200°C.

15. The method of any one of claims 9 to 14, wherein the pressurizing is carried out at a pressure ranging from 30MPa to 120 MPa.

16. The method of any one of claims 9 to 15, wherein the pressurizing is carried out for a duration ranging from 15 to 30 seconds.